Preview

Australian Society of Exploration Geophysicists

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This edition of Preview contains, a 'Conference Review', which should bring back memories of Perth. Of particular interest is Mike Smith's address at the Opening Ceremony. He demonstrates very well the broad interests of our society, the challenges we face, and the opportunities we have to 'make a difference'. I would like to thank our publisher Brian Wickins for compiling the photographs of the conference shown in this edition, well done Brian.

There are a couple of changes in this issue of Preview. Firstly, a welcome to Natasha Hendrick's initial column on Web Waves. We seem to be spending more and more of our lives plugging in to www, so I hope you will find Natasha's reviews of what you can find will be of help.

The second change is that there is no Branch News. Because most Branches were fully occupied with the Conference and changing committee members, there was not much to report in the way of plans and meetings. Consequently, we will have to wait until the June issue to read what the Branches are doing. In a somewhat perverse way this helps a little. Because we are being limited to about 40 pages for each Preview, if we miss out the Branch News, we can include more of something else. However, at present we have more copy than we can publish so some items may be delayed. To fix the page-limit problem we need more advertisements in Preview, so if any members or their colleagues have products or services they would like to advertise, please consider Preview.

The plans for the rest of the year include an article by Terry Crabb on airborne gravimetry; a series of three articles by Carl Notfors and his colleagues on recent advances in the data acquisition, data processing, and interpretation of seismic information; and of course the usual Rock Doctors, Seismic Windows and Geophysics in the Surveys. There should be lots to look forward to in future editions.

The ASEG is a member of the Federation of Australian Scientific & Technological Societies, which represents some 50,000 working scientists who belong to over 50 professional societies throughout Australia. In the past FASTS has not been active on Geoscience issues, but recently it has made representations to the New South Wales Government on training geoscience teachers in NSW schools, and to the Commonwealth Government to request a government sponsored study to estimate the value of:

1) Mineral and petroleum exploration in the context of the:

   a) value of future discoveries resulting from exploration activity,

   b) flow-on economic effects in regional Australia as a result of exploration activity; and

   c) returns to governments;

2) Regional geoscience information provided by the Commonwealth and the States/NT in the context of encouraging exploration; and

3) Publicly funded geoscience research in the context of developing new ideas/methodologies/innovations that can be applied to assist the exploration and geoscience service industries and generate wealth for the nation.

In arguing the case for government investment in the geosciences, we often have difficulty in estimating the value of our work in several key areas. This proposal aims to rectify this situation.

Finally, FASTS is organising another 'Science meets Parliament' day in Canberra on 1st November 2000. Last year, Mike Smith and Ray Shaw represented the ASEG at this very successful event where 170 scientists and technologists met 140 Parliamentarians to raise the profile of science in the Parliament. Well, it's on again this year.

David Denham

David Denham, Editor

Congratulations to the Perth Conference Committee on a successful conference and exhibition. The Federal Executive wishes the Brisbane Conference Committee all the best for their planning of the next conference in August 2001.

Many issues were discussed at the ASEG Council meeting that was held at the beginning of the Perth Conference. All State Branches were well represented and we were fortunate to also have the attendance of SEG President Bill Barkhouse and past ASEG President Hugh Rutter. Some the issues discussed included:

- Bill Barkhouse suggested we align ourselves with similar societies in the Asia - Pacific Region. Of the 17 000 SEG members, 42% reside in 106 countries. Last year, SEG membership grew at 6.5%.

- Sustaining and attracting individual and Corporate Memberships is very important for our growth. It has been recommended that unemployed members be given an opportunity of up to one year to pay their membership dues. To follow up non-financial members, State representatives agreed to actively assist our Membership Chairman, Koya Suto.

- As a conference usually results with a surplus, these proceeds help offset the costs of our publications. When there is no conference in a year (as in 1999 and 2002), our society operates with a budget deficit. The Conference Advisory Committee has been asked to review the possibility of an annual conference. An alternative and mid-way between the 18 month period between conferences, is for a State Branch to organise a one or two day 'thematic' workshop or mini-conference.

- To assist the smaller State Branches such as NT, ACT and TAS Branches, it is proposed to change the formula for State Capitation to allow more funding being allocated to these States.

- To help trim some of our publication costs, the Publication Committee is to consider that all authors to Exploration Geophysics and Preview use a standard template 'pdf' format. Perhaps hardcopy will be restricted to B&W and the ASEG may then instigate an electronic version in full colour.

- To involve the State Branches more in current issues within the ASEG, it is proposed to have all State Presidents as mandatory members of the Federal input, it is proposed that the monthly Federal Committee meetings be teli-conferenced. Similar meetings are now successfully held by the AIG.

For more details on these issues, please have further discussions with members of your State Executive. The Federal Committee would like your feedback.

David Robson, Honorary Federal Secretary
robsond@minerals.nsw.gov.au

Contents

The material published in *Preview* is neither the opinions nor the views of the ASEG unless expressly stated. The articles are the opinion of the writers only. The ASEG does not necessarily endorse the information printed. No responsibility is accepted for the accuracy of any of the opinions or information or claims contained in *Preview* and readers should rely on their own enquiries in making decisions affecting their own interests.

Material published in *Preview* aims to contain new topical advances in geophysical techniques, easy-to-read reviews of interest to our members, opinions of members, and matters of general interest to our membership.

All contributions should be submitted to the Editor via email at pdenham@atrax.net.au. We reserve the right to edit all submissions; letters must contain your name and a contact address. Editorial style for technical articles should follow the guidelines outlined in *Exploration Geophysics* and on ASEG's website www.aseg.org.au. We encourage the use of colour in *Preview* but authors will be asked in most cases to pay a page charge of $400 per page for the printing of colour figures. Reprints will not be provided but authors can obtain, on request, a digital file of their article, and are invited to discuss with the publisher, RESolutions Resource and Energy Services, purchase of multiple hard-copy reprints if required.

Deadlines

Preview is published bi-monthly, February, April, June, August, October and December. The deadline for submission of all material to the Editor is the 15th of the Month prior to issue date.

Therefore, editorial copy deadline for the June 2000 edition is 15th May 2000.

Advertisers

Please contact the publisher, RESolutions Resource and Energy Services, (see details elsewhere in this issue) for advertising rates and information. The ASEG reserves the right to reject advertising, which is not in keeping with its publication standards.

Advertising copy deadline is the first week of the month of issue. Therefore, the advertising copy deadline for the June 2000 edition is the first week of May.

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Events for 2000/2001

2000

May 7-10
APPEA 2000, Brisbane, Queensland, 'Innovation for the Third Millenium'.
Enquiries: http://www.appea.com.au

May 23-26
The 8th International Conference on Ground Penetrating Radar, (GPR 2000) Gold Coast, Queensland, Australia.
Call for Papers and information to:
Email: grp2000@csee.uq.edu.au
Website: http://www.cssip.uq.edu.au/gpr2000

May 29-June 2
European Association of Geoscientists & Engineers, 62nd EAGE Conference and Technical Exhibition, Glasgow, UK.
Website: http://www.eage.nl

May 30-June 3
American Geophysical Union, 2000 Spring Meeting, Washington DC, US.
Website: http://www.agu.org

July 3-7
Geological Society of Australia, 15th Australian Geological Convention, Sydney, NSW.
"Understanding Planet Earth - searching for a sustainable future".
Call for papers and information to: GSA, Suite 706, 301 George Street, Sydney 2000
Tel: (61) (02) 9290 2194
Email: 15thagc@gsa.org.au
Website: http://www.science.uts.eedu.au/agc/agchome.html

July 10-11
Yandal Belt Symposium
Regolith, geology and mineralisation of the Yandal Greenstone Belt
AIG (WA Branch), PO Box 606, West Perth WA 6872
Tel: (08) 9226 3997

August 6-11
Society of Exploration Geophysicists, International Exposition & 70th Annual Meeting, Calgary, Canada.
Website: http://www.seg.org

September 19-22
Indonesian International Oil, Gas & Energy Conference & Exhibition 2000 (IIOGE)
Jakarta Convention Centre, Jakarta, Indonesia
Contact: Ramson Piter
Email: rpiter@ptrei.com
Website: http://www.ptrei.co.id

October 15-18
2000 AAPG International Conference & Exhibition (joint meeting between AAPG & Indonesian Petroleum Association), Bali, Indonesia
Theme: 'Energy for the new Millennium'
Contact: AAPG Convention Department
Tel: 918 560 2679
Fax: 918 560 2679
Email: convene@aapg.org
Website: http://www.aapg.org
or at IPA Secretariat
Tel: +62 21 527 3663 Fax: 62 21 520 7672
Email: ipa@cbn.net.id
Website: http://www.ipa.or.id

December 15-19
American Geophysical Union, 2000 Fall Meeting, San Francisco, California, US.
Website: http://www.agu.org

2001

May 29-June 3
American Geophysical Union, 2001 Spring Meeting, Boston, Mass., US.
Website: http://www.agu.org

June 11-15
63rd EAGE Conference & Technical Exhibition, Amsterdam, The Netherlands
Website: http://www.eage.nl

August 6-9
Australian Society of Exploration Geophysicists, 15th International Conference and Exhibition, Brisbane, Qld.
Theme: '2001: A Geophysical Odyssey'
Website: http://www.aseg.org.au
Event Manager: Jacki Mole
Tel: +61 7 3858 5579 Email: aseg2001@im.com.au

September 9-14
SEG International Exposition & 71st Annual Meeting, San Antonio, Texas, US.
Website: http://www.seg.org

September 24-28
4th International Archaean Symposium, University of Western Australia, Perth.
Convenor: Susan Ho
Tel: (61 8) 9332 7350
Email: susanho@geol.uwa.edu.au

2002

May 27-30
64th EAGE Conference & Technical & Exhibition, Florence, Italy
Website: http://www.eage.nl

Sep 22-27
SEG International Exposition & 72nd Annual Meeting, Las Vegas, Nevada, US.
Website: http://www.seg.org

ASEG's 15th International Conference and Exhibition

After the success of the Perth meeting we can now all look forward to the ASEG's 15th International Conference and Exhibition, to be held in Brisbane, from August 6-9th, 2001.

Jenny Bauer and Wayne Stasinowsky have assembled a strong team to organise the meeting and the key people and chairs of the committees are shown below.

The website is: http://www.aseg.org.au and the Event Manager is Jacki Mole who can be contacted by telephone on +61 7 3858 5410 or on Email: aseg2001@im.com.au.

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Web Waves

We all know the World Wide Web contains a monumental amount of information, on every topic imaginable. The problem with accessing this information is the time it takes to find exactly what you're looking for. WEB waves will highlight a few useful websites in each edition of Preview to make your web surfing so much easier! If you have any favourite sites you'd like to share with our members please email me, Natasha (natasha@geoph.uq.edu.au). Meanwhile find yourself a computer, sit back and enjoy this month's waves.

Case Histories in Applied Geophysics

www.science.ubc.ca/~eoswr/geop/appgeop/ch-list.html

A wide range of case histories are presented - primarily consisting of summaries from the literature with one or two relevant figures. Original references are provided for your convenience. Case histories from the University of British Columbia, and company case histories are also available. Topics covered include gravity, magnetics, seismic methods, DC resistivity, IP, SP, electromagnetics, GPR and inversion methods.

Journal of Applied Geophysics

www.elsevier.nl/homepage/sad/appgeo/fp.sht

SITE OF THE MONTH with temporary free access to the full text of the journal. In the next few months access will be limited to users affiliated with libraries that subscribe to the print edition of the journal. Search facilities based on authors, keywords and journal volume number are provided. Full text of special issues is also available. Topics include ground-penetrating radar; macro-model independent seismic reflection imaging; electric, magnetic and EM methods applied to cultural heritage; methods for modelling EM fields; and recent advances in exploration geophysics. Take advantage of this opportunity while you can!

The Northern Mine - Geology 101

www.northernminer.com/toolkit/geology_101.htm

Brush up on your mineral geology with these twenty-nine feature articles published in the Canadian The Northern Mine magazine from April 1997 to December 1999. The articles provide a brief overview of the geologic formation of particular types of mineral deposits as well as an assessment of their economic viability. Mineral deposits discussed include epithermal, placer gold, diamond, banded iron, zinc copper, quartz-carbonate vein gold and porphyry deposits.

Society of Exploration Geophysicists

www.seg.org

Natasha Hendrick

A comprehensive site containing everything you want to know, and more, about our sister geophysical society. Here you can search the Digital Cumulative Index for references of every paper published in SEG, EAGE, ASEG and CSEG journals between 1936-1999; download abstracts of technical papers being presented at the upcoming SEG International Meeting and Exhibition; search for job opportunities; check out the calendar of Continuing Education courses; or visit the SEG Student Connection for geophysical education resources.

Well worth a visit!

Natasha Hendrick

David Howard to Lead ASEG Web Committee

At the ASEG web committee meeting held on Tuesday 14th March, David Howard (WA) was elected as chairman for 2000. As a primary task, the committee has been asked to consider the strategic issues for the ASEG web site - with particular emphasis on content and site management - and make recommendations to the Federal Executive regarding the implementation of a new or expanded website.

It is planned for the committee to be permananetly convened in an electronic discussion forum hosted on the ASEG website. Debative membership is open to all - members can access the forum from the ASEG cover page. Core membership is open to ASEG members who explicitly indicate a willingness to undertake investigative or executive tasks associated with committee activities (nominations to d.howard@dme.wa.gov.au). Current core members are Voya Kissitch (ASEG webmaster Qld), Koya Suto (Qld), Lindsay Thomas (Vic), Tim Mackey (ACT) and Graham Heinson (SA).

Any member wishing to contribute should contact David as indicated.

Heard in Canberra...

While most members were enjoying the pleasures of the Burswood Casino and the delights of the Perth Zoo, I was chained to my desk in Canberra watching developments in the Government and its supportive bureaucracies.

May Budget Expected to be Tough

The May budget is expected to be difficult for science and technology, unless one can raise strong political arguments for spending increases in key areas. The Expenditure Review Committee of Cabinet is already reported as holding a very tough line. Perhaps we can expect a more generous budget in 2001, which will be an election year and by then the Government will have realised it will be getting much more revenue from the GST that it expected. Anyway time will tell.

Innovation Summit Implementation Group (ISIG) Appointed

On 16th March, Senator Nick Minchin, the Minister for Industry, Science and Resources, announced the appointment of a group of nine people to carry forward the recommendations from the National Innovation Summit, held in Melbourne last month.

David Miles, Senior Partner at Corrs Chambers Westgarth, will chair the Group, which comprises:

- Robin Batterham, Australian Chief Scientist, Managing Director, Research and Technology Support, Comalco and Chief Technologist, Rio Tinto Limited
- Tim Besley, President, Academy of Technological Science and Engineering
- Ruth Dunkin, Deputy Vice-Chancellor, RMIT University
- Peter Grant, Department of Education, Training and Youth Affairs
- John Keniry, Chairman, Ridley Corporation
- Christopher Knoblanche, Chief Executive, Arthur Andersen Australia
- John Spasojevic, Deputy Chief Executive Officer, Department of ISR
- Peter Thomas, Executive Director, Planning and External Affairs, Holden Ltd

The Minister tasked the group to 'develop the strategies that will create a culture of innovation in Australia that encourages risk-taking and the development of strong linkages between the research, industry and government sectors.'

The Terms of Reference are:

1. Consider the ideas and recommendations made at the Summit and:
   - refine proposals and remove duplication;
   - provide concrete potential actions;
   - identify relevant responsible groups;
   - provide adequate information to enable effective decision-making; and
   - provide advice on the priority of actions, their timing and implementation so as to enhance innovation in Australia.

2. Consult with relevant affected parties to test proposals and help establish priorities.

3. Present an interim report for the June 2000 meeting of the Prime Minister's Science, Engineering and Innovation Council.

4. Present the final report to the PMSEIC Ministers by 30th August 2000.

We will have to wait until June to get an indication of the group's thinking, and probably until much later in the year to obtain the Government's response. Let's hope we don't finish up with just another set of words.

$1 M for Science and Technology Awareness

On 16th March Minister Minchin also announced funding of $1 million for projects to raise community awareness of the importance of science, engineering and technology for Australia's future.

This is 10% more than the ~$900 000 allocated during the last financial year.

The Science and Technology Awareness Program is designed to help establish a scientifically literate community capable of facing the challenges of the new millennium.

The theme for this year's round of grants is 'Science and Innovation for the Future'.

Applications from non-metropolitan groups and from partnerships between city and regional groups are encouraged, as are applications for projects that are associated with Australian industry or industry groups.

Project funding ranging from $20 000 to $100 000 in a financial year is available.

Previous grants from the Science and Technology Awareness Program have supported projects ranging from workshops and travelling science shows to school-industry partnerships and the production of animated science series and science magazines.

Other projects have included a series of science seminars for women in remote areas and publication of science experiments in the rural press.

Further information and application packages can be obtained by contacting the Department of Industry, Science and Resources' Science and Technology Awareness Program.

The closing date for applications is 20th April and it is expected that successful projects will be announced by late July 2000.

Technology Diffusion Program Continues

ISR continues to administer the Government's Technology Diffusion Program, which helps industry and researchers to

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ASEG's 14th Conference a Success

Introduction

ASEG Conferences are very important for our Society. They present a unique opportunity for members from the resource industries, universities, service companies, government institutions and many others, to interact over a wide range of issues relevant to geophysics.

The Perth Conference was no exception, and in spite of the downturn in mineral and petroleum exploration in Australia, the presence of over 630 delegates, and 99 trade booths, coupled with the presentation of 275 talks, 20 poster sessions and a first class exhibition indicates to me that we have a very healthy society able and willing to take up the challenges of today. The organising committee should be proud of compiling such an attractive program of events.

This review in Preview is not in any way a comprehensive analysis. Rather it contains some snapshots, which serve as reminders of the event.

We start with the opening ceremony, which essentially provided the political umbrella for our operations, proceed to the ASEG awards, which recognise the efforts of our members in maintaining a vibrant and effective society, and go on to some personal comments by Henk van Paridon, and a pictorial collage put together Brian Wickins our Publisher.

I hope you fine this review of interest and that it brings back memories of ASEG in Perth.

David Denham

Opening Ceremony

Mike Smith, ASEG President, Jean-Claude Grosset, Past President of EAGE, and Bill Barkhouse, President of the SEG addressed the opening session before the Deputy Premier of Western Australia, Hendy Cowan opened the Conference.

Messages from the SEG and the EAGE are contained in Preview 84, the Conference issue. Mike Smith's address and a summary of Hendy Cowan's follow.

President's Address - ASEG Conference Opening

The ASEG's newsletter PREVIEW has contained copies of letters from the ASEG to the Federal Government lamenting severe cuts to Australian research funding, and to State Ministers urging continuation of regional geoscience programs and arguing for support for High School geoscience teachers. ASEG delegates went to Canberra to meet government and opposition members. We have a prominent politician as our guest tonight.

You may ask "What is this new political activism of the ASEG?" The fact is we must speak up for our members to sustain our industry. We have suffered the termination of cooperative research centres, cuts to AGSO, cuts to CSIRO, cuts proposed for the WA Geological Survey. And we have a financial community infatuated with as yet unprofitable DOT COM companies.

Together with sister societies (AIG, GSA, AusIMM) we must press for solutions to land access problems, we must promote our commercial contributions, and we must urge

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access and adopt new and leading edge technologies developed in Australia and overseas.

The Program commenced on 1st July 1998 and will run until June 2002. Over this period about $90 million will be provided to industry and the research community.

The Technology Diffusion Program provides support for national and international activities in two elements - **Technology Alliances** and **Technology Transfer.**

Technology Alliances contribute to the non-research costs (eg travel and living expenses) of the following:

- Researchers and industry undertaking international collaborative research with commercial potential.
- International collaborative research projects which support inter-governmental agreements and industry development priorities.
- International show-casing of Australian science and technology capabilities.
- Australian scientists accessing major international research facilities.
- Australian scientists collaborating with their peers overseas through missions, workshops and exchanges.
- Technology Alliances identify opportunities for technology diffusion and industry innovation flowing from Australia's involvement in global science and technology. They enable better links to be forged between industry, the Australian research community and the international science and technology community.

Technology Transfer improves access for Australian industries to the best available technology.

Activities focus on national activities, enabling industry to access and apply new technology and to capitalise on international science, engineering and technology alliances.

If any member has a collaborative research proposal in his/her top drawer, then dig it out and get your application in. More information can be obtained from the ISR homepage (www.isr.gov.au)

Eristicus, Canberra April 2000

sustained funding of both state and national geoscience programs.

In Canberra, I met with Senator John Herron, Minister for Aboriginal and Torres Strait Islander Affairs and with Martyn Evans, Opposition Spokesman for Science & Technology. Both have a strong science background, both are receptive to our views on land access problems and research funding difficulties, and both are sympathetic to concerns about the decline in rural life. Both of these representatives of either side of politics are very amenable to hearing our views. However, the Canberra visit also revealed that most politicians (in contrast to Herron and Evans) have an anti-science prejudice. In general our Federal politicians are intimidated by science, sceptical of the real benefits of science, and hesitant to develop a close liaison with science.

I suggest therefore, that a key goal of the ASEG must be to promote our significant contributions to the national economy, to expound on the achievements of Australian geoscience, and to explain to Canberra that Australian geoscientific technology leads world practice in many areas. We need our leaders to appreciate that, without sustained support for our national and state geoscience agencies, this Australian technological advantage is left to the commercial world, itself subject to the capricious whim of non-geoscientific management and unsympathetic accountants, lawyers and economists, and worst of all, short sighted fund managers.

We welcome our special visitors to this Opening Ceremony. From the USA we are delighted to have SEG President Bill Barkhouse and SEG Marketing Manager John Van Gurdy with us. From Paris, we welcome EAGE Secretary/Treasurer Jean-Claude Grosset and EAGE Business Manager Anton van Gerwin. We thank our Special guest of Honour this evening Minister Hendy Cowan for making himself available to address this gathering. I take this unique opportunity to present the Minister three proposals, which he may wish to take back to his colleagues in Government:

1. Can we lift Australia's native title problem out of the Federal responsibility versus State responsibility debate and achieve a result to assist our industry.

2. Can we avoid the budget slashing at the Geological Survey of Western Australia.

3. Can we address the steady drift of country Australia to urban Australia?

To all our guests, delegates, exhibitors and friends: We welcome you all to the 14th International Conference and Exhibition of the Australian Society of Exploration Geophysicists. We hope you truly benefit from the next four days of exposure to our Society's great scientific accomplishments. Thank you.

Mike Smith,
Past President and International Affairs

(Mike's question on budget slashing at the WA Geological Survey obviously did no harm because I understand the threat to cut was largely resisted by the WA Government Ed)

Opening Address by Hendy Cowan, MLA, Deputy premier of Western Australia

(Abridged version)

Two of the biggest challenges confronting you as individuals and your industry as a whole are:

- Managing your business within a fluctuating world market, and
- Keeping pace with technological change.

I would like to comment on these issues and mention some initiatives that the Government has taken to help industry address these challenges.

We are all aware of the cyclical nature of the resources sector and its price fluctuations. Oil, as an example, was valued at US$16 per barrel in January 1998. It experienced a downward slide to a low US$10 in December 1998, where it remained unchanged for 3 months, before starting an upward trend to reach $30 in February this year.

The net result was that many exploration and development projects were put on hold and overnight the industry went from being extremely busy to very subdued.

The prices of gold, diamonds and most minerals have been depressed for some time - and in Western Australia investment in exploration in the sector fell by 12% in 1997/98 and 15% in 1998/99.

I am aware that many of you have experienced business difficulties as a result of this sectorial slow-down. The good news is that the Asian economies are recovering and prices for mineral and energy commodities are projected to rise between 2000 and 2002, and a resurgence in exploration is expected. However, there is increased global competition for exploration dollars. The relatively under-explored parts of the world, particularly South America and Africa, are demanding greater attention.

Mining and petroleum companies have undergone considerable rationalisation and cost reduction programs. They are leaner and more efficient than they were a few years ago. Exploration is a high-cost, high-risk activity and companies will be looking for service providers offering the most cost effective options with minimum risk.

Governments and industry are recognising that science and technology are drivers of innovation and economic growth. It is also clear that Governments and industry need to adopt a more co-operative approach to research and development. Governments have a role and responsibility to the industry, to encourage investment in new exploration and development in new technology.

Our Government has established a number of programs to promote science and technology and to enhance R & D capability. These include:

- The Centres of Excellence Program, established in 1996, which has committed ~$14M to 22 centres to provide R&D infrastructure such as buildings, equipment and personnel.

- The Government's contribution is being matched by commitments of $25M in cash and $40M in kind by the universities and CSIRO. Over half of the funding has gone to minerals and petroleum related activities.

  : CRCs for Petroleum Research, Australian Mineral Exploration Technologies, and Geodynamics,

  : Australian Centre for Geomechanics,

  : WA Geotectonic Mapping Centre, and the

  : Centre for Mass Spectrometry.

- The Australian Resources Research Centre, which is being built by CSIRO in Perth, is particularly important to the industry. The State is contributing almost $27M towards construction costs, and $8M on equipment and relocation, including $1M for a Computing and Visualisation Centre.

These are some of the initiatives taken by Government, in its ongoing commitment to encouraging world's best practice in the resources industry. These investments will enable scientists, academics and industry to develop leading-edge technology in minerals and petroleum exploration and production. Those who embrace the new ideas, new technology, and are prepared to collaborate and share will, I am convinced, be the ones to reap the benefits and rewards that are being offered.

Ladies and gentlemen, enjoy your exhibition and conference - and thank you for your attention.

Frenchman Eats His Words at ASEG 2000

A personal perspective by Henk van Paridon

During a keynote address at the ASEG's 14th International Geophysical Conference and Exhibition in Perth, Professor Mathias Fink demonstrated a technique where a person could literally eat their words. Using a series of time reversal mirrors it was possible to deconvolve sound waves in a chamber and reconstruct the individual components that contributed to the overall signal. Thus loose comments made in a crowded room might be deciphered and the words replayed in the mouth of the originator. Professor Fink gave some examples of this technology in medical applications and left the audience to consider its geophysical use.

John Gibson of Landmark Graphics pondered why oil companies were out of favour with stock market investors in his address. The market's love affair with technology stocks and their extra-ordinary returns meant that oil companies looked stodgy in comparison despite the fact that they were very profitable. He suggested that service companies needed to provide technological advice in all aspects of business in order to adapt to the current investment climate.

The conference got off to an early start on the Sunday when the opening ceremony preceded the icebreaker. Hendy Cowan, Deputy Premier of WA, declared the conference open. He departed from his prepared speech to address points made by Mike Smith and to declare his personal interest in groundwater issues.

The conference dinner continued the exotic animal theme at the Perth Zoo where we are glad to report that there were no disappearances. MC, Mr Barry Long, again kept the audience enchanted with his charm and bonhomie. He presented a special Y2K Readiness Award to Schlumberger for their 2000 mouse mats that turned out to be Y2K non-compliant. They immediately became collector's items. The story can now be told of the covert covin that was able to reproduce the poster size replica of the mouse-mat less than 1m from the Schlumberger Booth. A supplementary award could have also been presented to the Murray Street Mall proprietors who haven't taken down their Year 2000 countdown clock.

I had the pleasure of escorting a group of high school students around the exhibition and was holding their attention well as we entered the pseudo sub-terranean entrance. I then lost them as we passed the Veritas booth, which was handing out free shopping bags enabling the kids to collect even more souvenirs. I felt like I was herding one-day old chicks. Special thanks should go to all the exhibitors for taking the time to talk to the various groups that invaded. Those of you attending talks at that time will now understand what happened to the ice creams.

Part of my conference experience was the daily ritual at Miss Maud's. The smorgasbord breakfast and coffee were excellent and was followed by a walk to the railway station and short train trip to Burswood. This required feeding coins into a vending machine and heaven help those who didn't have the change as Perth Transport Inspectors were almost as common as conductors might have been. Because of my longer stay the hotel offered me a larger room. I felt fairly pleased about this until I noticed that all the rooms on my floor were about the same size.

At the closing ceremony the announcement for the ASEG/2001 conference went down well and those of us on that committee wish to thank Kim and Mike and the Perth COC for their efforts. Many thanks to Western Geophysical and the other sponsors for their great support of the Conference. Hope to see you all in Brisbane.

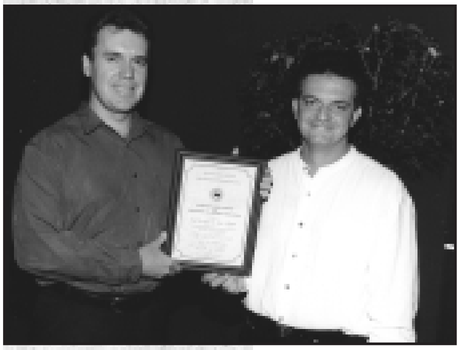
Citations for ASEG Award Presentations Perth 2000

Grahame Sands Award for *Innovation in Applied Geoscience*:

Neil Goodey and Nino Tufilli of UTS Geophysics

This award is based on an endowment made by members of the ASEG and the geoscience profession in memory of Grahame Sands who was tragically killed at the prime of his life and career in an aircraft crash in 1986, whilst developing and testing new navigational equipment for geophysical survey aircraft. Because of Grahame's abilities to turn scientific theory into innovative application, the award is made to a geoscientist who introduces a significant practical development or innovation of benefit to applied geoscience in Australia.

The Grahame Sands Award for 2000 is made jointly to Neil Goodey and Nino Tufilli of Western Australia for the development of stinger-mounted magnetic sensors on helicopters and the introduction of ultra low-level airborne surveys using fixed wing aerial agricultural aircraft.



Neil Goodey and Nino Tufilli of UTS Geophysics.

Neil and Nino established UTS Geophysics in 1991 to offer new and innovative developments in airborne geophysics to the mining and environmental industries. They have succeeded in doing this in no uncertain way, and are now significant and successful players in the Australian geophysical exploration scene.

Stinger Magnetometer Sensor: Neil and Nino developed a stinger-mounted magnetic sensor for a helicopter and demonstrated that it was possible to obtain high-resolution magnetic measurements using this sensor. Since 1992 this innovation has allowed helicopter surveys to be conducted closer to the ground in rugged terrains than with the towed bird sensor systems previously used for helicopter surveys. Their innovative development has been accepted throughout this region as a new industry standard for helicopter magnetometer installations.

Low-flying Fixed-wing Surveys: Neil and Nino adapted fixed-wing aerial agricultural aircraft for geophysical surveying and demonstrated that these aircraft are highly effective for very low-level, high-resolution airborne surveys in flat and undulating terrains. The lower operating costs associated with these aircraft have provided the exploration industry with airborne magnetic and radiometric data of very high spatial resolution at survey costs hitherto unknown by the exploration industry. These surveys usually flown at heights of around 20 m (safety permitting) have to a large extent replaced extensive ground magnetic surveys.

It especially noteworthy that Neil and Nino both came from non-geophysical backgrounds into an industry that they knew little about and set about achieving these developments. They are continuing to develop new technology such as electromagnetic systems, drones, and agricultural navigation systems.

The developments made by Neil and Nino are now acknowledged by the ASEG, through the presentation of the 2000 Grahame Sands Award for technical innovation in applied geoscience.

ASEG Service Medal *for extraordinary and outstanding service to the ASEG over many years*:

Andrew Mutton, Rio Tinto

Andrew commenced his career with the BMR in 1974 working mainly on airborne surveys and uranium exploration. In 1980 he joined Geopeko in Perth and subsequently BP Minerals also in Perth. His work on the Abra base metal deposit and the Rocky's Reward nickel deposit were notable achievements in this period. He lectured at Curtin University in 1986 before joining CRA in Brisbane where he was responsible for geophysical surveys in Queensland. The discovery of the Century zinc deposit was a highlight of this period. Since 1996 he has been working for RTZ Technical Services as a Principal Consultant mainly on high resolution and borehole geophysics applied to mine evaluation, environmental and engineering problems.

Andrew has a long involvement with the ASEG. He joined in 1973 as a graduate of Sydney University. Throughout his membership he has made a concerted effort to give something back to the profession and the Society. Most recently he has given outstanding service during the period that the ASEG Federal Executive was in Brisbane and by his stewardship of the Publications Committee.

Andrew has been a truly 'active' member. He first served in an executive capacity in 1976 when he was Secretary / Treasurer of the ACT Branch. In 1986 he was the Vice President of the WA Branch and he served on the Perth 1987 Conference Committee. After moving to Brisbane in 1991 he served on the 1992 Gold Coast Conference Committee and became President of the Queensland Branch. In 1996 he joined the Federal Executive; initially as the Membership Chair and later as First Vice President in charge of Publications.

As Membership Chair of the Federal Executive, he spent many hours working with the secretariat attempting to verify the Society's membership database and took a pivotal role in establishing a new format for the Membership Directory. He also took on the exacting responsibility of finding the database of ASEG founding members from which the ASEG is now able to offer Silver Certificates to members with 25 years of continuous membership.

Somehow the role of Membership Chair also included Honours and Awards and he can take considerable credit from the way that this committee has been restructured since the Hobart conference and his advice is always sought when major issues arise.

Perhaps Andrew's greatest achievements for the ASEG have occurred since he became Chairman of the Publications Committee. The intention was that this committee would report to the FE where Andrew, in his role as First Vice President, would act as a liaison officer. For a variety of reasons he found himself occupying both roles and took on some of the most difficult issues that the Society has faced. Andrew spent many hours helping formalise a publications tender process and subsequent contract that will place the Society in good stead for many years. He instituted a more formal process for the appointment of all Editors and it was his initiative to introduce a Chief Editor to oversee the increasingly complex nature of the society's publications.

His professional, thoughtful and diplomatic manner has been of tremendous value not only to the Publications Committee but also to the ASEG at large. The changes that he has instituted have made the Society more professional.

Nominated by the Queensland Branch and Federal Executive.

ASEG Service Certificates for *outstanding service to the ASEG*:

Koya Suto, Oil Company of Australia

Koya graduated from Akita University in Japan and studied further at the University of Adelaide. He has worked for Esso Australia in Sydney, CRA Exploration in Melbourne, Boral Energy in Adelaide and Oil Company of Australia in Brisbane. During his moves he has somehow managed to serve continuously on three Federal Executives (Melbourne 1992-95, Brisbane 1996-98, Sydney 1999-2000) and has set an exemplary standard of service to the ASEG. Koya has consequently provided a valuable continuous link between these three executives.

The task of maintaining the membership records of the Society is critical to the invoicing of members for membership fees, the correct mailing of publications to members, and sustaining accurate records of our members. Koya has shown tenacity and determination in reviving the ASEG records since the transition in 1997 from the previous to the current Secretariat and has undertaken most of the compilation and production of the 1999 ASEG Membership Directory. He has also agreed to compile and produce the 2000 ASEG Membership Directory.

Koya is a tireless promoter of geophysics and has organised educational sessions for high school students and teachers. He has also been responsible for the ASEG library. He has shown great sensitivity to the plight of unemployed and retired geophysicists in maintaining their ASEG membership and consistently contributes to debate on ASEG affairs.

Nominated by the Federal Executive.

Ted Tyne, NSW Department of Mineral Resources

Ted graduated from the University of NSW in 1972 and then worked as a geophysicist with the Geological Survey of NSW up until 1985 on a wide range of projects. He then lectured in geophysics at the University of NSW and completed his PhD specialising in borehole IP logging. He rejoined the Geological Survey of NSW as Principal Geophysicist until 1993 when he joined Geoterrex as Data Processing and Interpretation Manager. He then joined Encom Technology as Manager of Business Development. Recently he has re-joined the Geological Survey of NSW as Assistant Director (Regional).

Andrew Mutton, Rio Tinto

Koya Suto, Oil Company of Australia

Ted served as an ASEG committee member between 1978 and 1980. He and Don Emerson organised the very first conference of the ASEG in Adelaide in 1979 remotely while both were resident in Sydney. Ted's long service to the ASEG has been most notable by his excellent efforts in acting as chairman of the technical papers committee and Editor of Exploration Geophysics for the ASEG-GSA Conference in Sydney 1991 and again as the chairman of the technical committee for ASEG-PESA Conference in Sydney 1997. Those who worked with Ted on those committees know what great dedication of personal time and effort he devoted to such a task. The excellent programs for these joint conferences, each containing his own innovations, stand as testimony to Ted's skill and enthusiasm in this endeavour.

Ted Tyne

He also provided advice to the technical papers committee for the 1998 Conference and in a similar way his fund of knowledge and experience is available to the society in general.

Ted has continued to maintain an interest in the ASEG at State level despite a heavy commitment to his career.

Nominated by the NSW Branch.

Laric Hawkins Award *for the most innovative use of geophysical technique from a paper presented at the Perth Conference*:

Jayson Meyers, Mathew Cooper, John Bishop and Michael Hatch for their paper entitled "Downhole Magnetometric Resistivity Surveying for Refractory Gold Ore at Wiluna Gold Mine, Western Australia"

The DHMMR technique was shown for the first time to be capable of locating off-hole refractory gold mineralisation along the Bulletin Shear Zone in Yilgarn Craton.

Mathew Cooper accepting the Laric Hawkins Award.

Above some snapshots of the ASEG 2000 Conference, Perth, Western Australia and below 'it's feeding time at the zoo'.

Pre-Stack Depth Migration: Myths and Misconceptions

By Andy Furniss

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Pre-stack Depth Migration (PSDM) is often sold as a tonic to cure all seismic imaging problems. While the technique has been applied with outstanding success in many areas, results sometimes fail to meet expectations due to misconceptions about what the method is designed to achieve.

The primary purpose of PSDM is simply to improve the focussing of the seismic image in a more precise way than time migration does. At the most fundamental level, the main difference between these two approaches is the way in which seismic traces are re-positioned along calculated traveltime curves. Time migration collapses seismic diffractions along hyperbolic traveltime curves to the apex of a hyperbolic diffraction whereas pre-stack depth migration will reposition traces along non-hyperbolic travel paths calculated by ray-tracing through a velocity-depth model. In the real earth, where horizon layers are not flat or parallel and do not have isotropic velocities, the hyperbolic assumption of time migration breaks down and we obtain an imperfect image in which traces are mis-positioned and consequently, poorly focussed. This is illustrated schematically in Figure 1. In depth migration, if we can accurately model the raypaths, we can migrate traces to their correct spatial location and consequently improve our seismic image. A poorly imaged time migration (Figure 2) is shown for comparison with a PSDM section scaled back to time (Figure 3). Notice the improved imaging of fault planes and internal stratigraphy.

The key to accuracy in PSDM imaging lies in the ability to accurately determine the 3D raypaths taken by our seismic waves. While traveltime estimates based on the Eikonal equation provide rapid initial estimates, we need to use a model-based approach to estimate a realistic velocity-depth model of the subsurface. The sensitivity of PSDM algorithms is such that more time is often spent building and refining the velocity model than in running the migration itself.

The use of model-based velocity estimation techniques such as coherency inversion provides a rapid and generally accurate initial velocity model. Global tomography, in which the velocity model is updated, based on depth CRP gather delay analysis, results in an optimal velocity-depth model for producing the best seismic image in depth.

The optimal velocity model produced for PSDM imaging will not tie well-measured velocities nor will the depth horizons mapped on PSDM data coincide with formation markers without further calibration.

The velocity field recorded by the seismic acquisition process is essentially a horizontal one recorded over large offsets with seismic travelpaths propagating through an infinite number of vertical velocity micro-layers. Borehole velocities are typically measured over small intervals very close to the well bore and measure the vertical velocity component which leads to an apparent anisotropy effect in which observed velocities are generally faster in the horizontal direction than the vertical. Consequently, our velocities calculated from seismic traces will be faster than any well-based velocity estimate over the same interval. For this reason, seismic events after depth migration need to be calibrated to the vertical velocity field for them to tie formation markers. This is done in several ways usually based on calibration of the PSDM velocity model to well-based formation velocities.

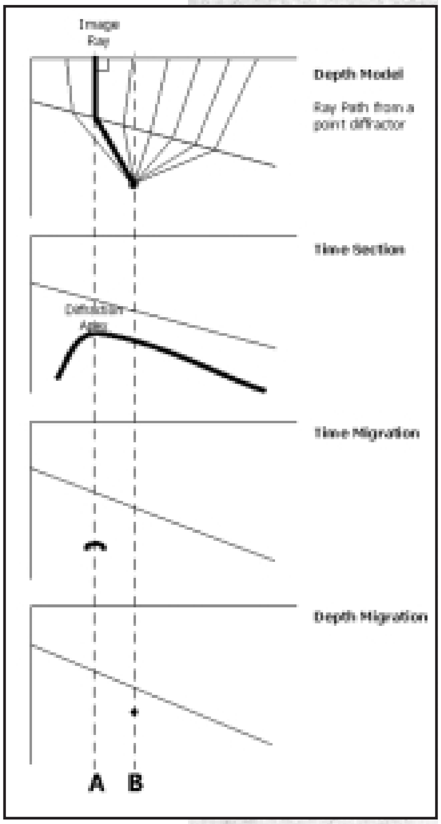

Fig. 1. Schematic showing focussing distortion and positioning error caused by time migration. Depth migration corrects for both.

PSDM is often seen as an add-on processing step to be done where interpretation of time-migrated data cannot be completed in confidence due to poor imaging. This approach is out-dated and needs to change. If a decision is made up-front to perform PSDM on a seismic line or volume, then the steps of processing, interpretation and depth conversion become integral to the whole workflow rather than being

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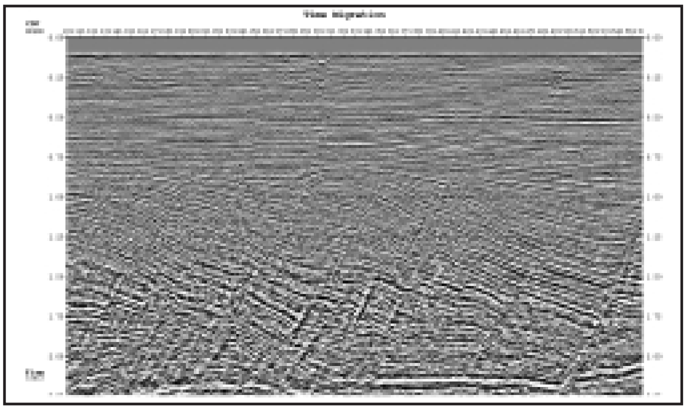

Fig. 2. Post-stack Time Migrated image.

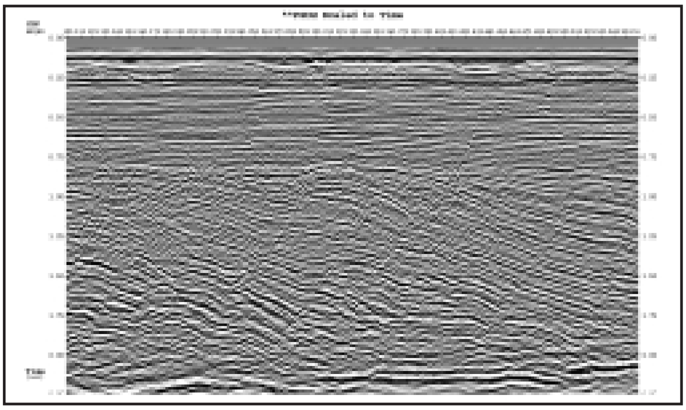

Fig. 3. Pre-stack Depth Migrated image scaled to time. Note improved focussing of events and faults and changes to positioning of structures.

Fault Shadows and Correlation Data

By Mick Micenko

Mick Micenko Exploration

Email: micenko@bigpond.com

Figure 1 is a time-slice from a seismic continuity or semblance volume and shows an interesting example of a pitfall. A well-defined lineament is seen parallel to a less well-defined lineament. In this case it would be tempting to interpret a fault along the well-defined feature, however this is an artefact associated with the "shadow" beneath a major bounding fault. The bounding fault appears as the less well-defined feature in Figure 1.

The seismic section A-B shown in Figure 2 illustrates the cause of the fault shadow effect. A large velocity contrast shallower in the section creates a time delay and hence a sag in the reflectors below the fault plane. On these data, the sag gives rise to a discontinuity below the faulting of the shallow reflector and this is detected by the continuity processing. Because the two lineaments can be observed running parallel for several kilometres it was relatively easy to identify the pitfall in this case.

Suggested reading:

After I put this article together I noticed an excellent summary of the fault shadow effect by Eduardo Trinchero in The Leading Edge, 19/2, Feb 2000.

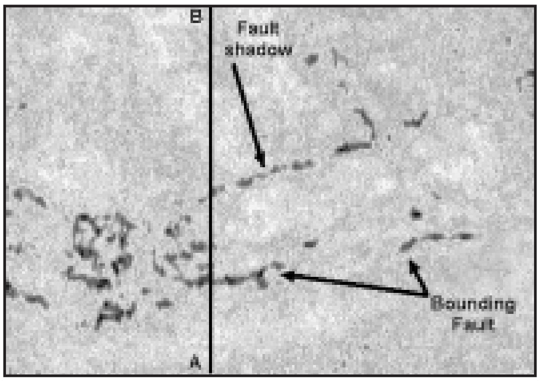

Fig. 1. Time slice (3100 ms) through continuity seismic data showing a major bounding fault and an artefact caused by a shallower velocity contrast or fault shadow.

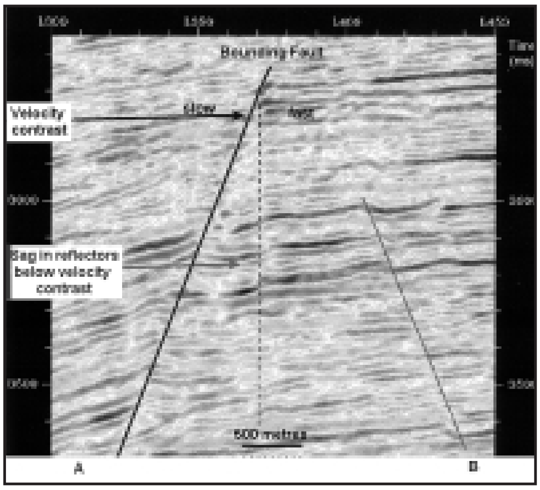

Fig. 2. Vertical seismic section A-B showing the major bounding fault and sag beneath the fault and distortion that gives rise to fault shadow artefact.

Continued From Page 17

disassociated steps along a linear workflow. By the time the final PSDM section is complete, the data are already processed, interpreted and depth converted.

This interpretive processing workflow, afforded by PSDM, provides the interpreter with a more complete understanding of the data area than can ever be achieved by simply mapping traverses on seismic data provided by a remote processing centre. PSDM is a replacement for the conventional seismic evaluation workflow, not a luxury add-on for those that can afford it. In any depth imaging project, the most interpretive value is gained from data that has been given the most interpretive input.

The Importance of Geophysics in South Australian Government Initiatives

By Domenic Calandro and David Cockshell

Minerals & Energy Resources South Australia

Historic use of Geophysics

The use and application of geophysical techniques has had a long and distinguished role in the South Australian Government's aim to facilitate mineral and petroleum exploration and development. Since the formation of the Geophysics Branch in the Department of Mines in 1948 there has been a proactive group of geophysicists in the Department (now Primary Industries and Resources, South Australia - PIRSA). This group has been responsible for extensive geophysical mapping of the State, particularly in the fields of gravity, aeromagnetic and radiometric surveying. In the 1960s and 1970s the Department also operated two seismic crews fulltime. Discoveries such as Radium Hill (uranium), Olympic Dam (copper, uranium, silver, gold), Cooper Basin (oil, gas) and Otway Basin (gas) were made using Departmental geophysical data.

The Department was also involved with the National Geoscience Mapping Accord in conjunction with the Australian Geological Survey Organisation between 1988 and 1992. This program contributed extensive aeromagnetic and seismic coverage, particularly in the Gawler Craton and Officer Basin.

South Australian Exploration Initiative

In 1992, the South Australian Government stunned the geophysical world with the implementation of the South Australian Exploration Initiative (SAEI). This direct injection of $23 million into geotechnical projects, primarily geophysical programs, has been one of the greatest events to stimulate the mining and petroleum industries in Australia's history. This innovative approach has been replicated by most other Australian States as well as internationally.

The SAEI was carried out between 1992 and 1997, and focussed on the following programs:

- acquisition of extensive high resolution aeromagnetic and radiometric data
- processing and merging of airborne datasets
- compilation of GIS datasets
- bedrock drilling
- acquisition of new seismic data
- collation, cataloguing and transcription of existing seismic data
- seismic mapping of key petroleum and frontier provinces
- environmental research and database development.

These programs were successful in providing a dramatic increase in exploration for minerals and petroleum in South Australia. The discovery of several gold prospects, such as the Challenger deposit in the Gawler Craton can be directly attributed to the SAEI program.

The introduction of Native Title legislation at this time caused significant delays in licensing. Otherwise much more extensive company exploration would have surely occurred as a result of the initiative.

A long-term outcome of the SAEI has been the greatest ever coverage of mining and petroleum tenements in prospective areas in the State's history. It will take many more years for the full impact of the SAEI in terms of developed mines, jobs and wealth for the community, to be identified. Such is the nature and timeframe of the mining and petroleum industries.

Targeted Exploration Initiative

The South Australian Government has signalled its continuing confidence in the ability of the mining sector to play a key role in the State's economic growth by committing $23.2 million, to be spent over the years 1998-2002, on a phased, regional exploration strategy for minerals, petroleum and groundwater.

This strategy, known as the Targeted Exploration Initiative South Australia (TEISA), is providing comprehensive, accurate and relevant geoscientific data to encourage private companies to focus their exploration efforts in targeted areas of South Australia.

Consultation with industry during the planning stages of TEISA identified acquisition of high-resolution airborne geophysical data and regional gravity data as high priorities.

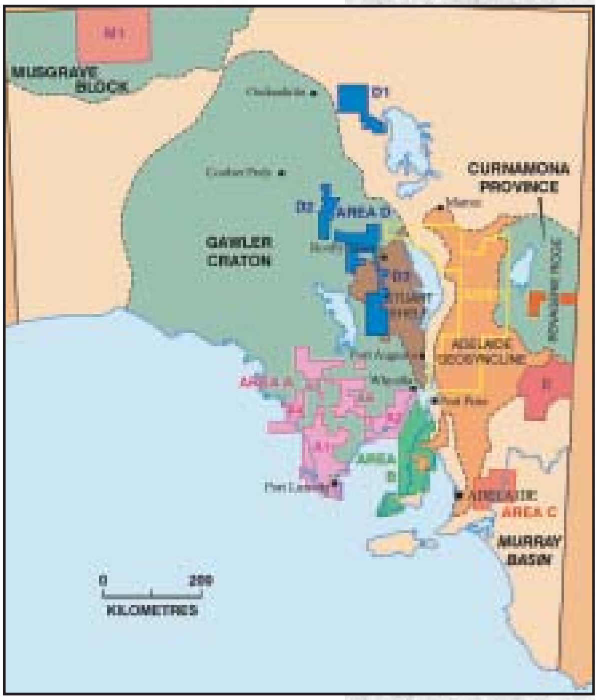

Fig. 1. TEISA airborne surveys, locality map.

Minerals Projects

During the first and second years of TEISA the major focus has been to further improve the airborne geophysical coverage over targeted areas, which include the Musgrave Block (a geological province in the Anangu Pitjantjatjara Lands), the Southern Gawler Craton (including the Eyre and Yorke Peninsulas), the eastern Adelaide Geosyncline, and the Curnamona Province. In 1999, PIRSA and AGSO flew surveys totalling nearly 300 000 line-km, at a line spacing of 400 m with company's infilling at a line spacing of 200 m.

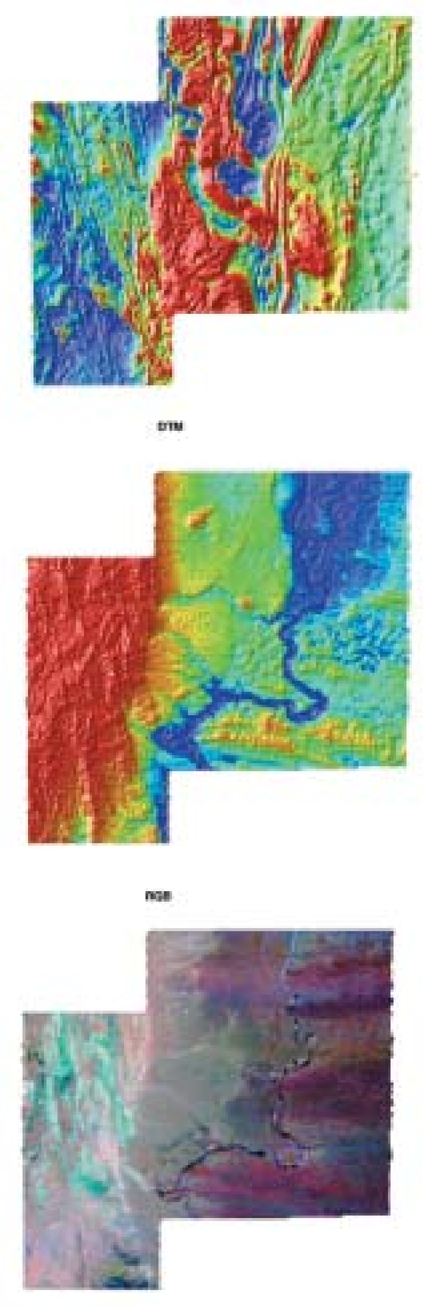

Fig. 2. TEISA Area C, images of Total Magnetic Intensity, Digital Elevation Model and Ternary ?-ray spectrometric data over the Mannum - Kanmantoo region.

Airborne hyperspectral surveys and the acquisition of ortho-imagery over the Curnamona province and the Musgrave Blocks provided excellent insights into the use of new and developing technology in mineral exploration. Gravity programs in the Curnamona Province and the Southern Gawler Craton have been undertaken to further improve the quality of the geophysical data coverage for those regions.

Drilling and mapping projects throughout TEISA target areas will be the main thrust of years three and four of TEISA. The newly acquired geophysical data will be exploited to help provide prospective targets for drilling and mapping.

Petroleum Projects

By far the biggest petroleum project in TEISA is the petroleum data capture and archiving project. This project focussed on scanning and validating existing hardcopy seismic and geological datasets. This includes approximately 30 000 seismic sections, 1000 boxes of ancillary seismic data and 1300 well completion reports. The project also includes collation of other datasets, transcription of tapes and investigation into e-commerce. This project aims to facilitate provision of data to clients, ensure appropriate storage and backup of original records and minimise physical storage volumes. Provision of such 'pre-competitive' or public domain data facilitates exploration by minimising duplication of exploration over the same area by successive explorers.

Other petroleum projects include a range of geological studies focussing on specific aspects of frontier Cambrian basins and the Cooper Basin. A chair at the National Centre for Petroleum Geology and Geophysics in Adelaide is also funded by PIRSA.

Groundwater Projects

Extensive groundwater programs have also been designed to facilitate the search for groundwater to support mining and exploration infrastructure in prospective areas.

The objective of the program is to improve the knowledge of groundwater resources associated with Tertiary/Permian palaeochannels and lineaments within fractured rock under the Gawler Craton.

Extensive ground geophysics and database studies will provide for testing of groundwater potential through drilling.

Future

Although the SAEI and TEISA programs have provided extraordinary funding in the geophysical and geological areas of the public resource sector, PIRSA, along with other Government agencies throughout Australia operates in a world of regular cuts to recurrent budgets. This precipitates a need to be able to 'do-more-with-less' in terms of geophysical resources. This is emphasised during the course of such Government initiatives where intensive and extensive projects need to be effectively and efficiently managed. It also occurs following successful initiatives through increased private exploration.

The focus on 'modernising' historical datasets for improved management by Departmental custodians should not only assist explorers in terms of data provision, but also streamline the storage and provision process by geophysical staff. The SAEI has resulted in major improvements in this area. Moves toward rapid access to and provision of geophysical and other geotechnical data via such technologies as the Internet, virtual data rooms or third party data 'banks' can be expected as a result of TEISA.

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Airborne Electromagnetic Bathymetry: An Overview of Several Australian Surveys With Implications for Maritime Defence in Littoral Waters

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Abstract

Airborne electromagnetic (AEM) methods can be used as a rapid tool for measuring seadepth (bathymetry) and sediment properties in shallow water, thus enhancing significantly the capability of the Royal Australian Navy's operations in littoral waters. The areas of defence application, which could be supported by current technology, include: mine countermeasures operations, amphibious operations, hydrographic reconnaissance and anti-submarine warfare. Several surveys have been performed recently to test the AEM technique and assess its defence applicability. The survey data, when combined with other datasets (single and multi-beam sonar and marine seismic reflection) can be used to rigorously test the accuracy of interpretation, inversion and modelling algorithms. The DIGHEMV survey of Port Jackson, Sydney Harbour, provided a useful case study because the bathymetry varies from about 1 to 30 m and the seabed terrain features a rock reef straddled by two shipping channels. The QUESTEM 450 surveys in Geographe Bay and over Cape Naturaliste, W.A, were used to detect a shipwreck (symbolic of submarine detection) and to determine the maximum depth of investigation respectively. Combined with accurate ground truth data, the dataset can be used to quantitatively assess the AEM system, and the efficacy of layered earth inversion and conductivity-depth imaging software. Conductivity sections can be used to estimate sediment properties and detect shallow bedrock.

Introduction

The application of airborne electromagnetic (AEM) methods for shallow water bathymetry is currently under investigation by the Defence Science and Technology Organisation (DSTO). Surveys in Sydney Harbour (Vrbancich et al., 2000) and Geographe Bay, Western Australia, show that the AEM method has the potential to enhance the Australian Defence Force (ADF) capability in the priority area of maritime operations in littoral waters. Used as a hydrographic reconnaissance tool, AEM bathymetry could provide a cost-effective remote sensing method to determine bathymetry and seabed classification to support Royal Australian Navy (RAN) hydrographic, mine warfare and amphibious operations.

A conductive earth overburden is a common feature of the Australian continent and this has led to the development of techniques to deepen the depth of AEM investigation. Thus emerging AEM technology is increasingly applicable to shallow seawater surveying and consequently, maritime defence. The results of two recent surveys using different AEM techniques are examined in terms of defence applications in littoral waters.

Defence Applications

DSTO sponsored AEM surveys

A recent survey of lower Port Jackson (Sydney Harbour), using the helicopter DIGHEM system, was interpreted on the basis of a one-dimensional model involving only two layers (Vrbancich et al., 2000). The survey area covers a bathymetry range of 1 to 32 m. The upper layer was assigned a conductivity representative of seawater and the semi-infinite lower layer (basement) was assigned a narrow conductivity range representative of marine sediment. The measured electromagnetic response was interpreted in terms of a variable upper layer thickness equivalent to the bathymetry. The bathymetry of the surveyed area is shown as an image in Figure 1. The validity of the technique was quantitatively assessed by comparison with accurate single and multibeam sonar echo soundings. The residual (defined as the difference between the AEM bathymetry and echo sounding bathymetry) and rms error is given in Table 1 for 10 m depth intervals (Vrbancich et al., 2000). With this system, useful AEM bathymetry data can be obtained to a maximum depth of about 30 m.

Depth Interval [m]	Mean Depth [m]	Standard Deviation [m]	Mean Residual [m]	Standard Deviation [m]	RMS residual [m]
0 - 10	7.1	1.6	- 0.2	0.8	0.8
10 - 20	14.6	2.3	1.6	3.5	3.8
20 - 30	23.2	2.4	3.5	2.6	4.4

Table 1. Bathymetry statistics in 10 m depth intervals.

Conductivity sections were also determined using multi-layered earth inversion and rapid conductivity-depth imaging (CDI). Seawater depth is estimated by grouping the layers with conductivity greater than 2.5 S/m. The resolution of sea depth using both methods gives good agreement with known bathymetry (within 10% or better) when inversion was unconstrained, except for the CDI method where, in water less than 10 m, there is poor discrimination between seawater and sediment conductivities. Unconsolidated sediment and bedrock was also identified in agreement with available marine seismic reflection data in areas where seawater is shallower than about 20 m.

A QUESTEM 450 survey, was flown from Geographe Bay, Western Australia, over Cape Naturaliste and out to the 200 m sea depth contour, and return over the same path. The bathymetry was determined from the EM response of the time domain fixed wing system operating at 25 Hz. The maximum sea depth obtained from this system was estimated to be about 70 m. The derived AEM bathymetry generally showed good agreement to better than 10% with sea depth soundings and contours shown on available RAN charts.

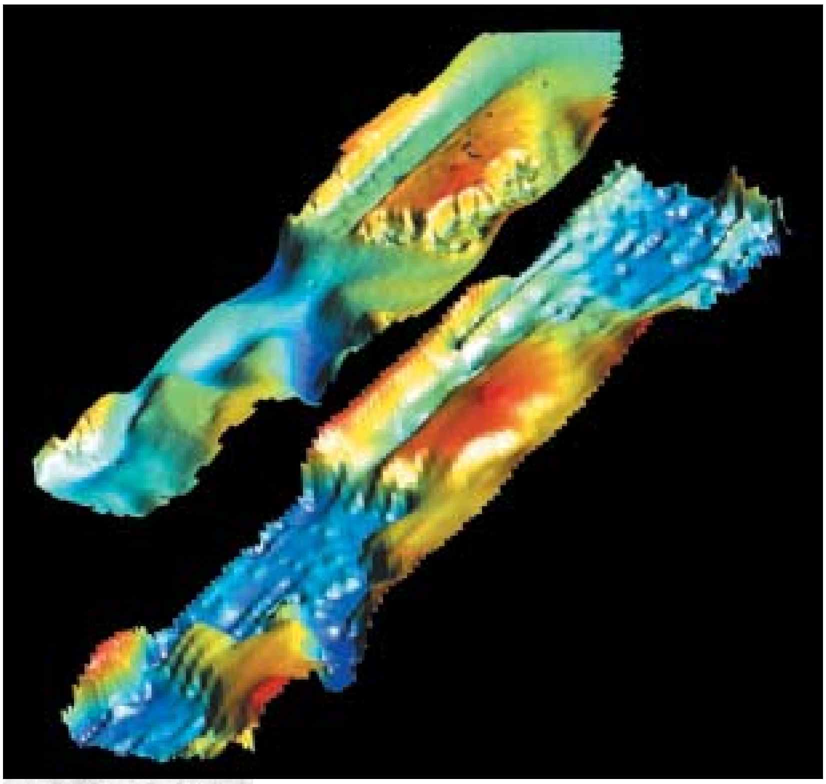

Fig. 1. Digital terrain map of a portion of Sydney Harbour, Port Jackson, showing the varied seafloor topography. Upper image represents combined single beam (courtesy of Sydney Ports Corporation) and multibeam sonar data. Lower image represents helicopter EM survey data. Both images are vertically aligned, with a vertical exaggeration of 14, and are colour draped to show the bathymetry: red (-4 m), yellow (-12 m), aqua to light blue (-16 to -20 m) and dark blue (-32 m). The major peak in the lower image is the tip of the Sow and Pigs reef which is too shallow to be surveyed using hull mounted sonar.

The quoted maximum AEM bathymetry depths based on DSTO sponsored surveys for both helicopter and fixed wing systems do not necessarily represent ultimate technical limits. Deeper penetration depths through seawater would no doubt broaden the scope for applying AEM to maritime defence needs. However, the current penetration depths could support certain mine countermeasures and amphibious operations.

Hydrographic Reconnaissance

The traditional method for measuring bathymetry relies on echo soundings taken from survey vessels. Recently, this relatively slow method has been improved with the use of high-resolution multibeam swathe mapping systems, which allow efficient and accurate mapping of the continental shelf (Hughes-Clarke et al., 1996). Hydrographic survey using airborne sensors has improved the coverage in littoral waters less than 50 m sea depth. Airborne sensors have the advantage of being able to operate in areas where strong tidal currents exist and over shoals and reefs where navigation is hazardous. The RAN initiated survey operations, using the LADS (Laser Airborne Depth Sounder) system, in 1993 (Penney et al., 1986) and since then has surveyed over 60 000 km^2 of Australia's coastline. The maximum survey depth and coverage is about 50 m and 170 km^2 per hour respectively, and is reduced by environmental and weather conditions. In 1998, the LADS Mk II entered operational service with an improved maximum depth capability of 70 m. The LADS system has proven to be an efficient, accurate and cost-effective hydrographic tool for bathymetric survey to International Hydrographic Organisation (IHO) standards.

Whilst vertical depth resolution for AEM bathymetry may meet the IHO standards within certain depth intervals, it is unlikely that the spatial resolution will meet IHO standards because of the AEM footprint size which at the sea surface, is about twice the receiver height (Kovacs et al., 1995). (By comparison, the LADS Mk I and II systems have a surface illumination spot size of 2.5 m diameter, and a 10 m by 10 m and 5 m by 5 m surface illumination grid respectively. Depending on water clarity, the footprint at about 15 m sea depth is 10 m.) Nevertheless, there is scope for AEM bathymetry to serve as a valuable hydrographic reconnaissance tool because of Australia's extensive, poorly charted and complex continental shelf. The areas within the 200, 70 and 50 m depth contours are about 2.6, 1.8 and 1.2 Mkm^2 respectively based on information provided by the RAN Hydrographer. Figure 2 shows the total area and inadequately surveyed areas of coastal waters shallower than 70 m that lie within Australia's region of charting responsibility. Accordingly, approximately 83% and 87% of the area of coastal waters shallower than 70 m and lying between 70 and 50 m depth respectively are inadequately surveyed. Thus, there is ample opportunity for AEM bathymetry to complement the work undertaken by the RAN Hydrographic Service, which currently uses both surface and airborne systems. Cost effective AEM bathymetry surveying could be used to reduce this extensive coverage.

Turbidity: - Based on information provided by the RAN Hydrographer, it is estimated that within the 70 m depth contour, an area of ~0.5 Mkm^2, i.e. about 30%, is affected by turbidity. Turbidity can drastically reduce the bathymetric depth of investigation for airborne systems using optical techniques. Since the optical transmission properties of seawater containing suspended sediment does not alter the conductivity of seawater significantly, AEM bathymetry is unaffected by turbidity. Investigation depths could be enhanced in areas where turbidity is caused by an influx of dissolved sediments, arising from freshwater runoff, which would lower the seawater conductivity.

Mine countermeasures - route survey: - Sea transport carries over 75%, in terms of value, of Australia's total international trade (99% by weight). Australia's ports and harbour entrances are vulnerable to mining and route surveys are an ongoing activity, supported by mine countermeasures operations. "General Route Survey" operations (Route Selection, Survey and Surveillance) are primarily a non-tactical activity in peacetime to obtain physical and environmental information about the seabed and water column surrounding the channel. One function would be to map harbour entrances and to provide, at short notice, alternative routes for vessels requiring port access where sea mines have been detected in shipping channels. A "Detail Route Survey" requires a suitable vessel to carry out a detailed sweep of the channel using high definition mine hunting sonar. AEM could be used to provide "General Survey" data to assist in the planning of mine hunting activities. Being relatively inexpensive, multiple HEM bathymetry systems could provide a cost effective method for simultaneously surveying geographically isolated areas using a range of helicopter assets.

The bathymetric survey of Sydney Harbour (Vrbancich et al., 2000) serves as an example of how HEM could support mine countermeasures route survey operations for most high priority ports that are inadequately surveyed. A 3D image of the bathymetry, obtained by gridding the inverted EM response for each survey line is shown in Figure 1. This image clearly defines various topographical features including channels and a reef, provides reasonably accurate water depths as shown in Table 1, and can identify areas of shallow bedrock and unconsolidated sediment. The available ground truth bathymetry and marine seismic reflection data can be used to refine and quantitatively assess the accuracy of various AEM interpretation schemes. Quasi-real time interpretation is feasible and could significantly enhance military applications.

Amphibious operations: - Amphibious operations take place in water depths from 10 m to the shore. AEM bathymetry derived from rapidly deployable helicopter systems has the potential to play an important role in cases where chart soundings are inaccurate, or unknown. Bathymetry will expose available channels, highlight navigational hazards such as shoals or sandbanks and can be used to determine gradients for beach approaches. Whilst vertical depth resolution is good in very shallow water, Table 1, the accuracy of the gradient could be influenced by the spatial resolution and 1D EM forward modelling assumptions.

Seafloor Mapping

Conductivity versus depth sections have been generated for the Sydney Harbour survey using both layered earth inversion and rapid conductivity-depth imaging. Interpreted seawater, sediment and bedrock boundaries were estimated from loosely defined conductivity ranges associated with each generic layer. The study has shown that it is possible to remotely sense seabed properties to identify areas of shallow bedrock and differentiate between consolidated and unconsolidated sediments, in areas where the seawater depth is shallower than about 20 m. This depth represents a useful starting point and was determined with AEM equipment that has since been superseded. Two improvements would lead to deeper investigation depths: lower operating frequencies for increased seawater penetration, and improved system stability and calibration to enhance signal to noise ratios. The AEM method simultaneously measures bathymetry and seabed properties. The success of the latter is dependent on well-established relationships between marine sediment porosity, formation factors and conductivity (Jackson et al., 1978).

East Timor: - The recent crisis in East Timor highlights the need for rapidly deployable tools to measure bathymetry and seafloor properties. For example, the RAN employed the LADS system to measure coastal bathymetry in poorly chartered waters. Two factors could have limited the usefulness of this survey if it had been undertaken during the wet season. Firstly, dissolved sediments would have given rise to turbidity, which could have significantly reduced penetration depths. Secondly, cloud cover affects the operability of LADS - the RAN LADS (Mk I) operates at a height of 500 m and the LADS Mk II operates between 300 and 500 m height. The AEM helicopter and aircraft operate at about 60 and 100 m respectively, below cloud cover. Another example involves an amphibious landing at the southern coastline village of Saui to secure the area for further operations. No port facilities exist and there is no road access. Landing craft carrying troops and equipment made numerous transits between the support vessel and the beach in poorly chartered waters. The risk of running aground during transit poses a logistic threat. Helicopter assets either from the amphibious support vessel or shore facilities, could have been deployed for AEM surveying to measure bathymetry and seafloor properties to determine safe routes for amphibious landing and to estimate the geotechnical properties of sediments, inferred from porosity, to support heavy landing craft.

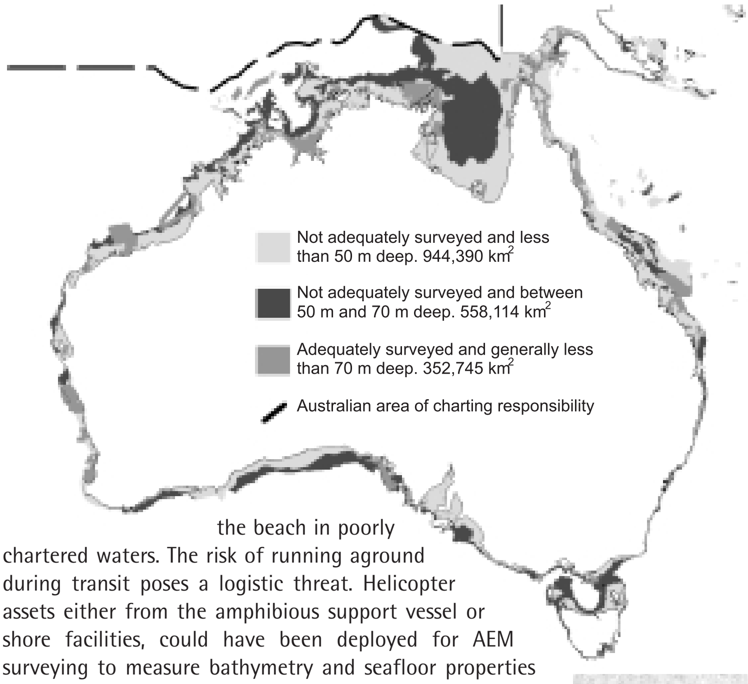

Fig. 2. Australian coastal waters. Areas based on information provided by the Royal Australian Navy Hydrographer. The entire area of charting responsibility is not shown.

Mine countermeasures and mine burial: - Shallow waters cover all of the entrances to Australia's priority ports, and include areas where it could be possible to lay mines for burial in unconsolidated sediment. From a "Route Survey" perspective, there is an uneven coverage of bottom and sub-bottom classification information. AEM could provide a cost effective remote sensing tool to map areas of expected different backscatter strength required for evaluating mine hunting sonar performance, and provide data showing areas of unconsolidated sediment for mine burial prediction and modelling.

Antisubmarine Warfare (ASW)

The recent shift in emphasis adopted by many navies from deep water, towards littoral warfare, has generated notable interest in the use of non-acoustic detection methods. The littoral environment plays a crucial role in the propagation of sound energy and hence, the detection probability and stealth characteristics of submarines. The intrinsic low acoustic signature of the target, the noisy environmental background and in some cases the difficulty in deploying towed sensor arrays as is common in deeper water, may limit passive acoustic detection. Active sonar detection may also be difficult because of the reverberant background and false echoes produced in the littoral environment.

AEM could complement the magnetic anomaly detection method, which is used as an airborne ASW capability for localised submarine detection. Older submarine classes rely on deperming methods that reduce the ferromagnetic signature, whereas newer boats such as the COLLINS Class are constructed with degaussing coils designed to actively manage the magnetic signature. Whilst effective degaussing can significantly reduce the submarine magnetic anomaly signature, the EM response will still remain unaltered.

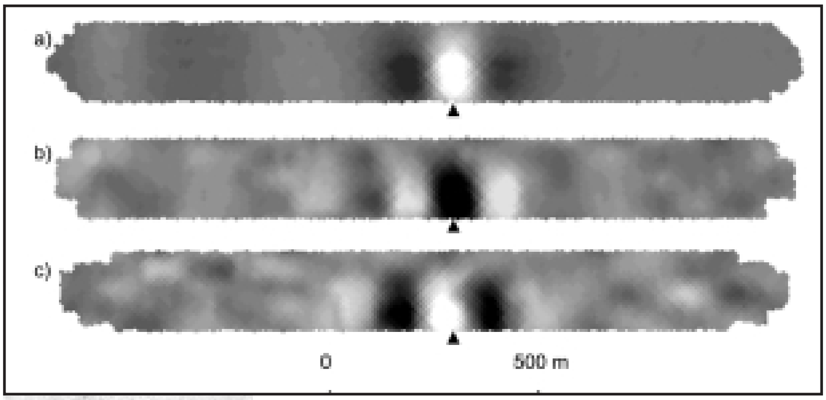

Fig. 3. Image of decommissioned HMAS SWAN dive wreck, Geographe Bay. (a): first vertical derivative of total magnetic field intensity. First vertical derivative of AEM response at 9.5 ms: (b), horizontal component along flight line; (c) vertical component. The 110 m length dive wreck lies orthogonal to the flight path, and the arrowhead marker shows its location.

Recently, the decommissioned HMAS SWAN, formerly a River Class destroyer escort, was scuttled in 30 m of water in Geographe Bay, as a dive wreck. This wreck serves as a convenient target for preliminary studies on the usefulness of AEM as an ASW tool. The decommissioned HMAS SWAN target was surveyed with the QUESTEM 450 digital time domain airborne EM system (World Geoscience Corp. Ltd.) transmitting at 25 Hz with a 4 ms pulse width. The EM transmitter and receiver heights were approximately 120 m and 80 m respectively and the total-field magnetometer was located in the aircraft "stinger".

A preliminary analysis of the magnetometer and AEM data shows that the dive wreck is detected with comparable effectiveness using both methods. Figure 3a shows an image of the first vertical derivative of the total magnetic field intensity, gridded from data obtained from the whole survey. Figure 3, b&c shows the first vertical derivative of the horizontal (x-component, along flight line) and vertical component, respectively, of the AEM response data centred at a mean window time of 9.5 ms. The dive wreck is readily detected using both EM and magnetic methods.

Conclusion

The DSTO sponsored AEM surveys were designed to appraise the use of available remote sensing geophysical EM exploration methods to support maritime operations in littoral waters. The Sydney Harbour site in particular serves as a useful case study for the analysis of previous and future HEM surveys. Accurate bathymetry data covering the whole survey area has been obtained from the Sydney Ports Corporation and from DSTO multibeam surveys. Thus accurate bathymetry and depth to bedrock ground truth data is available and can be used to appraise the accuracy of the EM interpretation.

The depths of AEM investigation are restrictive, however they are suited to supporting maritime operations where bathymetry and sediment properties can influence defence capability. In particular, amphibious operations take place in very shallow water, typically less than 10 m. Mine countermeasures operations also take place in very shallow waters that surround the approaches to many priority ports. A deeper depth of investigation in seawater would however broaden the scope for AEM to support a range of mine countermeasures and other defence activities, such as extensive mapping of areas suitable for mine burial and mapping sediment properties for low frequency sonar propagation modelling. The current depth limits for helicopter and fixed-wing and AEM surveys, of about 30 and 70 m respectively, are well suited to hydrographic reconnaissance, especially in waters affected by turbidity. A preliminary study has also examined the usefulness of AEM as an ASW tool. Localised magnetic anomaly detection is expected to be more sensitive than AEM detection for undegaussed submarines, however AEM would be useful for detection of fully degaussed submarines.

This communication has outlined several important areas where standard AEM methods used in the Australian geophysical exploration industry could be applied to support Australian Defence Forces operating in littoral waters.

Acknowledgements

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Australian Geomagnetic Reference Field, 2000 Revision

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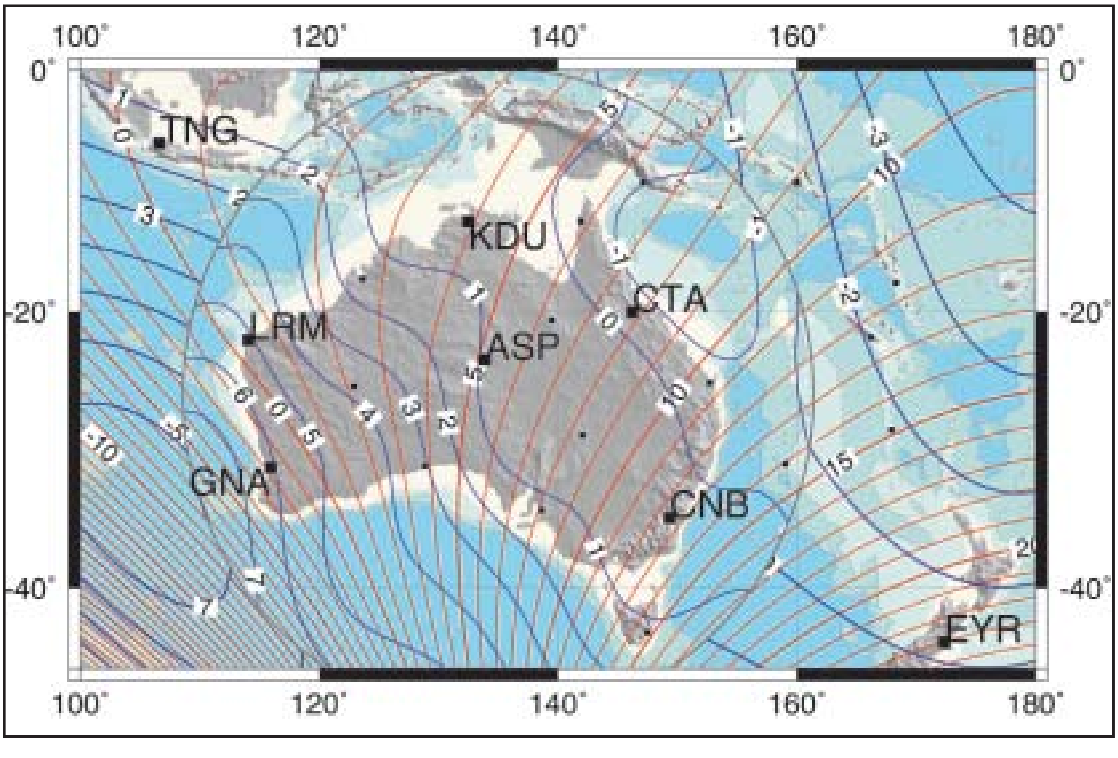
The Australian Geological Survey Organisation (AGSO) has recently released the year 2000 revision of the Australian Geomagnetic Reference Field (AGRF00). AGRF00 is recommended as the best available model for regional direction-finding applications. It also provides a basis for updating magnetic surveys to a common epoch, identifying large-scale crustal magnetic anomalies, and defining the magnetic field vector required for computer modelling of induced magnetic anomalies.

AGRF00 is a numerical description of the geomagnetic field and its secular (annual) change over the Australian region, including much of Papua New Guinea and eastern Indonesia. It is intended for use from 1995 to 2005 and supersedes the previous model, AGRF95. AGRF00 represents a combination of the Earth's main (core) field and the long-wavelength crustal field. It describes the geomagnetic field on a regional scale between the global scale of the International Geomagnetic Reference Field (IGRF) and the local scale of detailed ground and aeromagnetic surveys. Irregularities in the magnetic field caused by local crustal anomalies are not represented by AGRF00.

The main field model in AGRF00 is based on an extensive data set comprising all available vector survey data from the modelled area. This includes AGSO's 3rd Order ground survey (1967-1975), MAGSAT satellite data (1980), the U.S. Navy's Project Magnet high elevation aeromagnetic surveys (1983-1990), and magnetic observatory and repeat station data for the region. The secular variation model in AGRF00 is based on geomagnetic observatory and repeat-station data, including AGSO's geomagnetic observatories at Canberra (CNB), Gnangara (GNA), Learmonth (LRM), Charters Towers (CTA), Alice Springs (ASP) and Macquarie Island (MCQ), as well as observatory data from New Zealand and Western Samoa. Data from all the repeat station occupations made within the period 1995 to 2000 from the network maintained by AGSO throughout mainland Australia, offshore islands, Papua New Guinea and the southwest Pacific region, were used in the model. The model was developed as a spherical cap harmonic model of the residual crustal field, with respect to the IGRF 2000, within a spherical cap-shaped region of radius 28° centred on latitude 24°S and 135°E (see figure). It is recommended that the AGRF00 model be used only within a cap of radius 24° because of edge effects associated with the numerical modelling. The model must not be used outside the area of the 28° cap.

An AGRF00 software package is available from AGSO for $250. Two main programs to evaluate AGRF00 are included in the package, one for single point locations and the other for a regular grid in latitude and longitude. AGRF00 can also be evaluated for single sites on AGSO's web page at http://www.agso.gov.au/geophysics/geomag/rf/agrf.html.

The AGRF00 software provides the option of calculating either AGRF00 or IGRF 2000. The figure depicts a magnetic declination (variation) chart of the AGRF00 for epoch 2000.0. The circular boundary of the 24° spherical cap is also shown. Inside the cap boundary contours are derived from AGRF00, outside the boundary the data are derived from the IGRF 2000 model.



AGRF00 magnetic declination at epoch 2000.0, main field contoured in red (in degrees) and secular variation in blue (in minutes-of-arc per year). Positive declination indicates magnetic north is east of true north, negative values are west of true north. The permanent magnetic observatories are represented by three-letter codes (see text).

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Key words:

Aeromagnetic, survey, gradiometer, tensor, SQUID

Advantages of Measuring the Magnetic Gradient Tensor

Abstract

Measuring the magnetic gradient tensor will improve the interpretability of magnetic surveys, especially in areas where anomaly patterns are skewed by remanence or low magnetic latitudes. The benefits of total field gradiometry are well recognised, but the total magnetic intensity (TMI) is not a potential field and nor are its gradients. On the other hand, tensor components are true potential fields and possess desirable mathematical properties. The crucial difference between full tensor gradiometry and total field gradiometry is the production of more detailed and quantitatively interpretable maps and 3D models, rather than simple bump detection. Magnetics is still the cheapest and most widely used geophysical mapping tool in hard rock environments, with increasing importance and potential for further growth in hydrocarbon exploration.

Gradient tensor surveys will retain the benefits of vector surveys without the disadvantage of extreme orientation sensitivity. The tensor open up a wide range of new types of data processing techniques including application of invariants, directional filters, depth slicing, source moments and dipole location immune from sensor misorientation.

Superconducting interference devices (SQUIDs) are the sensors of choice for tensor gradiometry. They are vector sensors and are highly sensitive; they are small and consume little power. High-temperature SQUIDs (HTSs), which only require liquid nitrogen as opposed to liquid helium used for low-temperature SQUIDs, have intrinsic sensitivities ~100 fT (10^{-13} Tesla). It is also probable that in the future the required temperatures may be achieved without a cryogen. It has been estimated that gradiometer sensitivities of 0.01 nT/m can be achieved. This sensitivity is sufficient to detect anomalies over contacts between bodies with susceptibility contrasts as low as 60 x 10^{-5} SI at depths of over 100 m, and for contrasts of 600 x 10^{-5} SI at depths of over 1 km.

Tensor gradiometry will prove useful not only for aeromagnetic surveys, but also for environmental surveys, for defence applications such as submarine and unexploded ordnance detection and in down-hole magnetics. Any substantial improvement in this technology will have enormous benefits, in terms of new discoveries and lower exploration costs.

Introduction

Airborne magnetic surveys have improved dramatically over the past two decades with advances in both data acquisition and image processing techniques. Magnetic surveys form an integral part of exploration programs and are now routinely undertaken before geological mapping programs. These advances have been made despite treating the magnetic field as a scalar, wherein various processing procedures that assume a potential field are compromised. If the vector information could be retrieved, either by direct measurement or by mathematical manipulation, magnetic surveys could be improved even further. For instance, the total magnetic intensity (TMI) could be corrected so it represents a true potential field.

We discussed the calculation of vector components and lines-of-force from the TMI in a previous issue (Preview 70, October 1997, see also Schmidt and Clark, 1998) and implementing these techniques now forms part of a current AMIRA project (P602). Vector surveys, where the direct measurement of vector components has been attempted, have met with mixed success. The accuracy of direct measurement of the field vector is largely governed by orientation errors, which for airborne platforms are so large that the theoretical derivation of the components from the TMI is actually preferable. For this reason, and others listed below, it is desirable to measure the field gradient(s), rather than field vector.

Gradient measurements are relatively insensitive to orientation. This is because gradients arise largely from anomalous sources, and the background gradient is low. This contrasts with the field vector, which is dominated by the background field, i.e. that arising from the Earth's core. Gradient measurements are therefore most appropriate for airborne applications. Another advantage is they obviate the need for base stations and corrections for diurnal variations. They also greatly reduce the need for regional corrections, which are required by TMI surveys because of deeper crustal fields that are not of exploration interest, or the normal (quasi-) latitudinal intensity variation of the global field.

Gradient measurements also provide valuable additional information, compared to conventional total field measurements, when the field is undersampled. Undersampling is common perpendicular to flight lines in airborne surveys, is usual in ground surveys, and always pertains in down-hole surveys. Conditions under which calculation is preferable to measurement of vectors and gradient tensors have yet to be characterised by modelling and case studies. Synergistic interpretation of calculated vectors and measured gradients may allow significantly more information to be extracted from airborne surveys.

The advantages of magnetic gradients surveys are well known and include:

- Better resolution of shallow features and closely spaced sources
- Better definition of structural features
- Suppresses regional anomalies due to deep sources
- Subvertical contact mapper
- Anomalies tighter around compact sources
- Aids detection and delineation of pipe-like sources
- Constrains local strike direction*
- Determines on which side of line source lies*
- Common mode rejection of geomagnetic variations
- Relatively insensitive to rotation noise

- Constrains interpolation between flight lines* (important as all surveys are aliased to some extent across flight lines)
- IGRF corrections less important (usually unnecessary)
- Provides direct indication of Euler structural index when combined with measurements of field
- Higher resolution than conventional TMI surveys can be offset against survey height, allowing somewhat higher, therefore considerably safer, flying.

*not vertical TMI gradients

Total field gradiometry versus tensor gradiometry

Total field gradient surveys are common (Hood, 1981) and while they share many of the advantages of tensor gradients such as obviating or ameliorating the need for base stations and regional corrections, total field gradients are not vectors or true potential fields. Christensen and Rajagopalan (2000) suggest that the next breakthrough in magnetic exploration is likely to be the measurement of the gradient tensor.

To examine how the total field gradient and the gradient tensor are related, denote the regional geomagnetic field vector by F and the local field vector by F'. The anomalous field produced by subsurface sources is ΔB. Then

$$F' = F + \Delta B \qquad (1)$$

The measured total field anomaly is given by:

$$\Delta B_m = |F'| - |F| \qquad (2)$$

Traditionally, this is assumed to equal the projection of the anomalous field vector onto the regional field direction, $\Delta B_T = \Delta B \,.\, F/|F|$. ΔB_T has useful mathematical properties, because it is a potential field (it obeys Laplace's equation) and can be continued to other levels, if it is accurately known everywhere over one surface. In fact, the measured total field anomaly is equal to the ΔB_T only to first order in $\Delta B/F$. When anomalies are strong (thousands of nT), the difference between the two "total field" anomalies becomes significant. The maximum error due to equating the two quantities is:

$$\Delta B_m - \Delta B_T \approx (\Delta B)^2/2F \qquad (3)$$

This implies a relative error of ~10% for a 10 000 nT anomaly in a 50 000 nT regional field.
Whereas ΔB_T obeys $\nabla^2(\Delta B_T) \equiv 0$ (Laplace's equation), the Laplacian of ΔB_m is given by:

$$\nabla^2(\Delta B_T) \text{ » } [BXSIG^2 + BYSIG^2 + BZSIG^2 - ANSIG^2]/F \qquad (4)$$

where $BXSIG$ is the analytic signal derived from ΔB_x (i.e. calculated using tensor components B_{xx}, B_{yx}, B_{zx}), $ANSIG$ is the analytic signal calculated from the total field gradients in the x, y and z directions etc. The RHS of the above expression is, in general, non-zero. For a body elongated parallel to y, $BYSIG^2 \approx 0$ and $BZSIG^2 \approx ANSIG^2$. Thus the RHS $\approx BXSIG^2/F > 0$. Because ΔB_m does not obey Laplace's equation exactly, it is not a potential field, and neither are its *derivatives* $(\partial \Delta B_m/\partial x,\ \partial \Delta B_m/\partial y,\ \partial \Delta B_m/\partial z)$. Specific expressions for the z-component and total field analytic signals are respectively:

$$BZSIG = \left(B_{zx}^2 + B_{zy}^2 + B_{zz}^2\right)^{1/2} \qquad (5)$$

$$ANSIG = \left(\left(\frac{\partial B}{\partial x}\right)^2 + \left(\frac{\partial B}{\partial y}\right)^2 + \left(\frac{\partial B}{\partial z}\right)^2\right)^{1/2} \qquad (6)$$

Specific advantages of magnetic tensor gradiometry and benefits that are specific to gradient tensor surveys include:

- Retains benefits of vector surveys, without disadvantage of extreme orientation sensitivity
- Tensor components are true potential fields, with desirable mathematical properties (important in areas with strong anomalies) - allows rigorous continuation, RTP, magnetisation mapping, etc
- Wide range of new types of processed data possible: invariants, directional filters, depth slicing, source moments and dipole location unaffected by sensor misorientation
- Each tensor component represents a directional filter, emphasising structures in particular orientations
- Combination of tensor components gives information on magnetisation directions
- Redundancy of tensor components gives inherent error correction and noise estimates
- Measurement of full tensor allows rotation of co-ordinate system, yielding transformed tensor components that emphasise specified structural orientations
- Allows direct determination of 3D analytic signal (defines source outlines; width/depth determinations - irrespective of remanent magnetisation)
- Measurement of tensor allows calculation of parameters with superior resolving power to conventional analytic signal
- Measurement of tensor allows calculation of parameters (e.g. invariants of the tensor) unaffected by aliasing across flight lines
- Superior Euler deconvolution solutions from measured tensor components with improved accuracy using true measured gradients along and across lines
- Tensor components are independent of skewing caused by geomagnetic field direction - ease of interpretability
- Defines direction to compact source directly from single station measurement
- Enables direct calculation of compact source magnetic moments
- Improved resolution of pipe-like bodies
- Improved resolution of sources subparallel to flight path
- Improved delineation of N-S elongated sources in low latitudes
- Spin-off applications to down-hole magnetics and remote determination of source magnetic properties *in situ*

Measurement of the gradient tensor

The most appropriate sensors for gradient measurements are Superconducting Quantum Interference Devices

(SQUIDs - see Foley *et al.*, 1999 and Foley and Leslie, 1998). SQUIDs detect minute changes of flux threading a superconducting loop. They are therefore variometers rather than magnetometers, but they are vector sensors since it is only changes perpendicular to the loop that are detected. So called high temperature SQUIDs, or HTSs, operate at liquid nitrogen temperatures (-197°C), overcoming the logistical problems of handing liquid helium. It is also probable that in the future the required temperatures may be achieved without a cryogen. Micro-miniature Joule-Thomson and low-power non-magnetic Stirling cryocoolers are being developed (Zimmerman, 1981).

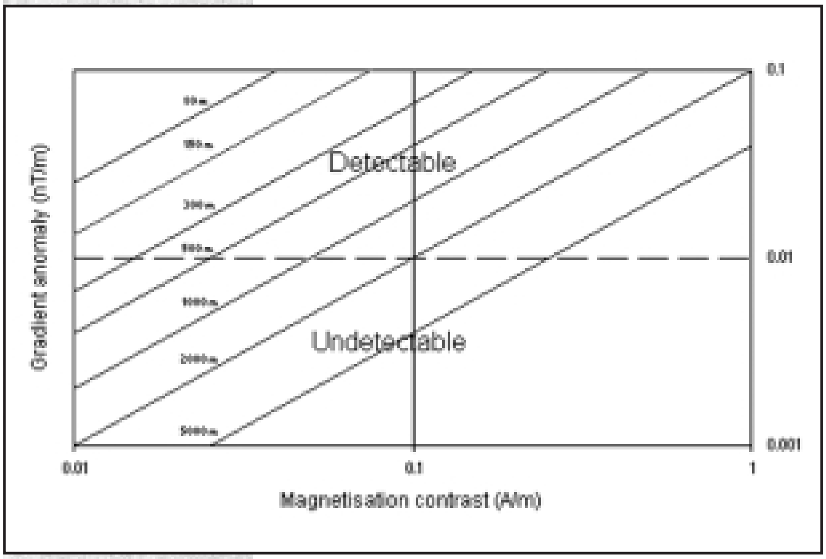

Fig. 1. Relationship between magnetization contrast across a contact and the vertical gradient anomaly of the total field. The graph is divided into detectable anomalies and undetectable anomalies for various depths from 80 m to 5000 m by the sensitivity level of 0.01 nT/m.

The sensitivity of SQUIDs is of the order of 100 fT (10^{-13} Tesla) and it has been estimated that gradiometer sensitivity should be better than 0.01 nT/m, on a baseline of 0.1 m. In Fig. 1 we have plotted the relationship between magnetization contrast across a vertical contact and the vertical gradient anomaly of the total field following Hood (1981). Although Hood's derivation is for total field anomalies over vertical contacts they are the same order of magnitude as gradient tensor components. In addition, the consideration of anomalies over vertical contacts is conservative because the Euler structural index, n, of a contact is only ~0.5, whereas for a thin dyke n = 1 and for a dipole n = 3. These higher structural indices translate into larger gradient anomalies.

For completeness however, Table 1 lists typical anomalies (assuming reduction to the pole for simplicity) of the gradient tensor component, B_{zz}. If we consider a vertical contact between two paramagnetic rock units such as a mafic and a felsic gneiss, which contain no magnetite or pyrrhotite, with a susceptibility contrast of ~60 × 10^{-5} SI, at 100 m the vertical field anomaly ΔB_z is 15 nT while ΔB_{zz} is -0.08 nT/m. This should be easily detected by a gradiometer with a sensitivity of 0.01 nT/m. If one rock unit contained ~0.2% magnetite the susceptibility contrast would be approximately 600 × 10^{-5} SI and detectable at depths of over 1 km.

SQUIDs are small (few cm) low power devices which may eventually find application down-hole or in drones. The very rapid sampling rate of SQUID sensors should allow

Source (Euler index)	ΔB_z	ΔB_{zz} (h = 100 m)	ΔB_{zz} (h = 500 m)
Sphere n = 3	100 nT	-3 nT/m	-0.6 nT/m
	10 nT	-0.3 nT/m	-0.06 nT/m
Pipe n = 2	100 nT	-2 nT/m	-0.4 nT/m
	10 nT	-0.2 nT/m	-0.04 nT/m
Dyke n = 1	100 nT	-1 nT/m	-0.2 nT/m
	10 nT	-0.1 nT/m	-0.02 nT/m
Vertical contact n ~ 0.5	100 nT	-0.5 nT/m	-0.1 nT/m
	10 nT	-0.05 nT/m	-0.01 nT/m

Table 1. Anomalies of the gradient tensor component, B_{zz}, assuming RTP.

unaliased detection of high frequency aircraft noise and efficient removal by filtering (total field magnetometers have much slower sampling, which is the cause of some compensation problems).

Deployment of SQUIDs in aircraft and down-hole present different problems. Platform stability will need to be addressed in aircraft - GPS, tilt meters and other methods need to be assessed. Down-hole instruments will have to be slim (25 mm?) robust and reasonably affordable. SQUIDs potentially fulfil all these requirements.

In the real world the gradient tensor is a 3 x 3 second order tensor:

$$\begin{bmatrix} \frac{\partial B_x}{\partial x} & \frac{\partial B_x}{\partial y} & \frac{\partial B_x}{\partial z} \\ \frac{\partial B_y}{\partial x} & \frac{\partial B_y}{\partial y} & \frac{\partial B_y}{\partial z} \\ \frac{\partial B_z}{\partial x} & \frac{\partial B_z}{\partial y} & \frac{\partial B_z}{\partial z} \end{bmatrix} \tag{7}$$

In practice we only need to know five of the components. Because the divergence of the field is zero, i.e.

$$\nabla \cdot \mathrm{B} = \frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0 \tag{8}$$

This means that the gradient tensor is traceless, and only two of the diagonal terms are required. In addition, in the absence of currents and any significant time variations in electrical fields, the curl of the field is also zero,

$$\nabla \times \mathrm{B} = \begin{bmatrix} \boldsymbol{i} & \boldsymbol{j} & \boldsymbol{k} \\ \partial/\partial\mathbf{x} & \partial/\partial\mathbf{y} & \partial/\partial\mathbf{z} \\ \mathbf{B_x} & \mathbf{B_y} & \mathbf{B_z} \end{bmatrix} = 0 \tag{9}$$

This implies that the gradient tensor is symmetric since the three orthogonal components of the curl are zero:

$$\frac{\partial B_x}{\partial y} - \frac{\partial B_y}{\partial x} = 0 \tag{10}$$

$$\frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x} = 0 \tag{11}$$

$$\frac{\partial B_y}{\partial z} - \frac{\partial B_z}{\partial y} = 0 \tag{12}$$

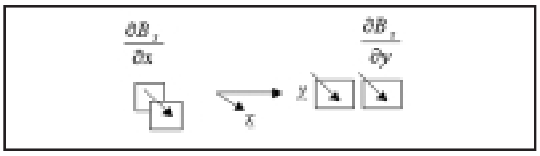

Fig. 2. Arrangement of SQUID sensors for detection of axial and transverse gradients.

Therefore only three off-diagonal terms are required. Fig. 2 depicts the arrangement of SQUID sensors for the detection of axial (diagonal) and transverse (off-diagonal) gradients. Detection of axial gradients requires two separate SQUID sensors but each transverse gradient can be detected using a single planar sensor, which greatly simplifies the total package. Thus seven SQUIDs are required in all to measure the magnetic gradient tensor.

Characteristics of tensor gradient components and derived quantities

In the following, the conventions used are:
+x = N; +y = E; +z = down.

- B_{xx} delineates E-W boundaries preferentially (symmetric for vertical magnetisation; antisymmetric for horizontal magnetisation)
- B_{yy} delineates N-S boundaries preferentially (symmetric for vertical magnetisation; antisymmetric for horizontal magnetisation)
- B_{xy} delineates body corners preferentially (anomaly signs depend on magnetisation direction)
- B_{zz} delineates steep boundaries preferentially (symmetric for vertical magnetisation; antisymmetric for horizontal magnetisation)
- B_{xz} delineates E-W boundaries preferentially (antisymmetric for vertical magnetisation; symmetric for N-S horizontal magnetisation)
- B_{yz} delineates N-S boundaries preferentially (antisymmetric for vertical magnetisation; symmetric for E-W horizontal magnetisation)
- The B_{ij} can be rotated into another co-ordinate system to resolve specific structural orientations
- Because B_{xz} and B_{yz} are acquired over a quasi-horizontal surface, they can be differentiated numerically to obtain $\partial B_{xz}/\partial x$ and $\partial B_{yz}/\partial y$. The second vertical derivative of ΔB_z, which has higher resolution than the first vertical derivative (B_{zz}), is easily calculated from these quantities:

$$B_{zzz} = \partial^2(\Delta B_z)/\partial z^2 = -\partial B_{xz}/\partial x - \partial B_{yz}/\partial y.$$

- The invariant I_1 outlines source boundaries and appears to have superior resolving power to the analytic signal. This is understandable, because of its faster fall-off

$$I_1 = B_{xx}B_{yy} + B_{yy}B_{zz} + B_{zz}B_{xx} - B_{xy}^2 - B_{yz}^2 - B_{zx}^2 \tag{13}$$

- The invariant I_2 preferentially outlines shallower features of complex sources, because of its higher fall-off rate than I_1.

$$I_2 = DET\left[B_{ij}\right] = B_{xx}\left(B_{yy}B_{zz} - B_{yz}^2\right) + B_{xy}\left(B_{yz}B_{xz} - B_{xy}B_{zz}\right) + B_{xz}\left(B_{xy}B_{yz} - B_{xz}B_{yy}\right) \tag{14}$$

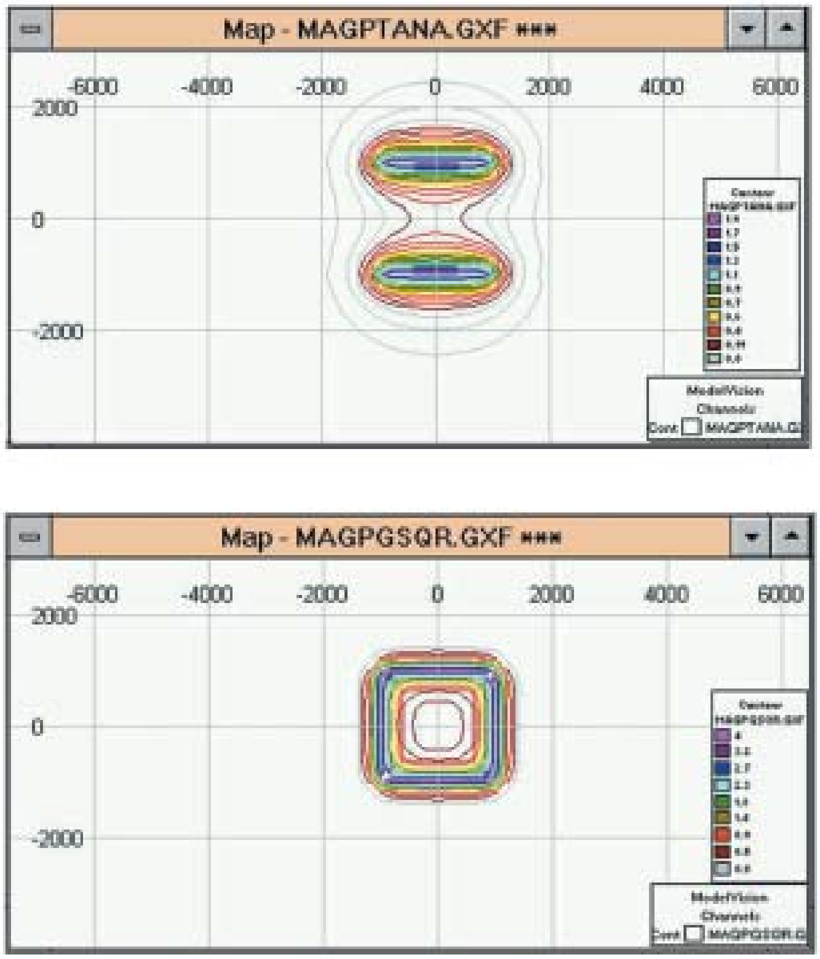

Fig. 3. Comparison of ANSIG and I_1 for a vertical prism model with vertical down (remanent) unit magnetisation at the (magnetic) equator.

The superior performance of the invariant I_1 is clearly shown in Fig. 3 which compares the *ANSIG* and I_1 for a vertical prism model with vertical down (remanent) unit magnetization at the (magnetic) equator. The ANSIG fails to detect the north-south sides of the prism, giving the appearance of two distinct bodies, while I_1 not only reveals these boundaries but also resolves them with greater clarity. Although the geometry chosen here is extreme it is emphasised that remanence should never be ignored and it is highly likely that somewhere in all surveys these or similar geometries exist.

Combined tensor/vector magnetometer packages

The tensor components along a short segment of a survey line or drill hole are sufficient to determine the location and magnetic moment of a compact (quasi-dipolar) source uniquely. There is insufficient information in $\nabla(\Delta \mathbf{B}_m)$ to solve for these parameters. A tensor gradiometer sensor package could record field components (i.e. $\Delta \mathbf{B}$), as well as the gradients of these components, which would also allow direct determination of compact source location and moment.

Although small pods or veins of strongly magnetic material adjacent to a drill hole will produce intense gradients, the fall-off rate is very rapid. This implies:

- small magnetic bodies not in the immediate vicinity of the hole produce negligible effects

- pockets of magnetic material adjacent to the hole produce very localised spikes, easily distinguishable from the smoothly varying signature of large off-hole sources, particularly when combined with vector data.

A combined tensor/vector magnetometer package would allow the remote determination of in situ magnetic properties of sources from the surface or subsurface, using natural geomagnetic variations, without the alignment problems that afflict the differential vector magnetometer method (Clark, 1997; Clark et al., 1998).

Conclusions

There are many reasons why gradient tensor measurements will improve the interpretability of magnetic surveys, especially in areas where anomaly patterns are skewed by remanence or low magnetic latitudes. Gradient tensor surveys retain the benefits of vector surveys without the disadvantage of extreme orientation sensitivity. The tensor components are true potential fields with desirable mathematical properties. The tensor open up a wide range of new types of data processing techniques including invariants, directional filters, depth slicing, source moments and dipole location unaffected by sensor misorientation.

The crucial difference between full tensor gradiometry and total field gradiometry is the production of more detailed and quantitatively interpretable maps and 3D models, rather than simple bump detection. Magnetics is still the cheapest and most widely used geophysical mapping tool in hard rock environments, with increasing importance and potential for further growth in hydrocarbon exploration.

High-temperature SQUID sensors are well suited for tensor gradiometry. They are vector sensors and have high intrinsic sensitivities (~100 fT) and only require liquid nitrogen. Developments in cryocooler technology promise that even the cryogen may be dispensed with in the future. If gradiometer sensitivities of 0.01 nT/m can be achieved then anomalies over vertical contacts (structural index ~0.5) between bodies with a susceptibility contrast as low as 60 x 10^{-5} SI can be detected at depths of over 100 m. 60 x 10^{-5} SI is a weak susceptibility contrast. Obviously anomalies over bodies with greater susceptibilty contrasts and/or higher structural indices can be detected at greater depths.

Tensor gradiometry will prove useful for aeromagnetic surveys with wide line spacings (e.g. over sedimentary basins), environmental surveys, defence applications such as submarine and unexploded ordnance detection and down-hole magnetics.

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Self-Demagnetisation in Practice: the Osborne Cu-Au Deposit

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Abstract

The Osborne copper-gold deposit, north-west Queensland, is hosted by ironstone bodies that have very high susceptibility. Neglecting the effects of self-demagnetisation during early exploration led to erroneous interpreted dips and consequent failure to intersect the magnetic target with initial drilling. Local deflection of the geomagnetic field by the intense magnetic anomaly at Osborne also distorts the measured anomaly with respect to the theoretical total field anomaly that was calculated by conventional modelling algorithms. The total error in interpreted dip is about 55° if these factors are neglected. When these effects are taken into account, the correct dip is interpretable. Self-demagnetisation is the most important effect, contributing about 50° to the error in apparent dip.

Introduction

In an earlier issue (Clark & Emerson, 1999) the principles of self-demagnetisation were discussed and a simple worked example was given. In this article I present an instructive case history that illustrates the consequences of neglecting self-demagnetisation.

If the external magnetic field arising from the subsurface sources substantially perturbs the geomagnetic field, it is probable that the field inside the sources is even more strongly perturbed, i.e. self-demagnetisation effects are likely to be strong. In this case it is folly to attempt to model possible sources of the anomaly without considering self-demagnetisation. Occasionally self-demagnetisation may be relatively unimportant, even though the anomaly is intense. For example, if the inducing field is fortuitously aligned with the long axis of a pipe-like body, the self-demagnetising field reduces the induced magnetisation by only a small amount, because the demagnetising factor along that axis is very small.

The Trough Tank prospect, north-west Queensland, which has now become the Osborne Cu-Au mine, is associated with an intense magnetic anomaly (up to ~15 000 nT on the ground) that represents a significant perturbation of the local geomagnetic field. The local geomagnetic field direction is therefore deflected significantly from the regional direction. Care must be taken when modelling such intense anomalies to match the observed total field anomaly with a calculated anomaly that corresponds to what is actually measured with a total field magnetometer, as is explained below. The susceptibility of the Osborne quartz-magnetite ironstones is very high and failure to account for self-demagnetisation can seriously mislead interpretation of the anomaly.

Component and Total Field Magnetic Anomalies

Denote the regional unperturbed geomagnetic field vector by $\mathbf{F}$ and its magnitude by F. The magnitude and direction of $\mathbf{F}$ can be taken as constant over a local survey area. At any survey point, the local distribution of magnetisation gives rise to an anomalous magnetic field, $\Delta\mathbf{B}$, which adds vectorially to the regional field to give a resultant field $\mathbf{F'} = \mathbf{F} + \Delta\mathbf{B}$. The regional field, the local anomalous field and the resultant field vectors have components with respect to geographic axes (+x = true north, +y = true east, +z = down):

$$\Delta\mathbf{B} = (\Delta B_x, \Delta B_y, \Delta B_z) \tag{1}$$

$$\mathbf{F'} = (F'_x, F'_y, F'_z) = (F_x + \Delta B_x, F_y + \Delta B_y, F_z + \Delta B_z) \tag{2}$$

The magnitudes of the perturbed and unperturbed geomagnetic fields are related by:

$$F'^2 = (\mathbf{F}+\Delta\mathbf{B})^2 = (F_x+\Delta B_x)^2 + (F_y+\Delta B_y)^2 + (F_z+\Delta B_z)^2 = F^2 + 2\Delta\mathbf{B.F} + \Delta B^2 \tag{3}$$

Near magnetic bodies the resultant field varies both in magnitude and direction. 'Total field' magnetometers, such as proton precession or optical pumping magnetometers, measure the magnitude of the resultant field, $|\mathbf{F'}|$, irrespective of its direction. Using the notation of Emerson, Clark & Saul (1985), the measured total field anomaly, ΔB_m, is the difference between the intensity of the local resultant field and the background level, i.e. the regional intensity. Thus

$$\Delta B_m = [F^2 + 2\Delta\mathbf{B.F} + (\Delta B)^2]^{1/2} - F \tag{4}$$

Note that $|\Delta B_m| \leq |\Delta\mathbf{B}|$. It is easily shown that:

$$\Delta B_T = \Delta B_m - [(\Delta B)^2 - (\Delta B_m)^2]/2F, \tag{5}$$

where

$$\Delta B_T = \Delta\mathbf{B}.(\mathbf{F}/F), \tag{6}$$

which Emerson, Clark & Saul (1985) called the "theoretical total field anomaly", is the component of the anomalous field vector $\Delta\mathbf{B}$ projected onto the unperturbed field direction.

It follows from (5) that when the magnitude of the anomalous field is everywhere small compared to the regional field ($\Delta B \leq \Delta B_{max} << F$), the second term on the RHS of eqn (5) is negligible compared to the maximum anomaly amplitude. For example, if ΔB_{max} is 500 nT (corresponding to ΔB_m and ΔB_T amplitudes of several hundred nT) and F is 50 000 nT, the error term is only ~2.5 nT. Therefore:

$$\Delta BT \approx \Delta B_m \qquad (|\Delta\mathbf{B}| << F). \tag{7}$$

Note also that

$$\Delta B_m \geq \Delta B_T, \tag{8}$$

with equality only when $\Delta\mathbf{B}$ is either parallel or antiparallel to $\mathbf{F}$. For very strong anomalies, the approximation in (7) is not as good: for a 10 000 nT anomaly (20% of F), the absolute error is ~1000 nT, corresponding to a relative error of 10%.

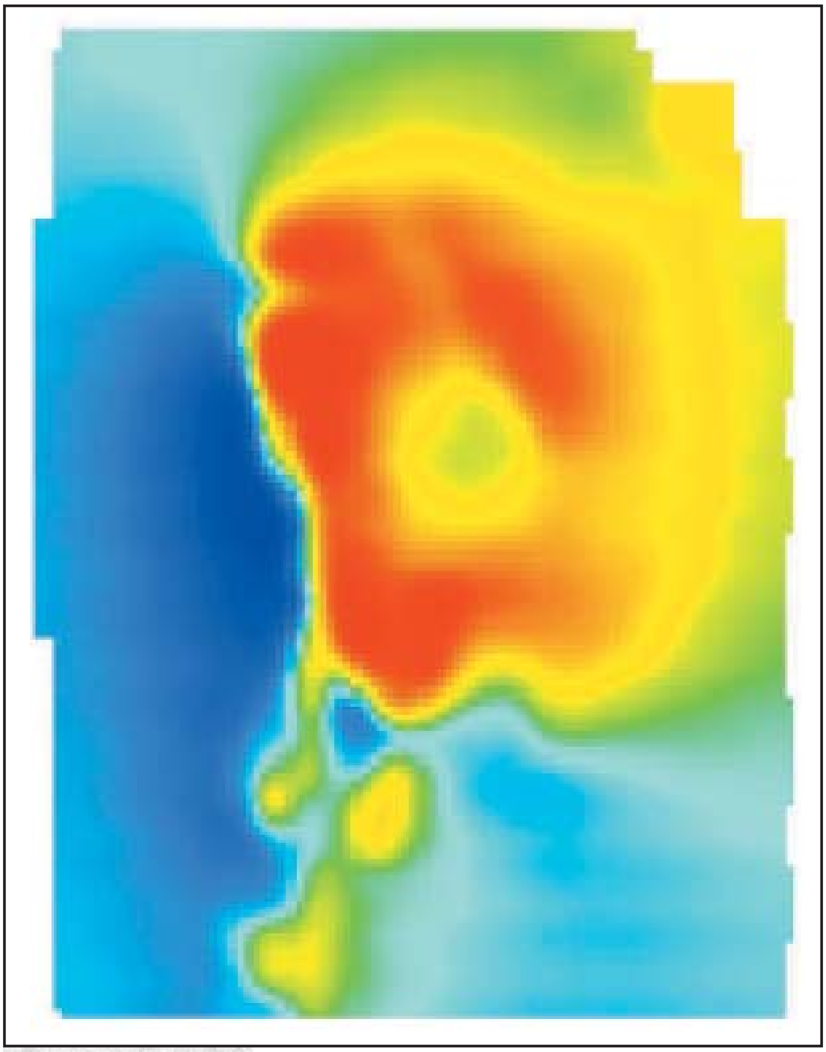

Fig. 1. Image of ground magnetic TMI anomaly over the Osborne deposit. Grid north (up the page) is 46.8°W of magnetic north.

The approximation of eqn (7) was introduced by Hughes and Pondrom (1947) and is valid to within 1% for anomalies less than 2% of the regional geomagnetic intensity (e.g. anomalies less than 1000 nT in a regional field of 50 000 nT). Kontis & Young (1964) presented an empirical test of eqn (7) using an airborne vector magnetic survey. Since introduced, this approximation has been the basis of nearly all subsequent magnetic modelling methods in the literature. However, Emerson, Clark & Saul (1985) and Clark, Emerson & Saul (1986) presented modelling algorithms that allow ΔB_m to be correctly calculated. The assumption that the anomalous field does not significantly perturb the direction of the regional field is deeply embedded in most published algorithms for interpretation of magnetic surveys as well as processing methods based on potential field theory, such as upward and downward continuation, derivative calculations, reduction to the pole, pseudogravity, susceptibility mapping etc.

ΔB_T is the directional derivative, along a fixed direction in space (the regional geomagnetic field direction), of the magnetic scalar potential, V, arising from the subsurface sources. Throughout a source-free region V obeys Laplace's equation: $\nabla^2 V = 0$. It is easily shown by interchanging the order of differentiation that ΔB_T also obeys Laplace's equation and is a potential field. On the other hand, ΔB_m is not a potential field, because it does not obey Laplace's equation. Thus the applicability of the various filtering operations, such as continuation, to measured total field surveys requires care when the anomalies are strong. For example upward continuation of the measured Osborne ground magnetics would significantly distort the predicted field at airborne survey height, because of the substantial difference between ΔB_m and ΔB_T at ground level compared to the much smaller discrepancy at height.

Geology and Exploration History of the Osborne Deposit

The Osborne deposit occurs within Proterozoic rocks of the eastern Mount Isa Inlier, about 190 km south east of Mount Isa. Copper and gold mineralisation is hosted by two north east-dipping quartz-magnetite ironstone units, within a sequence of mostly psammitic metasediments and minor mafic and felsic igneous rocks. The Proterozoic rocks are covered by 20-40 m of Mesozoic sediments.

Within the Trough Tank prospect, the ironstone units were defined beneath the cover from a 1974 reconnaissance aeromagnetic survey by Newmont Pty Ltd. Initial drilling guided by ground magnetics revealed barren quartz-magnetite ironstones beneath the cover, but the geology did not accord with the then exploration target and the ground was relinquished. Subsequent discovery of the ironstone-hosted Au-Cu Selwyn/Starra deposit, 60 km to the north north west, renewed interest in the prospect. Initial magnetic modelling of the anomaly sources did not incorporate self-demagnetisation, producing errors in the interpreted dips. As a result, the first two drill holes by CSR Ltd drilled down dip and missed the magnetic targets. When this problem was recognized, the next two holes successfully intercepted the magnetic sources (Gidley, 1988). Clark (1988) reported magnetic property measurements from the Trough Tank drilling program and analysed the effects of self-demagnetisation and perturbation of the geomagnetic field on the anomaly.

The lessons learnt during the initial exploration have since been routinely incorporated into magnetic interpretation at Trough Tank (Anderson & Logan, 1992; Logan & Angus, 1997). Since the discovery of the Osborne deposit and development of the mine, downhole magnetics have proved useful in defining ironstone units at depth and detailed modelling of known ironstones, using magnetic property information and incorporating self-demagnetisation and magnetostatic interaction effects, has been used to identify residual anomalies due to unintersected ironstones.

Figure 1 shows an image of TMI (ΔB_m) ground magnetic data over the Osborne deposit. The north west-striking magnetic ridge in the left half of the image corresponds to the ironstone in which mineralisation was originally discovered.

Magnetic modelling of the Osborne anomaly

The bulk susceptibility of the first intersected Osborne quartz-magnetite ironstones is high: ~0.5 G/Oe = 6.3 SI, but the remanent magnetisation is relatively low, with an estimated Koenigsberger ratio of ~0.2 (Clark, 1988). The *intrinsic* susceptibility anisotropy of the Osborne quartz-magnetite ironstones is not very high, because of the fairly massive nature of the magnetite. The ironstone units are macroscopically highly anisotropic, however, because of the high susceptibility and the sheet-like geometry, which produce strong self-demagnetisation. Thus the dip-dependence of the anomalies over such bodies is analogous to that associated with mesoscopically anisotropic BIFs.

Given the above discussion, the erroneously interpreted dip during initial exploration of the Trough Tank prospect is therefore attributable neither to remanence nor to intrinsic, mesoscopic anisotropy. Two effects, both related to the very high susceptibility of the Osborne ironstone, account for the departure of the observed anomaly shape from that expected for a north east-dipping sheet:

(i) the large deflection of the induced magnetisation by self-demagnetisation, away from the present field direction towards the plane of the sheet,

(ii) the perturbation of the local field by the huge anomaly at Osborne, producing a significant distortion of the ΔB_m anomaly compared to the shape predicted by standard ΔB_T modelling.

Conventional modelling ignores points (i)-(ii), thereby making two assumptions which may be justified in circumstances, but not in this case. These are:

Assumption (1): Induced magnetisation $\mathbf{J}_{ind}$ is parallel to $\mathbf{F}$,
Assumption (2) : $\Delta B_m = \Delta B_T$.

Points (i) and (ii) above may be regarded as aspects of a single phenomenon: perturbation of the ambient field by a magnetic body. Self-demagnetisation reflects perturbation of the internal field and the difference between ΔB_m and ΔB_T arises from perturbation of the external field. Because the internal field arising from the magnetisation distribution is stronger, given favorable geometry, than the distant external field, it can be expected that the effects of self-demagnetisation may generally be more pronounced than those due to violation of assumption 2.

Figure 2 shows the observed ΔB_m anomaly (12 000 nT for this line) and drilling information for a typical profile across the Osborne anomaly, upon which the initial modelling was based. The anomaly to be expected over the ironstones was calculated using MAGMOD VIIIB (Emerson, Clark & Saul, 1985), which can incorporate remanence, anisotropy and self-demagnetisation into the model. Assuming a susceptibility of 0.47 G/Oe (5.9 SI), which is consistent with the measured values from holes NQ3, NQ4 and NQ6 given the variability in the deposit, the calculated anomaly amplitude, based on the simplest, geologically plausible model that fits the drilling intersections, agrees well with the observed anomaly amplitude and the shape is approximately matched. Thus the general form of the anomaly is explained by the intersected material, with the correct north east dip.

The fit to the observed anomaly can be improved by adjusting the model, increasing the susceptibility of the south west sheet, whilst decreasing the susceptibility and increasing the width of the north east sheet. Such a model would still be consistent with the mid-range of measured susceptibilities and with the drilling intersections. However, the simple model of Figure 2 suffices to confirm the approximate agreement between the observed and predicted ΔB_m anomalies over Osborne, when self-demagnetisation is incorporated into the model. Because remanence only makes a minor contribution to the magnetisation of the Osborne samples, it was not considered worthwhile to incorporate it into the simple models, which are designed to illustrate the most important factors for interpretation of this anomaly. The modelling also does not take into account the finite strike length and the effect of interaction between the bodies, obviating the utility of fitting the anomaly very closely.

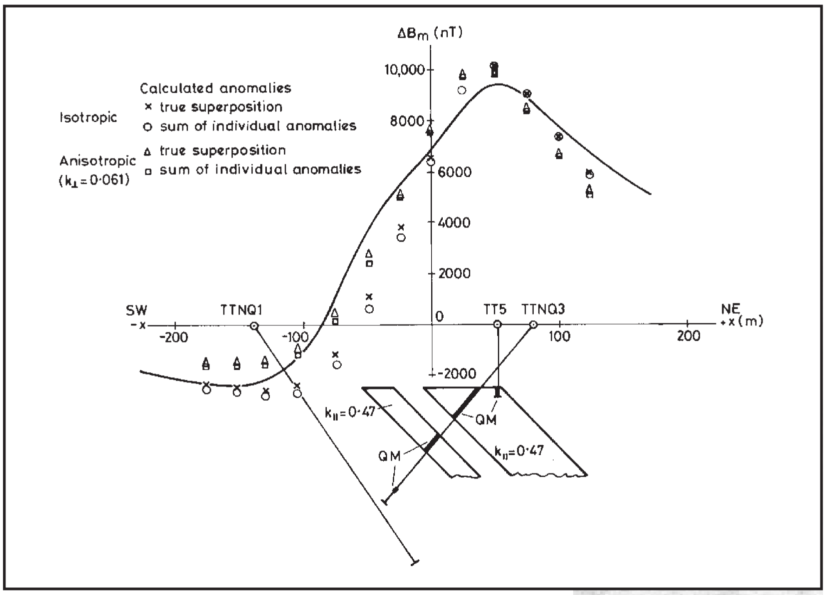

Fig. 2. Observed (solid line) and calculated ground magnetic anomalies along line 1770N (Keel grid), showing a twin dipping sheet model, constrained by drill intersections (Clark, 1988). Note that the first diamond drill hole (TTNQ1) was sited to intersect an interpreted SW-dipping target and failed to intersect ironstone. TTNQ3 was the first hole based on incorporation of self-demagnetisation into modelling, which indicated a NE dip (Gidley, 1988).

From Figure 2 it can be seen that a somewhat better fit to the observed anomaly can be made by assuming some intrinsic anisotropy of the ironstones due to mesoscopic banding. The effects of non-linear superposition are also shown in Figure 3. It can be seen that the true ΔB_m anomaly arising from the two sheets jointly plots above the sum of the individual ΔB_m anomalies. The difference is quite small in this case, however. Effects of comparable magnitude are to be expected from the interaction between the two units. This latter effect arises from the fact that the field within each body is perturbed by the other, nearby, strongly magnetic body, so that the induced magnetisation is modified. Because the anomalous field within each body is non-uniform, this effect cannot be simply incorporated into the model by modifying the model magnetisation, which is assumed to be uniform. Correction for this second order effect can be accomplished by iteratively solving a discretised integral equation for the non-uniform internal fields and magnetisation distributions (Scholar and Tervo, 1980). A similar approach is needed in order to correct for non-uniform self-demagnetising fields near the corners of the sheets. Logan and Angus (1997) reported an alternative, computationally efficient method for solving the general magnetostatic problem, which was applied to a more sophisticated model of the Osborne deposit, constrained by detailed drilling and petrophysical information. Theoretical calculations and analogue modelling studies (Hjelt and Phokin, 1981) indicate that distortion of the anomaly due to interactions and non-uniform self-demagnetising fields should be fairly minor at Osborne, although these factors are quite important for susceptibilities as high as those of the Starra quartz-magnetites, which have an average susceptibility of ~1.7 G/Oe = 21 SI (Clark, 1988).

The errors associated with assumptions (1) and (2) can best be evaluated using a simplified, isotropic single sheet model. This is quite a reasonable representation of the source, since the two units are only just resolved by the ground magnetics, and the principles involved can be discussed more clearly in the context of a simple geometry. Figure 3 illustrates the deflection of induced magnetisation due to self-demagnetisation, for the geometry of Osborne. Note that for 2D bodies the along-strike component of magnetisation does not contribute to the anomalous field. The effective regional geomagnetic field (i.e. the projection of $\mathbf{F}$ onto the vertical section normal to strike) makes an angle of 73° with the up-dip direction. The parallel susceptibility is simply the intrinsic susceptibility, k, because the demagnetising factor in the plane of the sheet is zero. On the other hand the perpendicular susceptibility is attenuated by $1/(1 + 4\pi k)$, or by $1/(1+k)$ if SI susceptibilities are used. Resolving $\mathbf{F}$ and $\mathbf{J}$ into up-dip and perpendicular components as shown, it can be seen that the induced magnetisation is deflected towards the plane of the sheet, such that the angle between the effective magnetisation and the up-dip direction is:

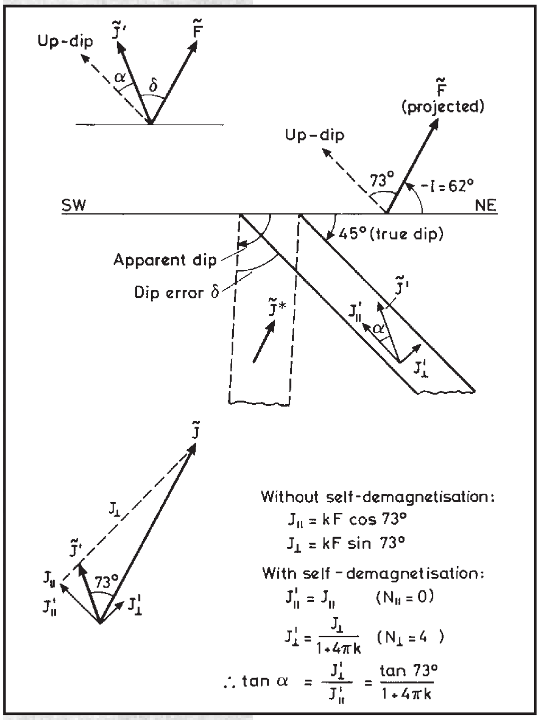

Fig. 3. Deflection of induced magnetisation for an idealised Trough Tank ironstone unit, representing the ironstones intersected by TTNQ3, which produces an erroneous apparent dip. When self-demagnetisation is taken into account, the correct dip is obtained.

$$\alpha = \tan^{-1}[\tan(73°)/(1 + 4\pi k)]. \qquad (9)$$

It is well known that the dip and magnetisation direction of 2D dipping sheets cannot be interpreted independently. Equivalent dipping sheets have the same depth to top and width (if the width is resolvable), and a fixed angle between the plane of the sheet and the effective magnetisation vector (perpendicular to strike). The equivalent sheet with magnetisation parallel to $\mathbf{F}$ is shown dashed in Figure 3. The angle of deflection, is equal to the error in the apparent dip interpreted from component-type anomalies. Thus, ignoring the difference between ΔB_m and ΔB_T for the moment, the error in interpreted dip to be expected from neglecting self-demagnetisation is:

$$\delta = 73° - \tan^{-1}[\tan(73°)/(1 + 4\pi k)]. \qquad (10)$$

The magnitude of the error is a highly non-linear function of susceptibility. For low susceptibilities the error is negligible (< 2° for k < 0. 01 G/Oe = 0.13 SI), but increases rapidly for susceptibilities above 0.1 G/Oe (1.3 SI). The rate of increase in the error levels off above k ~1G/Oe (12.6 SI), and approaches an upper limit of 73° (corresponding to induced magnetisation deflected completely into the plane of the sheet) as k increases without limit. For the mean measured susceptibility of the Osborne ironstone samples (k = 0.58 G/Oe) the error is 51° and for the interpreted susceptibility derived from modelling (k = 0.47 G/0e), the error is 48°. Such an error is likely to severely mislead drill targetting. The geometry at Osborne produces a deflection almost as large as the maximum possible, for a given susceptibility. More magnetic bodies, such as the Starra ironstones, can deflect induced magnetisation by almost as much as would a sheet that had infinite susceptibility.

The dip error discussed above applies to interpretation of the ΔB_m anomaly at a height above the body sufficient to ensure that $\Delta B_m << F$, so that $\Delta B_m \approx \Delta B_T$. For the ground magnetic anomaly at Osborne the difference between ΔB_m and ΔB_T is substantial. Figure.4 shows a comparison of the ΔB_m and ΔB_T anomalies for dipping sheets comparable in thickness and susceptibility to the Osborne ironstones. For each geometry the difference is greatest along the steep gradient on the south west flank of the anomaly, where the anomalous field vector, $\Delta\mathbf{B}$, is large and is approximately perpendicular to the effective geomagnetic field. The difference between ΔB_m and ΔB_T is smaller along the north east flank of the anomalies, because here $\Delta\mathbf{B}$, although large, is subparallel to the effective field, so the resultant field direction is not deflected as much from the regional field direction. The absolute difference between the two types of anomaly is greatest for the vertical sheet, largely reflecting the greater magnitude of the anomalous field over this sheet, for which the orthogonal thickness is greatest. The magnetisation of the south west-dipping sheet is the highest, accounting for the much larger anomaly over it than over the north east-dipping sheet, but the magnetisation-orthogonal thickness product is slightly less than the corresponding value for the vertical sheet.

The controlling influence of self-demagnetisation can be judged from the fact that the difference in anomaly amplitude between the north east-dipping and south west-dipping sheets in Figure 4 entirely reflects self-demagnetisation. Bodies dipping 45° north east and 45° south west with k = 0.001 G/Oe (~0.01 SI), say, would have practically identical induced magnetisations and total anomaly amplitudes (measured peak-to-trough), but very different anomaly shapes, with a much more pronounced low (to the south west) for the north east-dipping sheet than for the south west-dipping sheet. Where self-demagnetisation is important, however, the induced magnetisation is greatly attenuated if the effective field is at a large angle to the plane of the sheet, as for the north east-dipping sheet, but less attenuated for south west dips with the effective field subparallel to the sheet. On the other hand, the dip-dependence of anomaly shape tends to be suppressed by self-demagnetisation, because the induced magnetisation tends to rotate with the sheet as the dip changes.

Although the dip-dependence of anomaly shape is subtler in Figure 4 than for corresponding weakly magnetic sheets, the dips are nevertheless interpretable, provided the susceptibility can be estimated and self-demagnetisation is included in the analysis. The susceptibility can be determined, in principle, by modelling the location of the

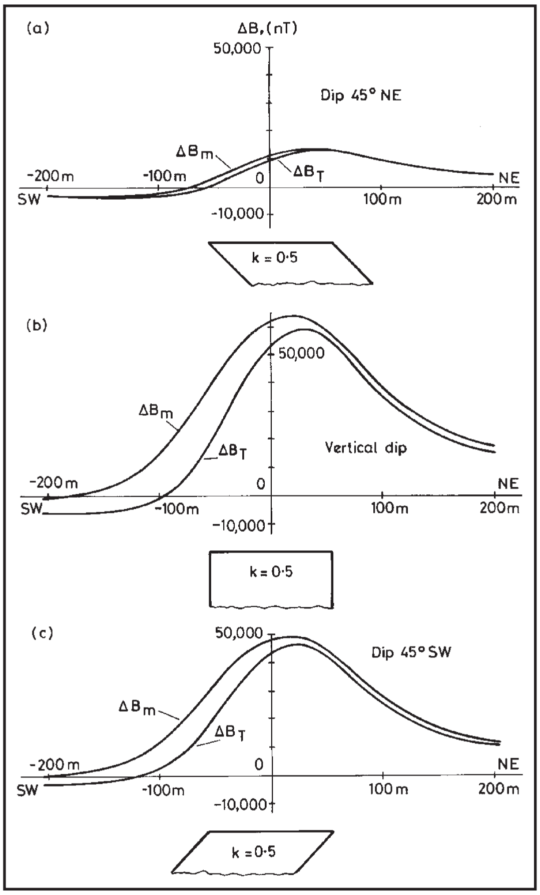

Fig. 4. Dip dependence of ΔB_m and ΔB_T anomalies as a function of dip for analogues of the Osborne ironstones. (a) approximates the geometry at Osborne. Note that much larger anomalies, and a much larger discrepancy between the two anomaly types, would be observed for vertical or moderately SW-dipping ironstones, as shown in (b) and (c) respectively.

For a susceptibility of 0.1 G/Oe, self-demagnetisation significantly reduces the size of the low relative to the anomaly high. The resulting anomaly shape resembles that of a low susceptibility body with a dip of 63° north west. For a susceptibility of 0.5 G/Oe the ΔB_T anomaly corresponds to an apparent dip of 86° south west but the ΔB_m anomaly shape corresponds approximately to the shape of the ΔB_T anomaly from a sheet with a dip of ~81° SW. Thus the effect of neglecting the difference between ΔB_m and ΔB_T is an additional dip error of about 5° for the Osborne ironstone, which is minor compared to the effect of neglecting self-demagnetisation.

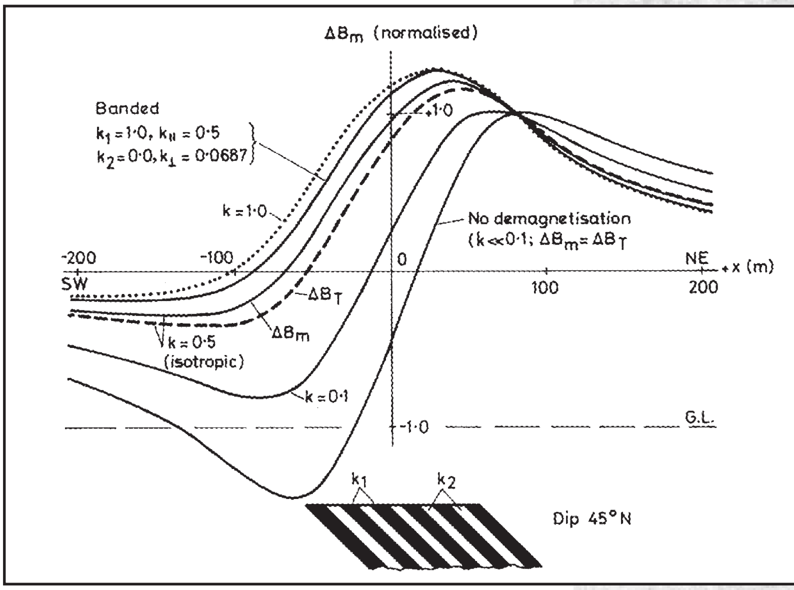

Fig. 5. Effects of self-demagnetisation and mesoscopic anisotropy on anomaly shape for a dipping sheet with the approximate geometry of the Osborne ironstones. Susceptibilities are in G/Oe. SI susceptibilities are larger by a factor of 4p. In order to illustrate effects on anomaly shape, all anomalies are normalised to unity at the point where the anomaly for the low susceptibility case is a maximum.

top corners of the sheet and matching the anomaly amplitude with the appropriate value of demagnetisation-corrected induced magnetisation × orthogonal thickness product, which is dip-dependent. This can only be accomplished uniquely for thick sheets, as no information on sheet thickness can be derived from the anomaly if $t << h$.

It is evident from Figure 4 that the ΔB_m anomaly lies above the ΔB_T anomaly, in agreement with (8), and that for ΔB_m the anomaly minimum to the south west is suppressed and the gradient on the south west flank is flattened compared to the corresponding features in the ΔB_T anomaly. These effects imply that the apparent dip of the sheet, as interpreted by matching the observed ΔB_m with a calculated ΔB_T is rotated towards the south west, i.e. the interpretational error due to neglecting the difference between ΔB_m and ΔB_T adds to the dip error from neglecting self-demagnetisation. Figure 5 shows the separate and combined effects of points (i) and (ii) above on the apparent dip of a banded ironstone unit comparable to Osborne. The anomalies plotted in Figure 5 are normalised to facilitate comparison of anomaly shapes. Conventional modelling of a sheet dipping 45° NE, neglecting self-demagnetisation and the difference between ΔB_m and ΔB_T, produces a dipolar anomaly shape with a very pronounced low to the south west.

The effect of mesoscopic banding or macroscopic sheet-like zoning on the anomaly shape is also shown for the case where the body consists of 50% high susceptibility (1 G/Oe = 12.6 SI) bands separated by non-magnetic bands. This corresponds to a parallel susceptibility of 0.5 G/Oe (6.3 SI) with an effective perpendicular susceptibility of 0.0369 G/Oe (0.464 SI), or an intrinsic perpendicular susceptibility of 0.0687 G/Oe (0.863 SI). The induced magnetisation for this case is parallel to the induced magnetisation of a homogeneous body with k = 1 G/Oe i.e. it is deflected by 59° and therefore contributes 59° to the dip error. Thus the difference between the curves for the anisotropic, banded body and the homogeneous body with k = 1 G/Oe reflects only the greater anomaly amplitude, and the consequently greater perturbation of the geomagnetic field, for the latter case. The anomaly shape changes only slowly with increasing susceptibility for k > 1 G/Oe. The relative contribution of the error from neglecting the difference between ΔB_m and ΔB_T becomes increasingly important for increasing k, because the distortion of the ambient field becomes greater as the anomaly amplitude increases. This is reinforced by the suppression of the dip-dependence of anomaly shape due to deflection of the induced magnetisation, which becomes subtler as the magnetisation approaches the plane of the sheet.

Conclusions

At Osborne the ground magnetic anomaly has a maximum amplitude of ~15 000 nT, which is a substantial fraction of the geomagnetic field. Thus the local anomaly significantly deflects the resultant field direction and distorts the form of the measured scalar ΔB_m anomaly with respect to the conventionally calculated total field anomaly (ΔB_T). The additional error in interpreted dip due to ignoring the difference between ΔB_m and ΔB_T is about 5°, which is relatively minor. This effect, however, becomes increasingly important with proximity to such highly magnetic bodies. The distortion of the ΔB_m anomaly would be much worse if the ironstones were dipping subvertically or to the SW.

The geometry of the Osborne ironstones is conducive to producing large self-demagnetising effects. The induced magnetisation of the ironstones is deflected significantly towards the plane of the sheet-like units, because the effective susceptibility perpendicular to the plane of the sheets is greatly attenuated with respect to the susceptibility parallel to the sheets. The magnitude of the deflection is about 50° for the Osborne ironstones, which corresponds to a ~50° error in the interpreted dip, if self-demagnetisation is not included in the modelling program.

Acknowledgements

Peter Gidley supplied drill core samples and magnetic survey data for the study of Clark (1988), which was part of AMIRA project P96B. Keiran Logan kindly supplied the ground magnetic image (Fig.1).

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Erratum: the following reference was inadvertently omitted from the previous article (Clark & Emerson, 1999):

Brown, W.F., 1962. Magnetostatic Principles in Ferromagnetism. North-Holland, Amsterdam, 202pp.

New Members

We would like to welcome the following 87 new members to the ASEG.

(approved on 29th February 2000)

NAME	AFFILIATION	STATE
Carina Simmat	Univ Sydney	NSW
Ian Brandes	Univ NSW	NSW
Lee Platek	Univ Melbourne	VIC
Lorena Banchero	Codelco	CHILE
Phong Thanh Tran	Curtin University	WA
Ray Lockwood	Fugro	NSW
Saman Perera	Geological Survey	SRI LANKA
William Guest	Woodside	WA

(approved in April 2000)

NAME	AFFILIATION	STATE
Aisuait Kusuma	Elnusa	INDONESIA
Alex Pauli		WA
Alex Shepherd	Curtin University	WA
Andrew Lambourne	Schlumberger	WA
Anthony Yeates	AGSO	ACT
Ashley Howlett	University of Tasmania	TAS
Bahar Alfian	Bandung	INDONESIA
Bastiaan Spaargaren		WA
Ben Bartlett		WA
Ben Hall		WA
Bettina Townrow	Ashton Manufacturing	WA
Bronwyn Stacey		WA
Bruno Thomas	SANTOS	SA
Bryn Bender		WA
Carlo Bevilacqua	Apache Energy	WA
Cedric Griffiths	CSIRO	SA
Chanios Arotorius	Angco American	S. AFRICA
Chris Moore		VIC
Christopher Pigram	AGSO	ACT
Darren Hunt		WA
David Heislers		VIC
David Jones	PGS Exploration	WA
David Maidment	AGSO	ACT
Djoko Santoso	Institut Teknologi Bandung	INDONESIA
Dogan Perincek	Perincek & Associates	WA
Douglas Newman	Trace Explorations Ltd	CANADA
Emad Tawadros	Curtin University	WA
Fatkhan Fatkhan		WA
Francisca Okeke	University of Nigeria	NIGERIA
Franklin Horowitz	CSIRO	WA
Geoffrey Garton		WA
Geoffrey Mansfield	Veritas DGC Asia Pacific	SINGAPORE
Godfrey Ngaisiue	Geological Survey of Namibia	NAMIBIA
Gordon Cooper	University of the Witwatersrand	S. AFRICA
Guy Taylor		WA
Harmen Rashid	Exspan	INDONESIA
N. Al-Andoonisi	Curtin University	WA
James Lee	BHP Minerals	NSW
James Low	Scintrex	WA
Jasmine Rutherford		WA
Jean Bernard	IRIS Instrument	FRANCE
Jennifer Scott	SANTOS	QLD
John Mitchell	P.T Grant Geophysical	INDONESIA
Joseph Kita		WA
Joseph Roux	COGEMA	FRANCE
Kaxia Lei	Bolliton Development B.V	CHINA
Keith Fisk	Fugro Airborne Surveys	ZIMBABWE
Keith Leslie	CSIRO	NSW
Kevin Pelletier	CSEG EAGE	CANADA
Krzywiec Piotr	Polish Geological Institute	POLAND
Larry Scott	Western Geophysical	SINGAPORE
Llew Vincent	Robertson Research	WA
Loek Tamadji		
Marcus Chatfield	Reeves Wireline Services	S. AFRICA
Mark Stanley	BHPP	VIC
Martin Kim		WA
Megan Evans		WA
Michael Rybaicov	Insititute of Israel	ISRAEL
Michael Schoenberg	CSIRO	USA
Paul Young	Schlumberger	WA
Peter Chan		WA
Peter Dreverman	Point Exploration Pty Ltd	WA
Peter Petkovic	AGSO	ACT
Poerwaka	Pt. Elnusa Qeosains	INDONESIA
Richard Osmond	Falconbridge Ltd	CANADA
Roberto De Souza F.	RUA Groenlandia	BRAZIL
Sean O'Brien	SANTOS	SA
Shane Schofield	Oil Search Ltd	NSW
Simon Williams		NSW
Stephan Lintker	DMT	GERMANY
Stephen Massey		WA
Steven Carroll	PGS Tensor	WA
Susannah Elvey		WA
Tanya Fomin	AGSO	
Tanya Johnstone		WA
Terence Nilsen	SANTOS	QLD
Trang Nguyen		WA
Troy Thompson	Curtin University	WA
Vicki Stamoulis	PIRSA	SA
William Barkhouse	SEG - Exxon Mobil	USA

Missing Members

Any member who knows the current contacts of the following members please contact the secretariat:
Ph: (07) 3257 2725 or
Email: secretary@aseg.org.au.

NAME	LAST KNOWN ADDRESS
Allister Wood	UK
Cliff Allen	WA
Harryb Cornelius	AUSTRALIA
Jaap Flentri	WA
Kristine O'Keeffe	NSW
Stefano Zannoni	WA
Zbynek Dvorak	CANADA

Exploration Expenditure Continues to Decline

The release of exploration expenditure statistics for the December quarter of 1999 by the Australian Bureau of Statistics showed that exploration activity continued to decline for the tenth consecutive quarter, and is at the lowest level since June 1993.

The 'trend' estimate for mineral exploration expenditure fell $4M to $170M during the December quarter of 1999. This was 23% lower than the estimate of $220M for the same quarter in 1998.

The main contributor to the decrease in mineral exploration once again was gold. Gold exploration expenditure fell by 10% in the December quarter 1999 to $92M, to be 34% lower than the expenditure reported in the December quarter 1998. This was the lowest reported expenditure on gold exploration since the June quarter of 1993.

However, exploration expenditure for base metals increased 34% to $45M between the September and December quarters of 1999.

The trend estimate for the number of metres drilled also continued to decline. During the December quarter 1999, 1.5M were reported drilled, the lowest estimate since the March quarter 1993.

However, we may be reaching the bottom of the cycle as shown in the Figure below.

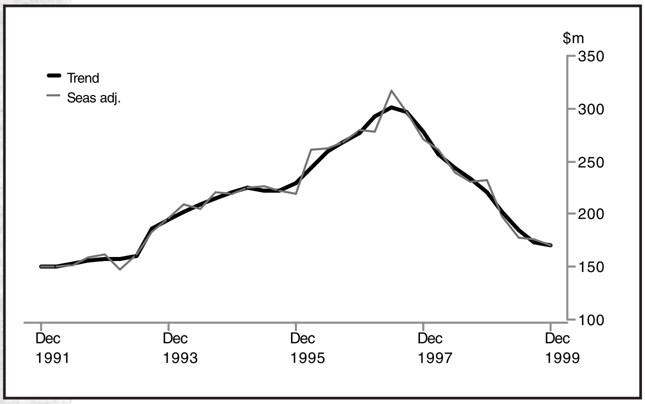


Fig. 1. Mineral Exploration Expenditure, Dec 1991 to Dec 1999.

Expenditure on petroleum exploration was $191M in the December quarter 1999, 25% ($64M) lower than the December quarter 1998. Total petroleum expenditure fell from the September quarter 1999 as a result of a 19% ($36M) fall in offshore expenditure, the majority of which was in drilling expenditure (down $26M).

Of the published regional data, both the Northern Territory and Western Australia (down $24M and $15M respectively) were the main contributors to the decline, while Queensland recorded an increase of $12M from the September quarter 1999.

The statistics for petroleum expenditure are notoriously variable, so there may not be serious long-term implications in the latest numbers. The chart below shows the statistics from June 1998 to December 1999.

In fact, as Warren Entsch the Parliamentary Secretary to the Minister for Industry, Science and Resources, reported earlier this month, 1999 was a good year for offshore discoveries with several significant oil and gas fields found in the offshore Carnarvon Basin. He reported a total of 51 exploration wells drilled offshore in 1999 and forecast 54 wells for 2000. (Charts provided by Australian Bureau of Statistics)

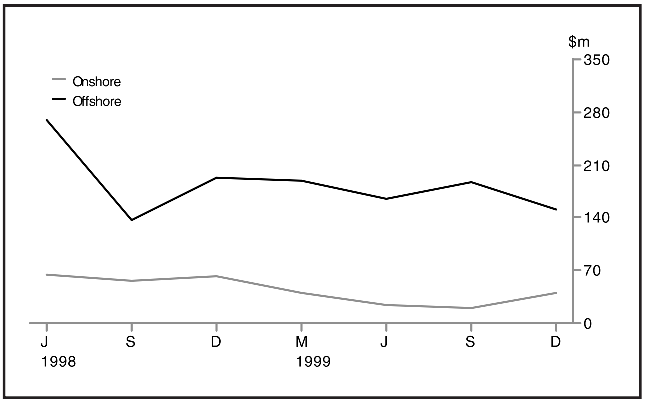


Fig. 2. Petroleum Exploration Expenditure, June 1998 to June 1999.

North Ltd Calls it Quits in Gold Exploration

North Ltd has announced that it will cease greenfields gold exploration.

'The Australian' reported on 17th March that North Ltd would channel its spending power to buying projects already in an advanced stage of development. "The strategic withdrawal from greenfield exploration puts North in line with BHP, Rio Tinto and WMC", according to the writer, Damon Frith. "A decade ago the big miners poured hundreds of millions of dollars into greenfield exploration to try to find the elusive world-class deposit. Big miners now comb the world looking at the main mineralised zones, targeting small exploration companies that have the best ground cover or projects that lack sufficient finance to advance."

We also hear that Billiton will no longer fund research directly, but will prefer equity in high-tech providers.

Normandy to Focus on Gold

In a major restructure, Normandy Mining will buy the 42% of Joseph Gutnick's, Great Central Mines it does not already own, for $21M. At the same time the company will dispose of its non-gold assets by selling 50% of its stake in Australian Magnesium Corp. to its partner Queensland Metals Corp, in return for 225M QMC shares, lifting its stake in QMC to 62.5%. It will also its industrial minerals sector, which is expected to raise about $150M.

According to business analyst, Jane Counsel, the deal will bring more than $500M of debt onto Normandy's books, which will push the total debt to around $1.4 billion. However, ownership of GCM should achieve one-off cost savings of around $15 and increase the company's annual gold production by 15% to a massive 72 t/yr.

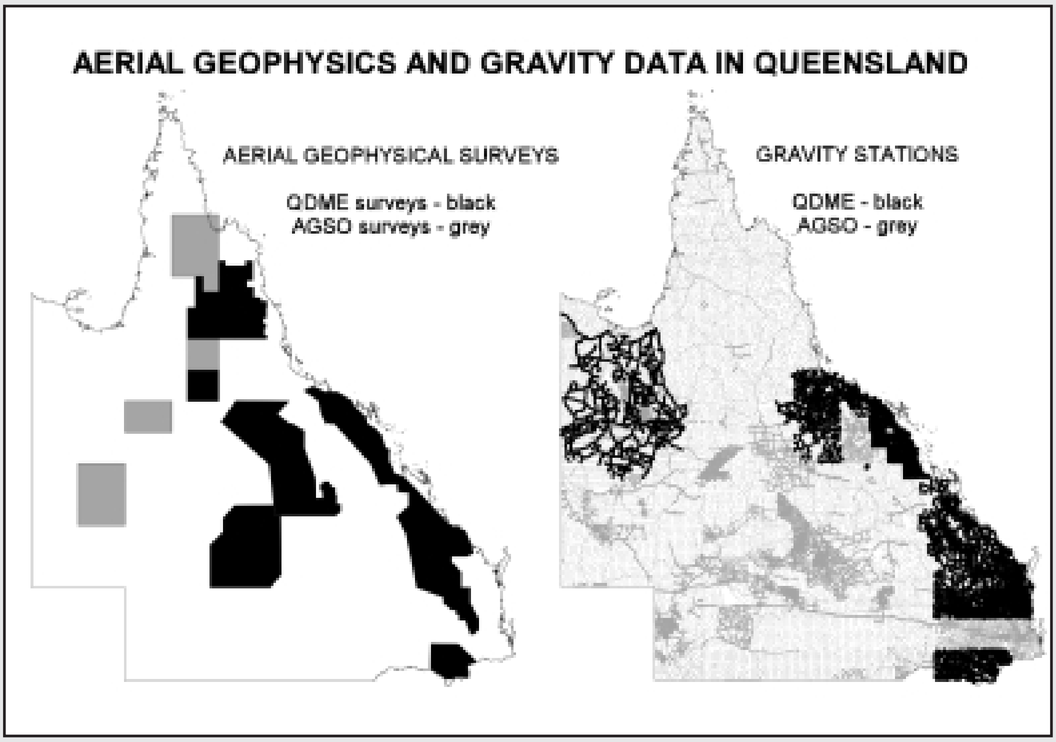
Fugro Contacts

Fugro has issued the following list of contacts:

- Managing Director - Steve Thomson (Sydney)
- Sales Manager - Bill Witham (Perth)
- Sales China, India and Pakistan - Toby Gilmour (Sydney)
- Sales East Coast Australia, PNG, Pacific - Mike Hallet (Sydney)
- Sales North Asia - John Canaris (Perth)
- Sales South East Asia - Simon Irwin (Jakarta)
- Operations Manager - Brett Johnson (Perth)
- Operations - Davin Allen (Sydney)
- Ground Geophysics - John Peacock (Sydney)
- EM Technology - Peter Wolfgram (Sydney) & Richard Lane (Perth)
- R&D Leader - Andy Gabell (Perth)

Geophysics in the Geological Survey of Queensland

In Preview 83 the figure below from David Searles article 'Geophysics in the Geological Survey of Queensland' (page 40), was not shown in its entirety due to space constraints.



The maps above show where GSQ and AGSO have collected modern airborne geophysical and gravity data in Queensland.

By Ernest Zebrowski Jr., Cambridge University Press

ISBN 0-521-57374-2, A$29.95 Paperback, A$44.95 Hardback

Reviewer: Kevin McCue AGSO

Perils of a Restless Planet Scientific Perspectives on Natural Disasters

Not another book on natural disasters I thought as I jammed the book into my briefcase for a long night flight to South America. My expectation was to browse through the book on the eastward flight and write the review during the equally long return flight. No such luck. Wherever I delved into the book I was hooked, alternatively outraged and delighted, outraged when Dr Zebrowski indulged his North American myopia or delved into Greek philosophy; delighted by the gems I found in a chapter titled *Restless Seas*, particularly the various discussions of tsunamis and by his thoughtful last chapter *Science and Irreproducible Phenomena*. This last chapter is built around a discussion of the 2nd Law of Thermodynamics and includes applets on chaos, global climate and what he calls the dilemma of irreproducibility (well known by all physics laboratory students).

As an engineer Dr Zebrowski presents a different perspective on risk, setting the scene in the *Hazards of Shelter* chapter in which he concludes that 'earthquakes themselves rarely kill people; for the most part, it is our buildings that kill people'. He uses the comparison of the death toll from earthquakes that struck Messina in 1908 and San Francisco in 1906 but the recent tragedies in Kobe, Turkey and Taiwan, which all occurred after completion of the book, illustrate the same point. Dr Zebrowski explains that most of California's buildings are designed to withstand a fair amount of ground shaking (implying they will survive) but follows that with: 'we have little alternative to accepting the fact that when the next East Coast (*read Australian*) earthquake strikes, the affected region will have been caught almost totally unprepared'. If East Coast planners could be convinced to prepare and plan for rare events as their West Coast colleagues do, perhaps their counterparts in Australia might follow.

My destination in Chile was a workshop on tsunamis not far from where the then Peruvian coast was swept by a 21 m high tsunami in 1868 killing some 25 000 people. Participants at the workshop were surprised that the resultant ingress and egress of the sea was observed in Sydney Harbour for several days. They were amazed at a photograph reproduced in *Perils of a Restless Planet* of the visiting naval vessel USS Wateree, built (too late) for the American Civil War and at the time having an engine overhaul in Arica. The Wateree with all crew was carried and dumped some 3 km inland by the tsunami, all the while trailing its anchor chain. More than all the words, this photo illustrated for port operators at the workshop the risk they face in their daily operations and for which they have to prepare disaster plans. Another participant happened to be a sea captain whose ship was rudely grounded by the 1960 Chilean earthquake, then refloated in the returning `tide' as he described it. The captain headed his freighter out to sea and managed to make deep water before the main tsunami struck thereby saving his ship and crew. His account was very similar to the almost unbelievable sequence of events recounted by Rear Admiral Billings, captain of the Wateree and quoted by Dr Zebrowski. I learned a lot about tsunamis in South America from the book, and just in time for the workshop.

Other chapters are predictable in such a book; *Volcanoes and Asteroid Impacts and Life on Earth's Crust*. They chronicle a number of well-known disasters such as the Krakatoa eruption in 1883 and including the demise of the population of Easter Island and the Minoan culture, the fate of the Easter Island community is a salutary lesson for many present societies including our own. There is a great anecdote about 5 British monks (sic) who observed an asteroid hitting the moon but interested readers can find out the details for themselves.

That he is not a seismologist is illustrated by his treatment of seismic waves and understanding of modern seismographs, better left to authors such as Bruce Bolt. In the chapter *Deadly Winds* Dr Zebrowski states that 'the United States has a virtual monopoly on tornadoes ...... and only rarely do they occur anywhere else in the world' which might surprise a few meteorologists in Australia and even Denmark which was recently struck by a twister. Emergency Management Australia has produced a poster with some magnificent pictures of a few of those *rare* tornadoes in Australia.

Despite the minor irritations mentioned above, the author's use of both metric and imperial units (yes they are still in use in the US) and his contention that clays can liquefy, I would recommend this book for anyone involved in disaster mitigation. It is a good general text on natural disasters for planners in local government, engineers and building code writers, especially for those rapt in tsunamis, and even for seismologists and geologists for the many quotable quotes scattered throughout the text.