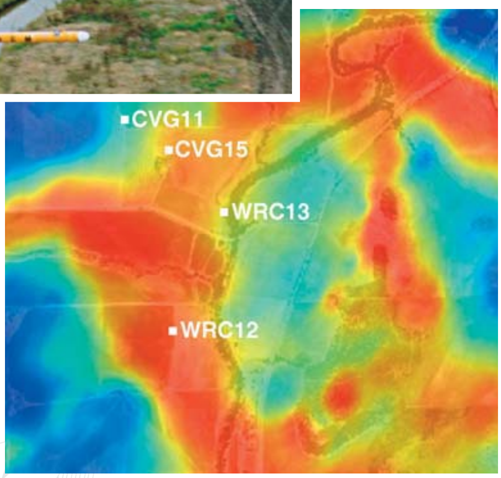
Preview

Australian Society of Exploration Geophysicists

ACN 000 876 040 October 1999 Issue No. 82

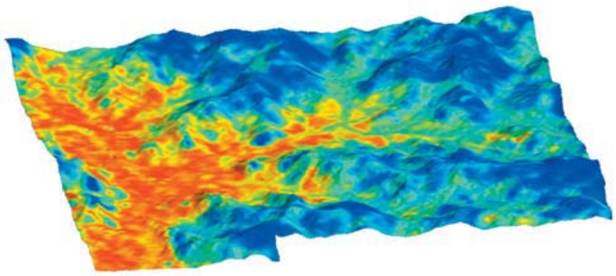
DIGHEM system in flight

SALTMAP system in flight

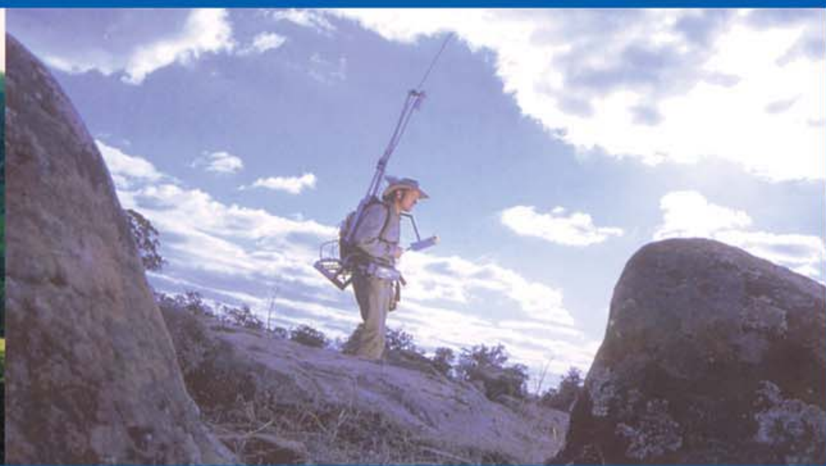


Toolibin apparent conductance draped over topography

Part of the Chapman Valley 7200 Hz apparent conductivity data overlying aerial photography



Special Focus on Airborne Electromagnetics



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Anglo American Corporation
Ashton Mining (WA) Pty Ltd
Australian Geophysical Surveys Pty Ltd
BHP Minerals Discovery Group
Boral Energy Resources Limited
Earth Resource Mapping
ECS International Pty Ltd
Encom Technology Pty Ltd
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Geosoft Australia Pty Ltd
Haines Surveys Pty Ltd
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Zonge Engineering & Research Organisation

Preview Deadlines 1999/2000

December - **Nov 15**

February - **Jan 15**
(Conference Edition)

April - **Mar 15**

June - **Apr 15**

August - **Jul 15**

October - **Sept 15**

December - **Nov 15**

The images and pictures on the front cover were compiled by Ross C Brodie of AGSO.

This issue of *Preview* is a first for both myself, as your new editor, and our new publisher, RESolutions Resource & Energy Services, based in Perth. RESolutions has extensive experience in publishing quality journals on time and within budget.

Under the new arrangements, advertising is a responsibility of the publisher, while the job of attracting feature and review articles remains with the editor. Of particular importance is the quality of the diagrams published in *Preview*. Along with the abstract, diagrams are probably the most widely read parts of any article. We want to ensure a high standard of readability throughout the publications and recommend that all diagrams be submitted to Brian Wickins of RESolutions in ample time for them to be quality controlled.

I look forward to a long and fruitful relationship between ASEG and RESolutions.

As your new editor, I would like to take this opportunity to thank Henk van Paridon for his contribution to *Preview* during his time as editor. Henk produced 14 editions of *Preview* from June 1997 to September 1999 and put in an enormous amount of work in this period to deliver a quality magazine. I am sure all our members have appreciated this. I have certainly welcomed the prompt and sound advice he has provided to me as the new editor. We must also remember that before taking on the editor's job Henk was President of the Society. He has served (and continues to serve) ASEG with distinction.

This particular issue focuses on the recent advances made in the field of Airborne Electromagnetics (AEM). These advances have contributed to a real success story in the last few years, through the efforts of AMET CRC and the main service companies, in providing new techniques for the acquisition, processing and interpretation of AEM data sets. There has also been a corresponding increase in the applications of AEM techniques. These are not just confined to mineral exploration problems, but also, as can be seen from Ross Brodie's paper, they are being applied to land management issues, which are of vital national importance.

Regular features continue in *Preview*, along with the addition of a regular Book Reviews section, and hopefully my friend *Eristicus* will be able to comment on the geo-political scene in and around Canberra on a regular basis. We plan to include articles of general interest and the notes on the Geocentric Datum in this issue fall into that category.

We still need more petroleum contributions to redress the emphasis on mineral exploration in recent issues, and letters to the editor on any issues relevant to ASEG members, will be welcome.

I see *Preview* as one of the most important communication vehicles in our society and encourage members to contribute by getting down to their keyboards and starting to write.

David Denham

David Denham, Editor

President's Piece

ASEG Conference Perth 2000

This is a call to all geophysicists to take the promotional literature for the ASEG's 2000 Perth Conference and Exhibition and tape it to their office door, wall or noticeboard, so that participation in the Perth Conference is uppermost in your planning for next year. A business promotion, a joint venture meeting, a mine tour or a holiday in the vineyards would be an ideal activity to combine with the ASEG's premier exchange of technological excellence and exploration creativity. Members are encouraged to set up parallel activities now, so that the cost of being in Perth is shared by multiple worthwhile events. ASEG in Hobart in 1998 was a great success. Perth is the commercial hub of the western side of our nation so we expect greater numbers of delegates, more exhibitors and fun and excitement at the major geophysical event in our region for the year 2000. The provisional program and exhibition layout may be reviewed at:

http://www.promaco.com.au/conference/2000/aseg/

Employment Difficulties

Retrenchments, the failure to renew contracts and the lack of consulting opportunities are characteristic of these difficult times in our industry. The ASEG is willing to lobby government (note recent correspondence to the Federal Minister for Industry, Science and Resources) and continues to provide a forum for communication through *Preview* and for skill enhancement through symposia and conferences. Our senior managers need to argue strongly for the retention of valuable in-house expertise and for the application of Australian technologies to solve exploration problems. Individuals may consider enhancing their competitiveness by attending low cost ASEG workshops and developing new talents, or even acquiring basic foreign language skills.

New ASEG Publisher

Part of the ASEG's effort to increase the appeal of our technical publications and to reduce overall expenditures has entailed the tendering of all of our publishing requirements. The successful tenderer, RESolutions of Perth, is already well known to many of our members as the Publisher of PESA News and commences its ASEG involvement with this issue of *Preview*. The Society's publications are our greatest cost and we must endeavour to reduce the outlay while maintaining the attractiveness of our publications and the technical calibre of our scientific papers. It is a difficult balance to achieve and one which has seen a much-reduced colour content in recent issues of *Preview*. The cost of publishing is partly offset by advertising revenue and we are impressed with RESolution's enthusiastic approach to providing a very appealing product for advertisers. We would be grateful if all of our manufacturers and suppliers could make their excellent capabilities known to their peers through stimulating displays of their products in our technical publications.

ASEG Finances

In Preview No. 77 (Dec1998-Jan 1999) the past President discussed potential challenges for the ASEG, as revenues remain static or decline while most costs increase, resulting in a reduction in overall funds. The current executive has confirmed the continuation of this trend during 1999 and is very concerned about the long-term implications. We have established a Revenue Committee to focus on opportunities to generate higher levels of income for the Society than has been achieved previously. The ASEG functions by purchasing the services of three expert professional bodies:

1) a secretariat to manage finances, membership and general inquiries

2) a publisher to deliver our scientific documents to members and

3) a conference organiser to ensure the success of our major gatherings of members

Virtually all other activities are accomplished by willing and enthusiastic volunteers who contribute their own valuable time towards achieving the goals of the Society. Without these volunteers at state level, on conference committees, managing our publications, on the Federal Executive and all through our diverse fields of endeavour, the ASEG would falter and ultimately fail. As President I would like to acknowledge every person who gives up time for the Society and I encourage those who have not yet become involved to do so as soon as they are able.

Directory of Geoscientists

The ASEG supported the AIG initiative to establish an Internet-based Directory of Australian Geoscientists and it is pleasing to observe the acceptance of this service. Members are encouraged to participate and also to check out the large number of Australian geophysicists who are already listed. ASEG also supported an AGC initiative to conduct a national census but this project will not proceed, partly as a result of the effectiveness of the directory.

Geophysics in School Syllabus

ASEG members will be interested to know of the recent addition of geophysics to the high school physics syllabus in NSW. In their final year, students are required to undertake three core topics and select the fourth component of their study program from five options. The options are geophysics, medical physics, astrophysics, from quanta to quarks and, the age of silicon. This is a recognition of the importance of our field of science in the community and It would be interesting to see if geophysics becomes part of the curriculum in other states as well.

Mike Smith

Mike Smith
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Preview is a publication of the Australian Society of Exploration Geophysicists, circulated to a membership of approximately 1,350.

ASEG is a non-profit company formed to promote the science of exploration geophysics and the interests of the exploration geophysicists in Australia. Although ASEG has taken all reasonable care in the preparation of this publication to ensure that the information it contains (whether of fact or opinion) is accurate in all material respects and unlikely, either by omission of further information or otherwise, to mislead, the reader should not act in reliance upon the information contained in this publication without first obtaining appropriate independent professional advice from his/her own advisers.

In the current difficult times it is very satisfying to see the great response by members in submitting technical papers for the next ASEG Conference in Perth. Just over 200 papers have been accepted with 100 of these papers currently in-hand and under review. We wish the Conference Editors, Mike Dentith and Mike Middleton all the best in dealing with this record number of papers. Besides the technical program, there has been a positive response by proposed exhibitors. The principle sponsor is Baker Hughes / Western Geophysical and over 70 booths are booked with at least 50 per cent of the deposit paid. On behalf of all members, we wish co-chairmen Kim Frankcombe and Mike Sayers and their near 20-strong Conference Committee all the best in finalising arrangements.

One of the significant goals achieved by the previous FEDEX committee, under the guidance of Noll Moriarty, was to set up a Business Plan for the ASEG. In Noll's words, one of its aims was, "to raise the society's awareness of its financial status, in conjunction with obtaining agreement on realistic financial goals to ensure the society meets obligations to all its members." To help achieve responsible financial management, the previous committee endorsed the Publications Committee's recommendation that *Exploration Geophysics* be restricted to just two (2) publications/year and for a restricted number of colour pages in *Preview*. Since the Federal Committee has been based in Sydney, the committee has been particularly concerned at a possible larger than expected financial loss in 1998 with a further loss currently forecasted for 1999. Most members are aware that during June/July there was a major membership push for several hundred non-financial members. With the current industry downturn there has been significant decreases in the advertising revenue being received for both *Exploration Geophysics* and *Preview*. To reverse this negative cash flow, the Committee has now appointed Steve Webster as Revenue Chairman. Steve will work closely with the Treasurer, the Chairman of the Publications Committee and through the Publications Committee, to advise our new publisher RESolutions on attracting additional income.

On behalf of the Committee, I wish to thank all members of the Publications Committee in their endeavours in reviewing tenders for the new Publisher and for preparing the 'Publisher Agreement'.

I recommend all members to purchase two special ASEG volumes that are about to be published. They are the 'Geophysical Signatures of Base Metal Deposits in Victoria' and the 'Geophysical Signatures of Mineral Deposits of SA'. Orders can be placed through Preview and the Secretariat.

This year has seen a great improvement in the content of our web site (www.aseg.org.au). Besides information on State Branch meetings, you can search for a member's address, read a wealth of information on the up-coming Perth Conference and much more! The site receives about 60 hits per day.

To assist unemployed members, the ASEG would like to run a one-day workshop in Sydney on employment opportunities. There are plans to invite approximately 15 speakers to discuss opportunities in the minerals, petroleum, environment, agricultural, urban planning, main roads and soil conservation professions. Hopefully this idea will be carried forward to other States.

This *Preview* is a big welcome to our new editor David Denham and for our new publisher RESolutions. We wish a happy marriage! On behalf of all members we give a very big thankyou for the efforts of out-going editor Henk van Paridon.

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

Calendar of Events

1999

December 13-17
American Geophysical Union, 1999 Fall Meeting,
San Francisco, California, US.
Website: http://www.agu.org

2000

March 12-16
Australian Society of Exploration Geophysicists, 14th International Conference and Exhibition, Perth, WA.
'Exploration Beyond 2000'
Address: PO Box 890, Canning Bridge, WA 6153
Tel: (61) (08) 9332 2900 Fax: (61) (08) 9332 2911
Email: promaco@promaco.com.au
Website:http://www.promaco.com.au/conference/2000/aseg/

May 7-10
APPEA 2000, Brisbane, Queensland, "Innovation for the Third Millenium". Call for papers to: Steve Taylor, Santos,
Email: steve.taylor@santos.com.au
Website: 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

June 11-15
16th World Petroleum Congress, Calgary Canada
Email: cdn.assoc@wpc2000.com
Website: www.wpc2000.com

This letter, from the Hon Warren Entsch MP, is in response to Mike Smith's letter to Senator Minchin, published in PREVIEW No. 81.

Dear Mr Smith,

Thank you for your letter of 8 July 1999 to the Minister for Industry, Science and Resources, Senator the Hon Nick Minchin, concerning funding arrangements for the Australian Geological Survey Organisation (AGSO) and Cooperative Research Centres (CRC) and the importance of sustaining geoscience technologies in Australia. I am replying on his behalf.

I would like to deal first with the issue of AGSO funding. You will be aware that the Government maintains a policy of Budgetary constraint in the interests of sound economic management. Within this setting, the Government has determined that it is necessary for AGSO to focus on high priority outcomes in relation to offshore petroleum promotion and marine zone management, minerals exploration promotion, geohazards and geomagnetism. I should emphasise that the priorities for offshore petroleum promotion and marine zone management should not be viewed as short-term activities. The Government see these as being of strategic importance to Australia's marine zone management and in attracting future investment in our significantly underexplored offshore region over the longer term.

As a consequence of these priorities, some of AGSO's onshore mineral and petroleum promotion activities have had to be reprioritised. It is important to note that onshore activities are essentially the responsibility of State and Territory governments. In this regard, the role of AGSO should not be seen as duplicating State mapping activities. Rather, as a national geoscience research and information agency, AGSO's role is to offer a range of specialist services to complement the work of the State and the Northern Territory. AGSO will continue to play an important role in onshore mineral and petroleum promotion but with an emphasis on national maps and data sets, concentrating on specialist activities and research skills that are best maintained and developed at a national level.

It should be noted that AGSO will still retain a staff of some 400 people and a budget of approximately $59 million per annum. The Government fully acknowledges the important role of AGSO and recognises the need to maintain a strong national geoscientific institution, subject to the continued need for responsible economic management and fiscal restraint. AGSO will continue to be a vibrant organisation producing valuable geoscientific outputs for the Government, industry and the community.

You suggested that there had been a cut to the funding of the CRC Program. On 16 April 1999 Senator Minchin announced that 26 applications had been selected for funding in the 1998 round. A total of $397 million will be provided over the next seven years to fund new research programs proposed by 22 existing centres and four new collaborative groups across a range of industry sectors. In 1999-2000, Program funding will be maintained at the level of $141 million, continuing the Government's commitment to maintain the ongoing level of funding for the program.

There were five applications for the 1998 selection round in the field of Mining and Energy for full CRCs. Four of these applications came from existing CRCs and one was from a new applicant group. Two of these were successful and will receive substantial funding from the CRC Program. Clean Power from Lignite has been offered $14.136 million and AJ Parker for Hydrometallurgy has been offered $18.5 million over a further seven years.

These two applicants were judged successful on the basis of a rigorous assessment process against 19 selection criteria conducted by the CRC Committee and its expert panels. Key aspects of the CRC concept are a clear strategy for application of research results and the strong involvement of industry or other research users. One of the elements assessed was the level of commitment of industry to applications. Another aspect is the likely contribution of the proposed CRC to national objectives which is judged competitively among all applicants.

It is the nature of competitive process that not all applications can be successful. In this instance, the two applications to which you refer were judged to be less competitive on a number of specific points. Even though the new applications for these two centres were unsuccessful, their current funding form the CRC program will continue until June 2000.

Overall, the CRC Program continues to provide strong support for the mining and energy fields of research. The program will continue to support eight CRCs in these fields over the next seven years. Total program funding over the life of these CRCs will amount to nearly $200 million, in addition to the nearly $30 million already committed to the two unsuccessful CRCs. The structure of CRCs means that this program funding will attract commitments from participants in the CRCs worth more than $400 million. I am sure you will agree that this is a substantial ongoing commitment to research in these fields.

You have suggested that it would be appropriate for the Australian New Zealand Minerals and Energy Council (ANZMEC) to consider the issues facing geoscience with a view to addressing these concerns. I acknowledge the difficult situation currently facing geoscience in Australia, but it is, I believe largely a consequence of the dismal market conditions facing the resources sector. While of little consolation, it is a situation not confined to Australia. The downturn in mineral and petroleum exploration reflects global cycles. I would caution against proposals which seek to create artificial solutions to these problems. Furthermore you will appreciate the difficulties for the Government in singling out one sector for assistance over other sectors in similar circumstances.

While the Government has no control over the global cycle of demand for minerals it does strive to improve the competitiveness of our resource industries and of Australia's competitiveness as a destination for investment. The Government has acted to improve land access and to simplify and clarify procedures under the Native Title Act. Our Budget strategy has delivered low interest rates, low inflation and has raised the pace of economic activity. Microeconomic reform has delivered and will continue to deliver intrinsic competitiveness throughout the economy. Taxation reform will further improve competitiveness by addressing the taxation of business inputs. The efficiency gains of the GST and changes to fuel excise arrangements will reduce the tax burden on our most important export sector. Despite the decline in global exploration expenditure, Australia has maintained its share of worldwide spending in this area at about 17.5 per cent.

Continued On Page 8

Victoria Branch News

Monthly meetings are held at the Kelvin Club, Melbourne on the 3rd Tuesday of every month, Recent meetings included the following:

July 20 - Paul Basford, Pasminco Exploration Pty Ltd, presented a talk entitled, 'A Comparison of Magnetic Surveys with Different Elevation and Data Density in a Near Surface Noise Environment'.

Despite being a last minute fill-in for Jovan Silic's presentation, 'The Importance of Current Loop Gathering in Moving Loop and Fixed Loop EM,' Paul Basford presented an enlightening discussion which was both practical and relevant to the exploration industry.

August 17 - We hosted a highly successful joint venture between the ASEG Victorian Branch and IAH (International Association of Hydrologists). The presentation entitled, 'Bundaberg Irrigation Area Ground Water Investigation', was given by Geoff Pettifer of Geo-Eng Australia Pty Ltd. So far this presentation holds both records for 'best attended meeting in 1999' and 'largest amount of party pies consumed at the Kelvin Club'.

September 7 - John Sumpton, Stockdale Prospecting Ltd, presented a talk entitled, 'The De Beers Airborne Multispectral Scanner'

Preparation continues on the publication of Dr Mark Jessel's Structural Geophysics Atlas.

South Australia Branch News

There is much news to report from the South Australian branch this time around.

Since we last wrote, we have had two technical meetings and a presentation, Distinguished Instructor Short Course has been through town, and we are planning quite a few events for the rest of the year. First things first.

Our August speaker was Professor Roy White of the University of London. His presentation was titled, 'A Systematic Approach to AVO Analysis', and provided both interest and enjoyment to people of varied backgrounds.

At the end of August we held our Student Information Night. Our speakers were yours truly, Mike Hatch, of Zonge Engineering; Nick Mumford, a first year geophysicist with SANTOS, and Megan Smith, also a geophysicist with SANTOS, albeit with a few more years under her belt. The talks were designed to show first and second year students something about life as a geophysicist. I enjoyed myself and I hope that the students did also. Many thanks to Nick and Megan for helping out. Sponsorship for this event was split between SANTOS and Zonge; many thanks to both of them.

Our September speaker was Graham Bubner, ex senior geophysicist for BHP Steel, based in Whyalla. His talk was titled, 'Iron Ore Exploration in the Middleback Ranges, South Australia', and was based on Graham's contribution to the upcoming volume, 'The Geophysical Signatures of Ore Deposits in South Australia'. The talk was of considerable interest, with a bit of a surprise ending.

The SEG (DISC) presentation in Adelaide attracted in the order of 60 participants, most from the oil industry in Adelaide, with at least one visitor from overseas, and a few from other states. The event was a complete success. Many thanks to Baker Hughes/Western Geophysical for their sponsorship of lunch for everyone. Also many thanks to PIRSA for allowing us to use one of their rooms for the course, as well as all their organisational help. Special thanks to Witold Seweryn, Dave Cockshell and Dragan Ivic, all of PIRSA, for their assistance.

Our October meeting on the 20th, was our Annual Industry Night. Also in the near to middle future, we will be holding our Melbourne Cup Lunch (on Melbourne Cup day) and our Student Night is planned for the end of November.

Our wine tasting was held at the end of August, with our long-suffering committee working its way through a veritable plethora of whites and reds. Competition was tight and we hope that you enjoy this year's selection. (See flyer for details).

Continued From Page 7

The Government appreciates the significant contribution made by geoscience through the resources and other sectors to the nation's economic well-being. However, the Government believes the best avenue for increasing employing opportunities is to continue our program of reform and to build on the strong macroeconomic settings and strong growth of the Australian economy.

Yours sincerely

Warren Entsch,
Parliamentary Secretary
To the Minister for Industry, Sciencs and Resources

New South Wales Branch News

In August the branch held its 1999 Annual Branch Dinner, during which a 'geophysical' trivia quiz was held. Katherine McKenna organised the dinner at 'The Different Drummer' in Glebe, with the private room and verandah commanding most impressive views of the city.

Those present enjoyed a delicious and extensive banquet, and a most convivial and informative evening. The wide range of prizes and awards made available by several of the New South Wales geophysics companies and 'The Survey' enhanced enjoyment of the evening. The quiz questions covered both classical geophysics and current geophysical surveys, complemented by questions about well known geophysicists-about-town.

The September meeting was held in the regular meeting place at the Rugby Club. Dave Robson, Chief Geophysicist of the Geological Survey of New South Wales, reviewed the considerable achievements attained to date by Survey as part of geophysical studies of the Discovery 2000 program. The presentation provided an interesting conclusion to the program as Dave had some few years earlier addressed the branch prior to commencing the survey program. Dave was able to report successful acquisition of over 900,000 line kilometers of high resolution magnetic and radiometric data, and extensive gravity data. Availability of those data has greatly enhanced exploration in the state.

With the Federal Committee, the branch has been invited to contribute to discussions about implementation of the Stage 6 Syllabus Earth and Environmental Science (Board of Studies New South Wales) for senior high schools.

WA Branch News

In August, Satyavan B. Reymond, Schlumberger - Geosciences Group, presented, 'Advances in seismic methods.'

In addition, Josef Holzschuh, PhD student with University of WA, presented, 'Geophysical Investigation of aquifers in palaeochannels in the Eastern Goldfields, WA.'

ASEG WA Branch thanks Schlumberger for sponsoring the August meeting.

In September, Simon Polomka, Woodside Energy Ltd, presented, 'WA-271-P - Integrated Prospectivity Evaluation'.

Abstract
Permit WA-271-P in the southern Exmouth sub-basin was initially gazetted as W96-20 in the 1996 gazettal round. After award, Woodside embarked upon an intensive data acquisition program that included 800 km^2 3D, 1,600 km 2D seismic, and 34,000 line-km of aeromagnetic data. The integration of these data was completed in the latter part of 1998.

In addition, Richard Lane and Andy Gabell, World Geoscience Ltd, presented, 'Fly-Drill - Airborne Geophysics in the Next Millenium.'

Abstract
Recent advances in airborne electromagnetics make the prospect of airborne data acquisition followed closely by drilling a viable exploration strategy.

ASEG WA Branch thanks Paradigm Geophysical for sponsoring the September meeting.

On Monday September 13, a group of 50 geophysicists were in attendance at the SEG's Distinguished Instructor Short Course, which was presented by Phil Schultz, Spirit Energy 76 (a Division of Unocal), at the Technology Park theatrette opposite Curtin University. 21 new ASEG members and 20 new SEG members resulted from the DISC registrations.

In October two technical meetings were dedicated to the geophysicists of the future. On October 13 and 20, five students each night presented the results of their post graduate studies. It was a great opportunity for industry to see what local students have achieved.

If your company would like to present a paper and/or advertise at future meetings please contact one of your committee members about sponsorship possibilities.

Abstracts for all past technical presentations are available on the WA Web page, www.aseg.org.au/wa, under Technical Meetings.

ASEG Golf Day: Friday, December 3rd, 1999 at the Meadow Springs Country Club. Vacancies are filling fast. Forms and details are available on the website at www.aseg.org.au/wa/golf or contact David Howard on 9222 3331 or d.howard@dme.wa.gov.au

Thanks to those companies that have already contributed sponsorship in cash or kind: PGS, Veritas, TGS-Nopec, IHS Energy Group, Mobil Exploration and Production, Tesla-10 and Tesla Airborne Geoscience, Ansett Australia, and Ellis Drafting and Graphics.

ACT Branch News

ACT branch has awoken from a period of hibernation and has been getting back on track with establishing a regular speakers' program.

After one false start (due to Melbourne's weather!) Dr Tim Munday (CRC-AMET) delivered our August talk on the 2nd September. His address was controversially entitled 'The Regolith - AEM's Saviour as an exploration technology in Australia?', and was well attended by 20 or so members and interested guests.

On September 10th the branch held its first student night. This was a joint activity with the ANU Geology Society, designed to showcase some recent student geophysical activities to interested fellow students and Society members in a relatively informal setting.

Short talks were given by two ASEG prize winners - Catherine Farmer (1998) and Alex Johnston (1999), an ASEG Research Foundation grant student - Chris Leslie, and one of our long-standing PhD student members, Adrian Hitchman.

The talks covered a new algorithm for 4D-earthquake location; a microgravity study of a Canberra tunnel; a shallow seismic reflection study of palaeochannels at West Wyalong and a report on the recent IUGG meeting in Birmingham. The talks were attended by 25 students and members, who then adjourned to 'beer and bix', hosted by the Geology Society.

On September 23rd the ACT Branch had a talk by Prof. Paul Morgan (Macquarie Uni.) on planetary thermal evolution entitled 'Venus -a planet with a midlife crisis'. This was held as a joint event with the GSA.

Our Annual Dinner (also a joint function with GSA) is scheduled for December 10th.

14th ASEG Conference & Exhibition

Workshops

Perth is the place to be for technical workshops early in 2000. There will be courses on petroleum, mining and ground water geophysics held throughout the weekend immediately preceding the conference in March 2000.

For the petroleum industry, Peter Dromgoole and Chris Lewis from IKODA Pty Ltd will conduct the 'Fundamentals of Seismic Attribute Analysis'. It is a one-day course covering topics such as lithology and fluid prediction from seismic and well data, seismic attributes and time lapse seismic. Case histories will include a 3D volume, volume segmentation and body tracking.

Loz Darmen is coming to town from Houston where he is the President of Flagship Geosciences. He will be presenting a couple of one-day workshops. In 'Practical Reservoir Geostatistics for the Petroleum Industry', he will cover topics such as spatial continuity analysis, Kriging, Cokriging and sequential gaussian simulation. His second course is more innovative and in keeping with the conference theme, Exploration Beyond 2000. It is entitled 'Seismic Facies Analysis – The Application of Geological Knowledge to Seismic Interpretation' and will show how the neural network is used to classify the shape of a seismic trace and how seismic facies mapping can be refined.

There has been considerable support from CSIRO, who is sponsoring Alistair Fletcher to come out from Bristol University in England to give a one-day course on 'Risk and Uncertainty'. It will be a workshop on the mathematical principles of risk and uncertainty modelling for geophysical prospect evaluation. Detailed industry examples from the North Sea will be shown. CSIRO themselves will be giving 2 half-day workshops run by Kevin Dodd, which are hoped to generate considerable discussion. A forum of experts will focus on the issues of 'Pore Pressure Prediction', and another forum, 'Fractures', will debate the influence of fractures in exploration.

CSIRO has also had much involvement in CRC-AMET and a workshop entitled, 'Advances in Electromagnetics for Exploration and Mapping in Australia – The view from CRC AMET', will be a presentation of the past eight years of CRC-AMET. It is a one-day workshop run by the centre's program managers and project leaders and will probably be the last one of its kind. 'Geological Applications of Airborne Electromagnetics', is a one-day course given by Stephen Thompson, Mike Hallett and Peter Wolfgram from Geoterrex-Dighem, Ken Witherly of Condor and Jovan Silic of Flagstaff GeoConsultants Pty Ltd. This course has been given before and has always been popular.

'State of the Art Aeromagnetics – Processing and Interpretation', will look at what we have achieved over the past few years, where we are going and highlight deficiencies that may need to be addressed before future discoveries can be made. It is a one-day course that will be presented by Gordon Cooper from the University of Witwatersrand, Duncan Cowan of Geodata and Mike Dentith and Ron List from the University of Western Australia.

There will also be a one-day workshop on 'Australian-German Ground water Studies', where practitioners and academics in the field of ground water exploration and mapping from Germany and Australia will meet in a forum to transfer knowledge.

We look forward to meeting you there.

Organisers of Conference Workshops:

John Jackson

Anita Heath
Anita.Heath@woodside.com.au

Exploration Levels Continue To Decline

Figures released by the Australian Bureau of Statistics confirm that exploration levels for both the mineral and petroleum sectors continued to decline in the March and June quarters of 1999.

The minerals trend is particularly worrying with the June quarter estimate of $181 million being the eighth consecutive quarter to show a decline, since the peak of $302 million in the June quarter of 1997. All states and the NT experienced significant declines but the effect in Western Australia dominates the whole country because it accounts for ~60% of our exploration investment. In that state ABS figures indicate a reduction from $198 million in the June 1997 quarter to $96 million in March 1999. Expenditure for 1998/99 was estimated at $838 million, 21% lower than for the previous year ($1,067 million) and 27% lower than the 1996/97 record of $1,149 million.

No wonder there are so many unemployed geoscientists in Perth!

The petroleum trends were also disappointing. In the March quarter the total expenditure on petroleum exploration was $227 million and it fell to $191 million in the June quarter. During 1998/99, reported expenditure on petroleum exploration fell to $868 million, a fall of 12% ($114 million) from the previous year. The reduced activity was due to an overall decline in onshore petroleum exploration and a reduction in offshore drilling activity.

The recent rise in oil prices has not yet been translated into an increase in exploration investment.

New Review of Australia's Science Capability

Senator Nick Minchin, the Commonwealth Minister for Industry, Science and Resources, has announced the first comprehensive scientific capability review to be carried out in Australia for several years. Dr Robin Batterham, Chief Government Scientist, will undertake the review. It will examine the nation's science base and the existing mechanisms of funding and support to ensure that resources are effectively targetted. Submissions should be provided by 30 November 1999 and the preliminary results are expected to be announced by the Chief Scientist at the National Innovation Summit, February 2000. This is a good opportunity to add grist to the mill.

More details and the terms of reference are to be found on the following website: http://www.isr.gov.au/science/review

Minchin Announces New Round Of CRC Funding

Senator Nick Minchin, has called for industry and researchers to develop new proposals for government funded research.

He announced that a formal call for applications will be made in November 1999, with a closing date for applications expected in July 2000.

There are currently 65 CRCs with funding of $140 million per year from direct Government grants and $320 million per year from other participants, including universities, CSIRO, AGSO and state Government bodies.

In the last round of bids, the Earth Science CRCs fared badly with both the Geophysical Exploration Technologies and the Geodynamics applications being unsuccessful. Under the present guidelines it will be very difficult to generate a viable geoscience bid because there is a requirement for strong industry support in cash over the seven-year life of the CRC. With the present state of the resource industries, because of low commodity prices, it will be hard for the industry to commit any funds over this time span. The present policy of industry support ensures that those who have resources for research will get more, and those that do not will get nothing. It looks like a rethink is urgently needed.

Ironically, in a media release in August this year, Senator Minchin waxed eloquently about the deep seismic reflection work being carried out in Western Australia by AGSO and the AG CRC, and yet he must have known that the current guidelines for CRCs precluded an extension for the Geodynamics CRC in the last round of bids.

CSIRO's Strategic Directions for 2000-2003

In June 1999, CSIRO produced an excellent overview of where it plans to invest research resources during the first triennium of the new millenium. With a finite bucket of resources available from government appropriation, and a huge client demand for more research, it is a tough job to balance the priorities.

In the plan those sectors of interest to geophysical research did reasonably well. Land and Water will increase from $69 million in the current triennium to $92 million in the next; Marine will increase from $69 million to $72 million, with emphasis on the North West Shelf; Mineral Exploration and Mining will increase from $52 million to $56 million and Petroleum will remain constant at $33 million.

Most of the increase will be allocated to the 'Glass Earth' project. This aims to assist in discovering the next generation of giant ore deposits in Australia by making the top one kilometre of the continent, and the processes operating within it transparent. The main activities will focus on, tensor gradient magnetometry, gravity gradiometry, airborne chemical mapping, hydro- and isotope- geochemistry, modelling chemical, fluid and heat flow in rock and regolith, and advanced data fusion.

The petroleum research activities are not specifically defined in the document but the 'improvement of Australian exploration performance' is identified as the first key issue.

Australia's Identified Mineral Resources 1999, Released By AGSO

Low commodity prices and a downward trend in exploration could reduce the value of 'Australia's mineral and energy exports, according to AGSO's report, Australia's Identified Mineral Resources 1999'. In 1997/98 our mineral and energy exports increased to a record $41 billion but with lower prices for gold and base metals this level of exports in not likely to be maintained, and hence there will be a significant impact on Australia's balance of payments.

According to the report, Australia's economic demonstrated resources of copper, magnesite, gold, ilmenite, nickel, platinum group metals, tantalum and vandium increased while those of diamond, iron ore, lead, manganese ore, lithium, silver, uranium, tin and zinc diminished.

Australia continues to rank highly as one of the world's leading mineral resource nations and the report provides an excellent review of each of the country's main commodities.

Eristicus, Canberra, September 1999

Investigating Salinity Using Airborne Geophysics

A Report on the National Airborne Geophysics Project

Ross Brodie - Australian Geological Survey Organisation

Abstract

Secondary salinity has emerged as one of Australia's worst land degradation problems. It is estimated to cost the nation at least $250 million annually (see George et al., 1999). In 1996, the Commonwealth and four state governments commissioned a project, to assess the contribution airborne geophysics can make to the understanding and management of dryland salinity. The project has concluded that the knowledge and services offered to the community would be considerably improved if airborne geophysics were added to existing datasets for use in developing management strategies. The technique has the ability to map many of the landscape attributes relevant to salinity management, including the spatial distribution of salt stored in the regolith. The study also found that the data are complex and need to be carefully interpreted by expert multi-disciplinary teams to avoid spurious conclusions. Community groups have enthusiastically embraced the potential of the technology and further use for future investigations.

Key words:

Dryland salinity
Airborne geophysics
Conductivity of regolith

Introduction

Salinity is now recognised as one of Australia's worst environmental problems. Annually it costs the nation at least $250 million in lost production, infrastructure damage, water resource degradation and ecosystem loss. Some 2.5 million hectares of once productive farming land are now saline. Land affected by salinity is increasing at three to five percent annually and a further nine million hectares are at risk of being affected in the long term if the spread of salinity is not stopped.

The salinity problem is not confined to agricultural regions. Recent reports suggest that 80 country towns and some cities are already affected through damage to roads, buildings, other infrastructure and drinking water supplies.

Salinity Processes

The accumulation of salt in the regolith is a natural process that occurs on a time scale of thousands of years. Most of the salt in the regolith originates as oceanic salt deposited in rainfall. The salt is distributed and stored throughout the regolith according to the resident hydro/geological regime.

The replacement of forests with agriculture has dramatically reduced water usage by plants within the landscape. The clearing of deep-rooted, perennial species and their replacement with shallow-rooted annual crops and pastures results in less evapotranspiration, more water available as recharge, and a general rise in groundwater levels. As groundwater rises through the regolith it mobilises stored salts. On reaching the near surface, it evaporates and concentrates the mobilised salts, resulting in a saline seep. This is known as dryland salinity.

Irrigation salinity occurs where excess water from irrigation systems causes groundwaters to rise. Both irrigation and dryland salinity are forms of secondary salinity. Where saline groundwater occurs within the root-zone it restricts or prevents plant growth because of the toxic effect of the salt and the reduced ability of plants to take up water and nutrients. Waterlogging significantly exacerbates the effects of salinity.

Project

Salinity takes centuries to develop and it may take centuries to reverse, along with large costs in terms of lost production, and management options such as tree planting, earthworks and pumping. Accordingly, farmers and other land managers have sought effective tools to help them understand the processes that drive salinity in their catchment, allowing them to make informed decisions rather than educated guesses on what management options to use and how they can most cost-effectively be implemented. For several years, airborne geophysics and particularly electromagnetics has been mooted as one such tool but has never been fully accepted.

In April 1996, having recognised a need for new tools to fight salinity, and following its earlier election commitments, the Federal Government committed $1 million of Natural Heritage Trust funds through the National Landcare Program to trial airborne geophysics. The governments of Queensland, New South Wales, Victoria and Western Australia joined the trial and contributed matching funds on a dollar for dollar basis. The trial, which became known as the National Airborne Geophysics Project (NAGP), was conducted under the banner of the National Dryland Salinity Program. It was driven by a Steering Committee, comprising members from the Commonwealth bodies AFFA, AGSO, CSIRO, and LWRRDC, and the participating State agencies; Agriculture Western Australia, Department of Natural Resources (Qld), Department of Land and Water Conservation (NSW) and Department of Natural Resources and Environment Victoria. The overall objective of the NAGP was to;

'Assess the contribution that airborne geophysics data (specifically time domain EM, frequency domain EM, magnetics and radiometrics) can make, in conjunction with existing datasets, to the understanding and management of dryland salinity through trial evaluation in selected catchments'.

Across Australia five trial sites were selected for data acquisition as part of the project. World Geoscience Corporation was awarded contracts to acquire SALTMAP AEM, magnetics, radiometrics and elevation data over three catchments; Balfes Creek (Charters Towers, Qld), Willaura (Ararat, Vic) and Toolibin (Narrogin, WA). Geoterrex–DIGHEM was awarded contracts to acquire DIGHEM AEM, magnetics, radiometrics and elevation over the other two catchments; Liverpool Plains (Gunnedah, NSW) and Chapman Valley (Geraldton, WA) (See Preview

Reference

George, R.J., Beasley, R., Gordon, I., Heislers, D., Speed, Brodie, R, McConnell, C. and Woodgate, P. (1999). Evaluation of Airborne Geophysics for Catchment Management, National Report, Agriculture Fisheries and Forestry Australia, pp 81.

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Issue No. 69–August 1997 for more details of the areas and systems flown). The surveys were flown during the later half of 1997. The contractors were required to process the datasets, produce maps, digital data and an interpretation report for each area.

Meanwhile the state agencies were collating and/or acquiring ancillary datasets, which included aerial photography, groundwater salinity, ground and downhole EM, soils and geology, satellite imagery and cadastre amongst others. Analysis of the data by the state agencies began upon delivery of preliminary data and maps in late-1997 to mid-1998. An extensive drilling program was carried out in the Western Australia catchments and some drilling was carried out in the other states. More rigorous analysis and interpretation of the data was carried out after delivery of final products. Principally the state agency representatives carried out this phase. Two three-day workshops were convened during 1998 at which the Steering Committee performed a joint analysis of each of the catchments.

Besides the data, map products and interpretations produced by the contractors and state agencies, the main outputs of the project were the National Report and the five Catchment Reports. These reports are available in hardcopy or digital form on CD-ROM or via downlond from the Internet at http://www.nrsc.com.au/nagp/nagphome.htm www.nrsc.com.au/nagp/nagphome.htm

Results

The principal finding of the trial is that airborne electromagnetics (AEM) does map the spatial distribution of salt stored in the regolith successfully at both a catchment and paddock scale, particularly in the more saline catchments of Liverpool Plains, Toolibin and Willaura. This observation is supported by the significant statistical correlations between AEM apparent conductivities and drill hole and ground based measurements of salt content (EC1:5, and ionic concentrations). The trial established that salt stored in the regolith, be it dominantly within the matrix and mobile (eg. Willaura, Toolibin) or lithologically-bound (eg. Liverpool Plains), is the main influence on the bulk electrical conductivity. Furthermore, AEM correlated well with ground-based EM31 and EM39 conductivity measurements. At Liverpool Plains and Toolibin, where soil physical property data were available, it was found that AEM conductivities did not correlate with percentage clay content but were strongly correlated with concentrations of Cl^- and Na^+ ions. Additionally, catchment managers and farmers reported a good agreement between anomalous conductivities in the AEM data and areas of known or previously predicted saline ground (eg. Liverpool Plains).

At the outset of the project it was anticipated that AEM data would provide an accurate discrimination of the vertical conductivity structure to allow interpreters to build up a three dimensional understanding of the salt distribution and processes. Unfortunately, the reliability of vertical information extracted from the AEM data are not always accurate. The three horizontal frequencies of DIGHEM and SALTMAP's early, mid and late time apparent conductance were very useful as a qualitative measure of the vertical distribution of salt. The quantitative inversions and other vertical data resulting from both systems were only useful in a broad catchment sense and could not be used to accurately predict conductive unit thicknesses or depth at the finer paddock scale. While only reflecting the current state of technology, in some cases the unsupervised inversion models derived were often inappropriate and the results inaccurate and misleading. Future work would benefit greatly from more sophisticated inversion techniques, the use of the appropriate model for different parts of the landscape, and better calibration of the instrumentation.

Statistical analysis confirmed that AEM data could be used to obtain a reasonable estimate of groundwater salinity (eg. Toolibin and Chapman Valley). The interpreted water resource target maps were a good indication of where to find low-salinity groundwater, high-salinity groundwater and geological structures significant to groundwater flow. However, aquifer yield and depth information could not be derived.

Catchment managers and farmers were enthusiastic about the use of radiometrics as a tool to map the boundaries of the major soil units, significantly increasing the detail of existing soils mapping. Field checking revealed that radiometrics did not always differentiate between soils of differing textural characteristics. Radiometrics can infer textural information about the landscape that may in future make handy input data for hydrological models. Experience at Liverpool Plains suggests that, combined with electromagnetics, the radiometrics can be used to identify soils that are more highly susceptible to saline outbreaks.

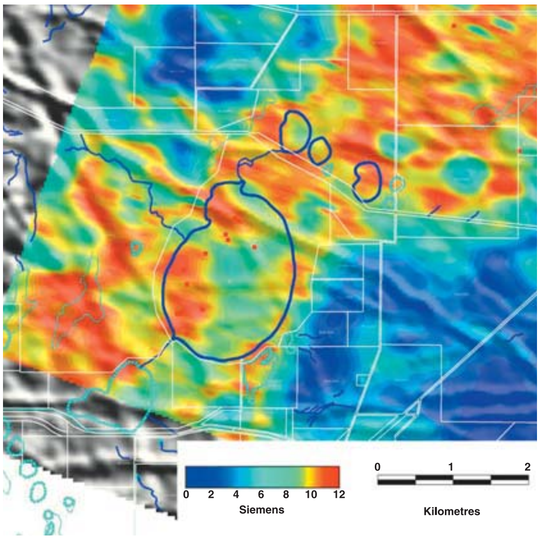

Fig 1. Ternary apparent conductivity (Red=400Hz, Green=7.2khz, Blue=56kHz) from Liverpool Plains. The yellow arrows indicate previously known saline outbreaks, which correspond well with bright areas on the image. Also note the less conductive valley west of the central resistive ridge compared to the valley to the east, although other saline areas may have been identified in the western valley. Ternary AEM images (such as in Figures 1 and 2) give a good qualitative indication of the three dimensional distribution of conductivity. Analogous to radiometrics ternary images, the deepest (late time or low frequency) response is assigned to the red band, intermediate depth (mid times or middle frequencies) to green and shallow (early time or high frequency) to blue. Thus areas that are resistive from near surface to depth appear as dark areas on the image. Bright parts of the images represent high conductivity from surface to depth. Bluish areas indicate high near surface conductivity with relatively less conductive material at depth – and so on.

Magnetic data proved to be extremely valuable. They significantly improved the geological understanding in all of the catchments. For example in the Chapman Valley the magnetic data suggested that development of the Chapman River had been structurally controlled and that seeps were sometimes related to dolerite dykes. At Toolibin the magnetics proved that the numerous dykes were not as hydrogeologically important as previously thought, although hundreds more were identified. Improved and new mapping of greenstones (and related faults) and basalt flows have significant implications for conceptual models and will assist in focussing ground-based investigations at Willaura. A previously unknown basin was interpreted from magnetics at Balfes Creek, which appears in part to control the flow of Balfe Creek along with intrusive units. A basement high interpreted from magnetics, corresponding with AEM anomalies and known saline outbreaks, is suspected of causing a pooling affect in the groundwater system at Liverpool Plains. It was also concluded that in combination with AEM, magnetics would prove to be useful for water resource identification.

Digital elevation models produced from the airborne data were useful for rapid familiarisation of geomorphological features and in most cases provided extra detail over previous elevation information.

Perhaps the most exciting aspect of the trial was how much information emanates from the datasets when they are combined. They can be rapidly overlaid, contrasted and compared on GIS systems allowing interpreters to see the big picture spatial confluence of geological units, conductivity anomalies (at various depths), soils and topography. Although this is a very qualitative process, the interpreter rapidly builds up a broad three-dimensional synoptic picture of the landscape and the processes driving it. Going to the finer paddock scale, farmers and catchment managers are able to relate localised anomalies to their detailed observations and question why/why not it matches their conceptual understanding, thereby beginning to put together the total jigsaw.

Todate the only direct management decision arising from the trial has been to lower the water table at Toolibin by pumping water from several new bores sunk into a high yielding palaeochannel aquifer. The aquifer was discovered after late-time SALTMAP data revealed a relatively low conductivity pattern in otherwise very conductive valley floor sediments on the eastern side of Lake Toolibin. Previous bores, sunk into a conductive area on the western side of the lake, had missed the aquifer, were low yielding and thus unsuitable for pumping.

Catchment interpretations are being redone at Toolibin to incorporate the geophysics data. A major advantage has been that all of the data have been collated with existing data in the form of a GIS CDROM easily accessible by the free ARC-EXPLORER software, allowing local people to positively use the data.

Conclusions and Recommendations

The foremost conclusion of the project was; 'airborne geophysics provides a very effective means of improving our understanding of the landscape, sub-surface structure and the hydrological process at catchment scale.'

The study found that because geophysical data are complex, and although a potentially powerful tool when interpreted with expert knowledge, misguided and spurious conclusions could be made if the geophysical data are not treated correctly. Where detailed catchment and farm plans are

Ternary display of electromagnetic apparent conductivities draped over satellite imagery

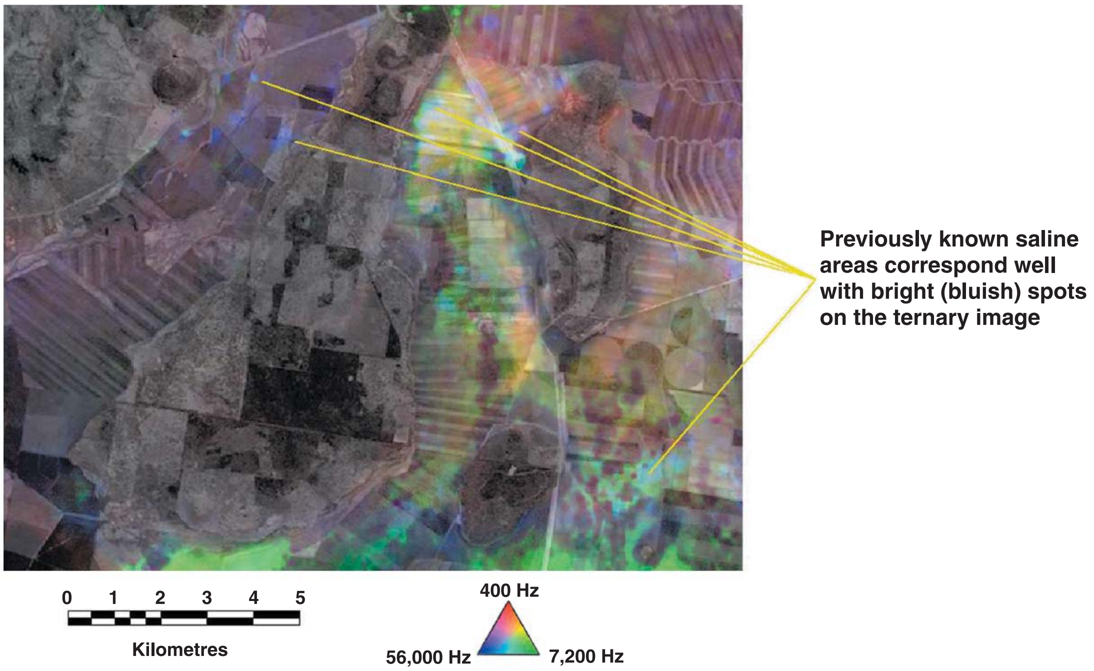

Fig 2. Willaura ternary apparent conductance (Red=Late, Green=Mid, Blue=Early time) overlying the vertical derivative of magnetics. The image shows the spatial relationship of geological structure and salt storage patterns.

to be developed, the geophysical data must be interpreted in conjunction with other datasets. In the greenfields situation where other datasets are not available, airborne geophysics will often be a cost efficient and effective method of obtaining an overview of the catchment attributes (salt store, regolith, soils and geology), enabling land managers to focus and prioritise their more detailed and expensive investigations.

The reaction of farmers to the project was positive. They see real on-farm benefits arising from the application of the technology. Except for the pumping at Lake Toolibin, so far the new information gained has not been distilled into management decisions. However, use will be made of the data in a modelling framework, which should enable better plans. At present the major limitation is the lack of skilled farm planners and lack of effective salinity management tools.

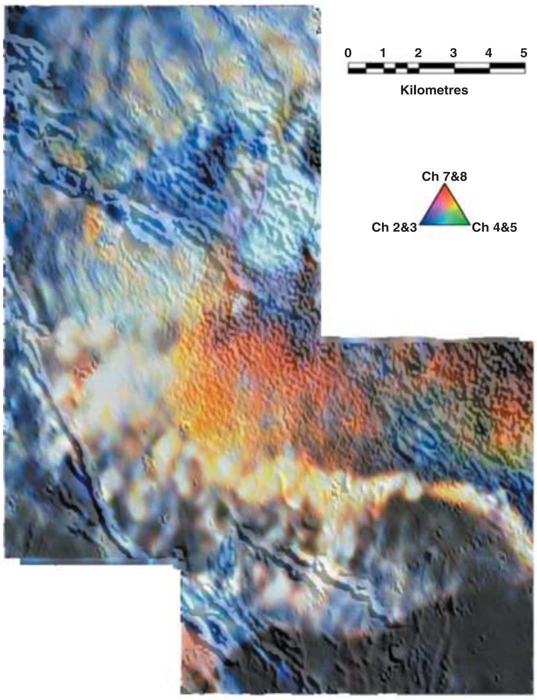

Fig 3. Principal component image of AEM data from Lake Toolibin with an interpreted palaeochannel and bores. The bore in the palaeochannel (red), was positioned on the basis of AEM data and intercepted a high yielding aquifer that is now being pumped to lower the water table. Earlier (green) bores had missed the aquifer. (PC analysis and image prepared and supplied courtesy of World Geoscience Corporation).

Since the trial began, at least three new AEM systems are now available in Australia. The technology is bound to improve and the pricing become more competitive. In a multi-disciplinary study, commissioned by the Bureau of Rural Sciences, AGSO, CRC-AMET and CRC-LEME, the TEMPEST system arising from the CRC-AMET is now being used in the study of geology, mineral systems and salinity near Temora.

In the national report, the project Steering Committee recommended, (subject to certain qualifications); the wider use of airborne geophysics via the systematic and coordinated collection of airborne geophysics over land at risk of dryland salinity. This and the other recommendations of the project were tabled at a recent Standing Committee on Agricultural and Resource Management (SCARM) meeting. Subsequently, Dr Richard George (AgWA) and Dr Andy Green (CSIRO) have been nominated to jointly chair a committee to foster the uptake and development of the application of airborne geophysics in relation to catchment management.

Acknowledgments

The material in this report is largely a synopsis of the issues reported in the project's national and individual catchment reports. The authors of the reports were Richard George, Russell Speed and Cec McConnell (Agriculture Western Australia), Ross Beasley (Department of Land and Water Conservation, NSW), David Heislers (Department of Natural Resources and Environment, Vic), Ian Gordon (Department of Natural Resources, Qld) and Peter Woodgate (formerly of Natural Resource Systems). Thanks also to Andy Green for his significant input of AEM expertise into to the project.

Undercover Assignment for TEMPEST

R. Lane, CRC AMET and P. Leeming, M. Owers & D Triggs - World Geoscience Corporation Pty Ltd

Key words:

Airborne Electromagnetics, conductivity modelling, mineral exploration.

Abstract

TEMPEST is a new broadband (25 Hz to 37.5 kHz) AEM system which delivers accurate, high-resolution information as a 3 dimensional (3D) conductivity distribution. Displays generated from 3D conductivity data complement traditional data profiles, window amplitude maps and apparent conductivity maps, and facilitate integration with other observations.

Vertical and horizontal conductivity slices and 3D conductivity isosurfaces are derived for depths of several hundred metres from a survey covering the Comet workings, part of the Tuckabianna Goldfield in Western Australia.

TEMPEST AEM System

TEMPEST was developed by members of the AEM Systems Program of the Cooperative Research Centre for Australian Mineral Exploration Technologies (CRC AMET). It is configured with a transmitter loop located on a fixed wing aircraft and receiver coils in a towed 'bird'. Unique features of TEMPEST include its extremely broad bandwidth, 25 Hz to 37.5 kHz, achieved through use of a square transmitter waveform, sophisticated receiver coil design, and high data sampling rate. Comprehensive calibration procedures and digital signal processing routines applied to complete recordings of 'streamed' data ensure that noise is attenuated, the system transfer function is accurately deconvolved from the data, and primary field effects are removed from the measured response to enhance the response from the ground. Measurement of 'system geometry' (transmitter loop, receiver coils and ground surface) significantly improves the accuracy and lateral continuity of derived ground conductivity results.

The relationship between the measured response from any AEM system and sub-surface conductivity distribution is complex. Profiles and images of time or frequency response contain essential information, but can be difficult to interpret in terms of conductivity and depth since these parameters depend on measurement system characteristics and the interrelationship between many time or frequency values.

One dimensional models derived from each observation are a first order approach to resolving this complexity. TEMPEST was designed to optimise this quantitative approach, and either conductivity-depth-imaging (CDI) or layered model inversion (LEI) methods are routinely applied to the data. Models are combined along flight lines to produce conductivity sections, and formed into 3D grids where conductivity values are assigned to elements in a regular (x,y,z) array. Visualisation methods were developed by World Geoscience Corporation (WGC) to identify and communicate conductivity relationships in 3D grids. Computer animation of a series of slices of increasing depth below surface is an example of the visualisation techniques applied to TEMPEST data. Isosurfaces (i.e. surfaces connecting points of a specific conductivity value) have also proved useful for showing the spatial geometry of bodies of elevated conductivity.

TEMPEST may be described as a conductivity 'mapping' system since the output of a survey is a 3D conductivity distribution. Presentation of results as conductivity values in 3D-space rather than time/frequency space facilitates integration with other relevant observations (surface measurements, drilling results). 3D conductivity output can show subtle low contrast variation as well as high contrast conductive bodies, allowing sophisticated geological/ hydrological models for base metal, diamond, ground water and land management applications to be utilised rather than being restricted to traditional 'bump' (discrete, high conductance target) identification.

Comet Example

The Comet group of gold workings is located 25 km east of Cue, in the Murchison Province of the Yilgarn Craton, Western Australia. They are adjacent to the NNE/SSW Mount Magnet - Meekatharra Shear Zone. TEMPEST data with a base frequency of 25 Hz were acquired around Comet on lines spaced at 200 m intervals. The flight path shown in Figure 1 amounts to approximately 550 line km. The digital terrain model derived from airborne measurements (Figure 2) reveals a very uniform and gentle slope of around 2 m/km towards Lake Austin on the southern edge of the survey area. A few scattered NE/SW trending ridges up to 20 m above the surrounding level are present within generally featureless terrain. Open pit gold

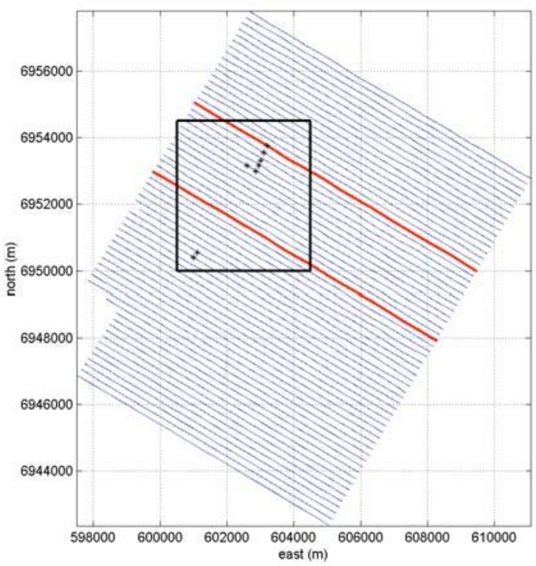

Fig 1. Flight path map for the TEMPEST survey at Comet. Line 10170 (figure 4a) is shown in red, closest to the NE edge of the survey. Line 10290 (figure 4b) is also shown in red, closest to the SW edge of the survey. The location of the Comet gold workings are shown with black asterisk symbols. The area of enlargement shown in figures 6 and 7 is indicated with the black rectangle.

workings are evident near (608000 mE, 6954000 mN), 'Friars', (603000 mE, 6953500 mN), 'Comet', 'Comet North' and 'Pinnacles', and (601000 mE, 6950500 mN), 'Venus'.

Total magnetic intensity (TMI) data collected during the TEMPEST survey (Figure 3) are dominated by intense linear anomalies related to banded iron formation and ultramafic

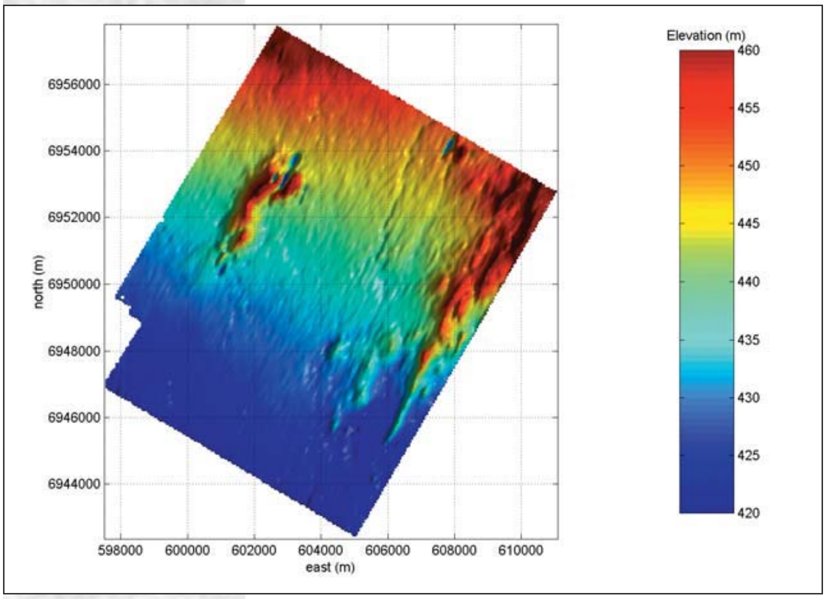

Fig 2. Surface topography derived from the airborne measurements.

units within the greenstone sequence. A lower amplitude magnetic curvilinear feature coincides with the arcuate ridge in the vicinity of the Comet group of workings. Homogeneous areas of magnetic response along the north west edge of the survey are associated with granite.

Conductivity values are extremely variable within the survey area, from less than 1 mS/m (>1000 ohm.m resistivity) to more than 1000 mS/m (< 1 ohm.m resistivity). Widespread cover of low to moderate conductivity is present in the top 50 m of line 10170 (Figure 4a). A strong discrete conductor occurs directly below the Comet North pit. The 1D assumption utilised by the CDI algorithm produces an underestimate of conductivity and overestimate of depth to top of such discrete features. Some artefacts may result from the conversion of measured response to conductivity near sharp lateral changes in shallow conductors due to the complex anomaly forms associated with these features. The majority of the features across section 10170 would be expected to be accurately portrayed.

The conductivity section for line 10290 (Figure 4b) shows the presence of multiple discrete conductors. These are evident in window amplitude profiles as slowing decays and enhanced amplitude in the later windows, between 2000 and 4500 m distance along line. It is anticipated that the conductors may be closer to the surface and more conductive than shown in the sections. A depression in the near surface conductive layer in the central part of the line is interpreted as a palaeochannel feeding into Lake Austin, a salt lake system to the southwest. The base of the channel is approximately 100 m below the present land surface and its width is around 1 km.

Conductivity data for all observations are combined into a 3D grid. Slices of average conductivity for various depth intervals are then extracted from the gridded volume. The depth interval over which conductivity values are selected

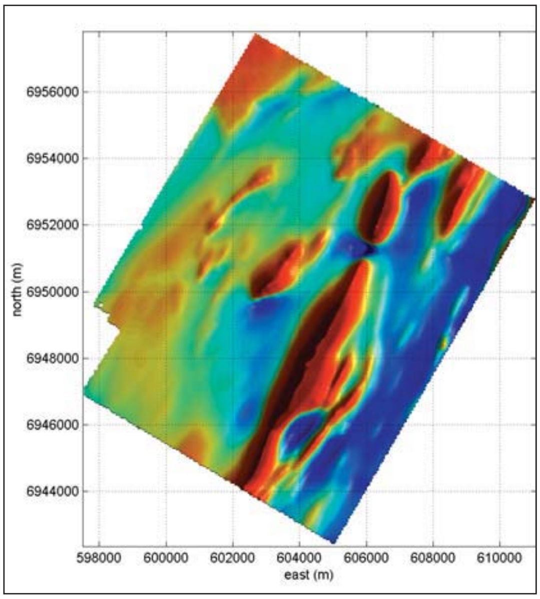

Fig 3. Coloured total magnetic intensity image. A gaussian (normal) stretch has been applied to the data, the dynamic range being 55250 - 60400 nT. An illumination from the SE has been applied.

depends on the range of conductivity values in the survey area and the specific application of the data. Thinner intervals are more practical in areas of higher conductivity. A wealth of spatial detail, evident in these slices, can be further enhanced by combining them into a time sequenced computer display ('animation').

A number of slices, representative of the varying spatial patterns observed between 0 and 200 m depth for the Comet data, are shown in Figure 5.

The near surface slice (0-10 m, Figure 5a) shows generally low conductivity values, with an increase in conductivity along the south west edge near Lake Austin. Weakly elevated values are present over most of the greenstone sequence in a NE trending band across the central part of the survey area, gradually increasing towards the south east edge of this band.

Dramatic changes in conductivity are evident by 20-30 m below surface (Figure 5b). Increasing conductivity, which is commonly observed in the Murchison and Eastern Goldfields areas of Western Australia, is associated with an increase in moisture content. Extremely high conductivity values along the southwest edge are associated with highly saline groundwater of Lake Austin. Conductivity values are enhanced over the covered central part of the greenstone belt, reflecting the presence of saprolite in this depth range.

Conductivity values in the 50-60 m depth interval (Figure 5c) are dominated by a branched pattern through

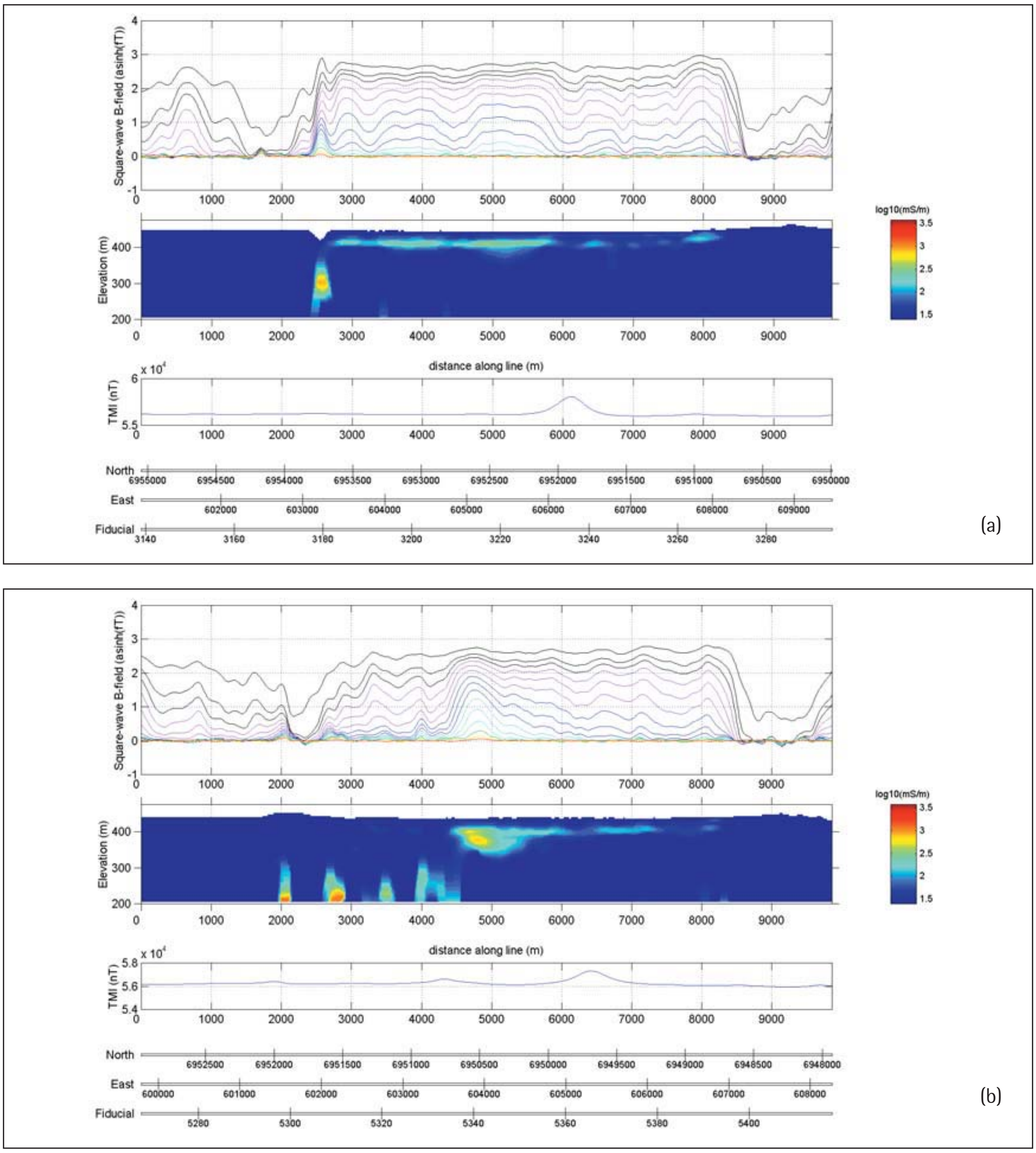

Fig 4. Square wave B-field profiles, conductivity sections and TMI profiles for (a) line 10170, and (b) line 10290. Window centre times for the profiles are 0.013, 0.040, 0.067 0.107, 0.173, 0.280, 0.453, 0.720, 1.120, 1.733, 2.693, 4.200, 6.560, 10.200, and 16.200 ms.

the central portion of the survey area, increasing in conductivity to the south west, and a narrower linear trend close to the south east edge.

Grey shading in the 150-160 m depth slice (Figure 5d) indicates where the depth penetration or 'skin depth' of the system has been exceeded due to the presence of overlying highly conductive material. The shading is used because it is difficult to accurately determine conductivity under these conditions. Conductance of overlying material in this instance exceeds 200 S.

A number of narrow discrete conductors are evident in the deepest slice. An association with massive sulphide or graphite is likely.

Distribution of conductive material can also be displayed in 3D using isosurfaces. These surfaces join points of a selected conductivity value.

Isosurfaces shown in Figure 6a enclose material of conductivity exceeding 15 mS/m, and reveal the presence of extensive near-surface weakly conductive cover. Colouring the isosurfaces by elevation above sea level highlights the separation between sheets of near-surface conductive material (red) and deeper conductors (yellow through blue). Gold workings are coincident with discrete conductors, seen through the narrow window in the conductive cover. The relationship between discrete conductors and gold mineralisation is consistent with the presence of pyrite and pyrrhotite with gold mineralisation in these workings.

By increasing the isosurface value from 15 mS/m to 90 mS/m (Figure 6b), the masking effect of near-surface weakly conductive material can be rolled back. A second zone of discrete conductors is revealed beneath cover, parallel to the Comet line of workings, and 1500 m to the south east.

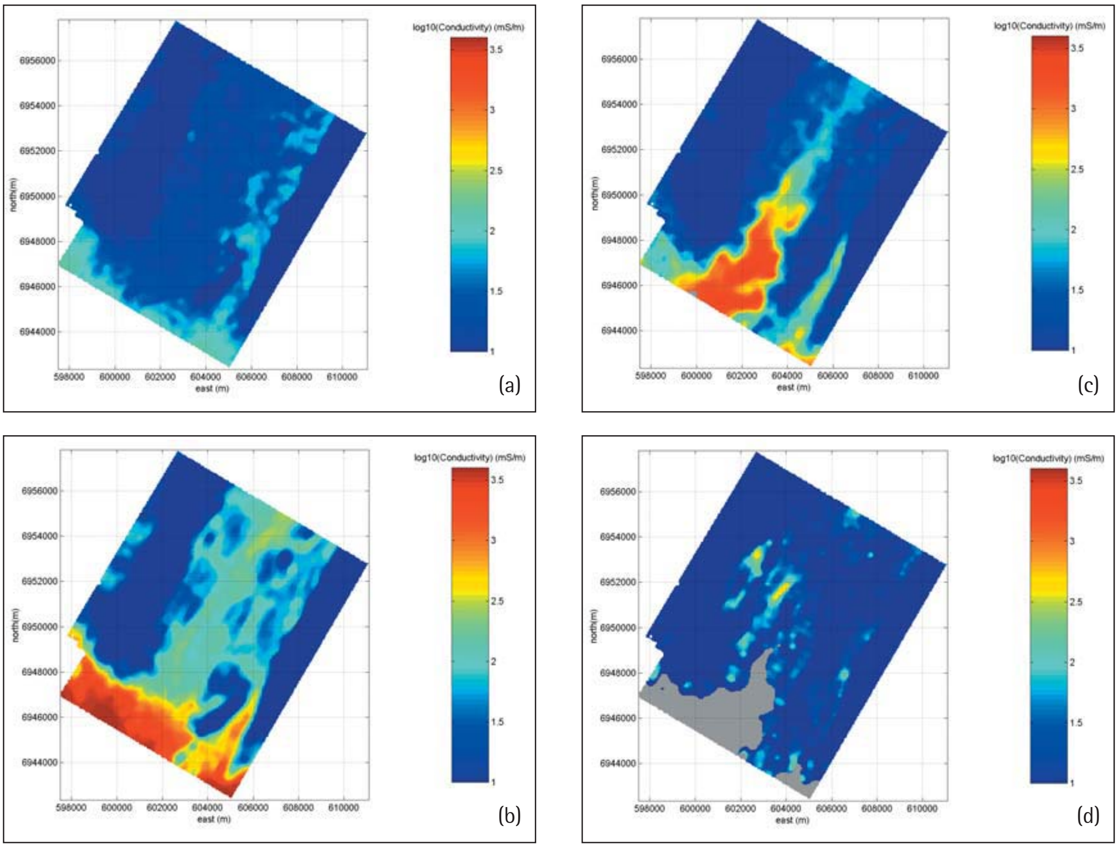

Fig 5. Interval conductivity slices for (a) 0-10 m, (b) 20-30 m, (c) 50-60 m, and (d) 150-160 m below surface.

A perspective view of the 60 mS/m isosurface (Figure 7) illustrates many of the features discussed above. A near surface, sub-horizontal layer of conductive material is evident along the eastern edge of the rectangular box and as a small fragment in the northwest corner. A deeper zone of conductive material extending down from the near-surface layer in the southeast corner is a part of the palaeochannel discussed in relation to Figure 5c. Two zones of discrete northeast trending conductors are present at depth. The northwest zone is associated with the Comet line of workings (the Comet, Comet North and Pinnacles open pits are evident in the surface topography mesh). The second zone lies 1500 m to the southeast, between the Comet line of workings and the edge of the palaeochannel.

Conclusions

TEMPEST data confirmed the presence of discrete conductors associated with gold mineralisation at the Comet. Similar strong conductors are detected beneath cover 1.5 km to the south east. Several lesser conductors are present across the survey area. A deep palaeochannel feeds into Lake Austin. A more detailed analysis of variation in the depth and conductivity of cover would provide further valuable insights into lithological and alteration

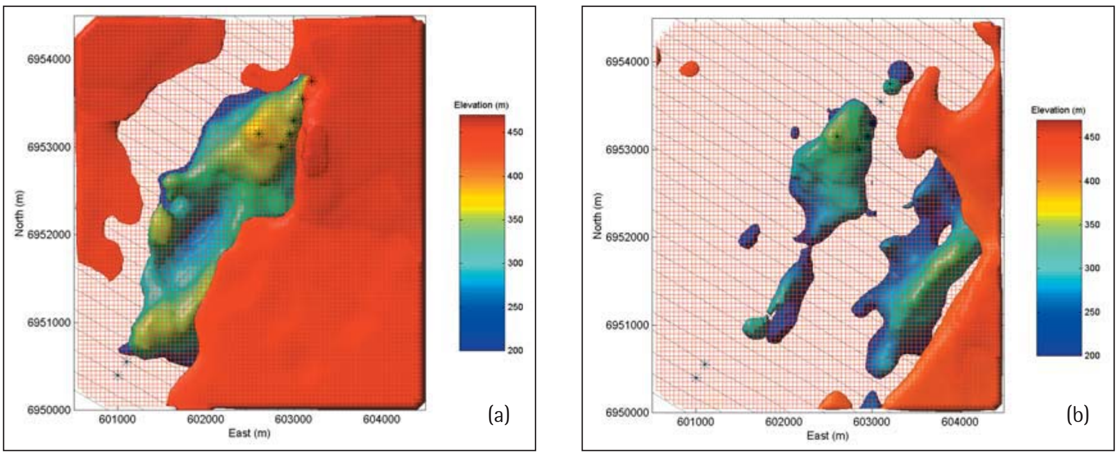

Fig 6. Isosurface representation of the conductivity distribution within a subset of data around the Comet group of gold workings, viewed from overhead. The locations of the workings are shown with black asterisk symbols. Flight lines are plotted in black. The mesh of surface topography and isosurfaces are coloured by elevation above sea level. (a) Isosurfaces for 15 mS/m. (b) Isosurfaces for 90 mS/m.

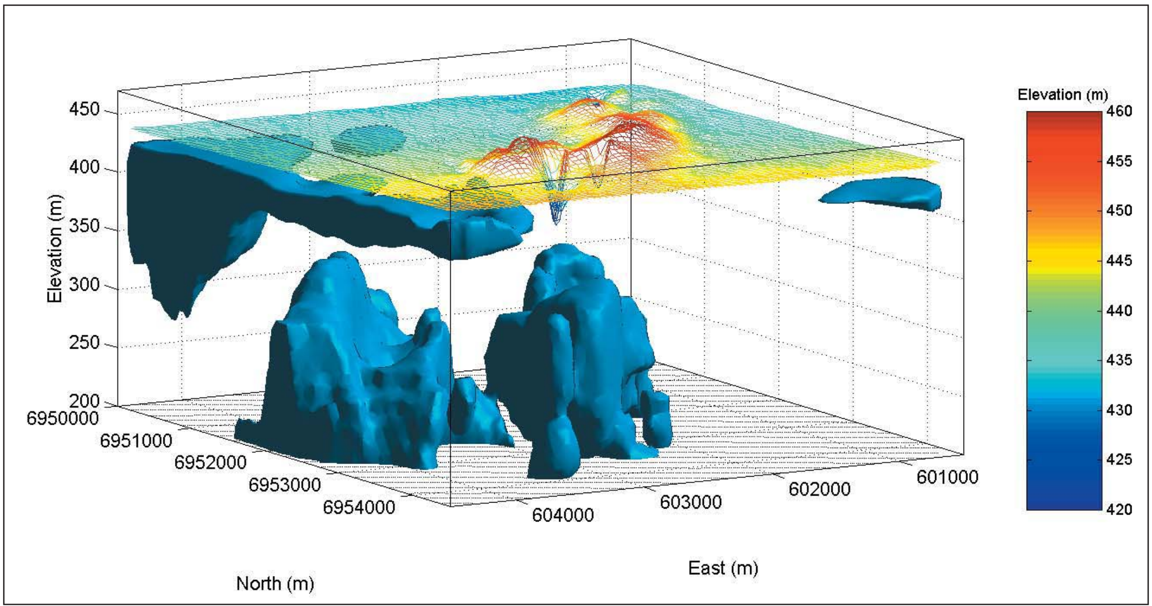

Fig 7. Perspective view (azimuth of 030 degrees, elevation 10 degrees) of the 60 mS/m conductivity isosurfaces for a subset of the data around the Comet group of workings. The mesh of surface topography is coloured by elevation above sea level. The position of the flight lines is shown projected as black lines along the base plane of the rectangular box. The isosurfaces have been given a uniform colour.

patterns. Extensive weathering and the presence of transported cover mask these important features from visual observation from the surface.

Attention during system development to critical elements for the conversion of measured response to conductivity and depth (bandwidth, calibration procedures, noise attenuation, deconvolution of system transfer function, primary field removal, geometry corrections) allow TEMPEST conductivity data to be presented in 3D form with an accuracy and resolution never seen before from an AEM system.

Acknowledgments

The TEMPEST Airborne EM System was developed by the members of the Airborne EM Systems Program within the CRC AMET. This paper is published with the permission of the CRC AMET, established and supported under the Australian Government's Cooperative Research Centres Program.

C_in_3D (Conductivity in 3 Dimensions) visualisation methods were developed through the CERBERUS Project, an R&D Start Project funded by the Industry Research and Development Board (Australian Department of Industry, Science and Tourism (DIST)) and WGC.

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Advances in Airborne Electromagnetics

Peter Wolfgram and Michael Hallett - Geoterrex-Dighem Pty Limited

Abstract

Advances in airborne electromagnetics (AEM) include not only advances in technology, but more importantly the benefits that these technological advances bring to the explorationist. New technology such as presented in the first part of this paper can be a powerful ally in the quest for mineral discoveries such as presented in the second part of this paper.

Technological Advances

New airborne electromagnetic (AEM) technology has been developed in-house within Geoterrex-Dighem as well as in cooperation with industry partners during this decade. The goal of the cooperative R&D was to increase penetration and improve the ability to resolve the electrical conductivity section. These improvements were achieved by strategic development in the areas of

- Airborne platform & transmitter power
- Transmitter frequency and pulse width
- B-field recording
- Innovative signal processing and
- DIGHEM resistivity mapping birds

Fig 1. The MEGATEM® system, mounted on the Dash 7 platform.

Airborne Platform & Transmitter Power

By 1995, Geoterrex-Dighem was increasingly receiving requests from clients to conduct GEOTEM® surveys in areas of the world at high altitudes and temperatures which either exceeded the safe operating capabilities of their GEOTEM® AEM system mounted on the twin-engine CASA 212 aircraft or severely restricted its operating efficiency. Recognising that a new, larger, more powerful survey platform was required to meet this new challenge, Geoterrex-Dighem chose the DeHavilland Dash 7 as the optimum survey platform. This latest version of the system, shown in Figure 1, is known as the MEGATEM® because its transmitter dipole moment is larger than 1 million Am^2. MEGATEM® has exceeded expectations and has already successfully flown over 30,000 line km of survey.

Lower Frequency and Wider Pulse

Large, very conductive targets (including those under cover), have long time constants and are best identified at late delay times. The base frequency determines how late a time window is available for observing the secondary field decay. Figure 2 shows how the "off time" has increased from 3 ms for the old 144 Hz INPUT system to over 30 ms for the latest incarnation of GEOTEM® - the 12.5 Hz, 8 ms system.

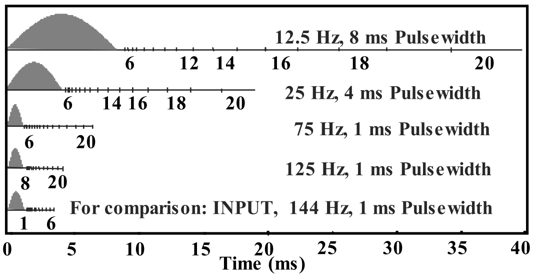

Fig 2. Configurations for 50Hz powerlines.

The eddy currents in a conductive target are best energised when the transmitter pulsewidth is comparable to the target time constant. Therefore, the development of the low-frequency systems went hand-in-hand with the increase in pulsewidth in order to enhance the response from long-time constant, high-conductance targets.

B-Field Recording

The *B field* has advantages over *dB/dt* in exploration regimes characterised by conductive cover, including an enhanced response from high conductance targets, relative attenuation of overburden response, and a decreased dynamic range. These are illustrated in Figure 3 which shows the GEOTEM® response along a test line across a conductive target under conductive overburden. The B field shows a larger signal to noise ratio over the target, and it responds to longer time constants than the corresponding dB/dt profile.

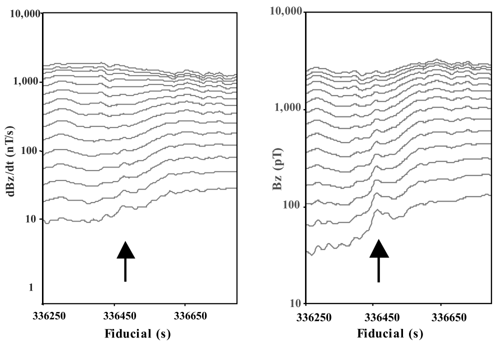

Fig 3. dB/dt (left) and B field (right) recording over a conductive target.

Innovative Signal Processing

In addition to the standard system calibrations performed ever since the first GEOTEM® was commissioned in 1986, Geoterrex-Dighem have steadily improved fidelity and accuracy of AEM survey data. This has resulted in signal to noise improvements by more than an order of magnitude over the last ten years. As an example of these developments, Figure 4 illustrates the correction for sensor rotation that is applied to raw GEOTEM® data. It avoids any adverse effects on the signal, that might be encountered from smoothing filters, as the rotation correction only rotates the three sensor components back into the nominal orientation.

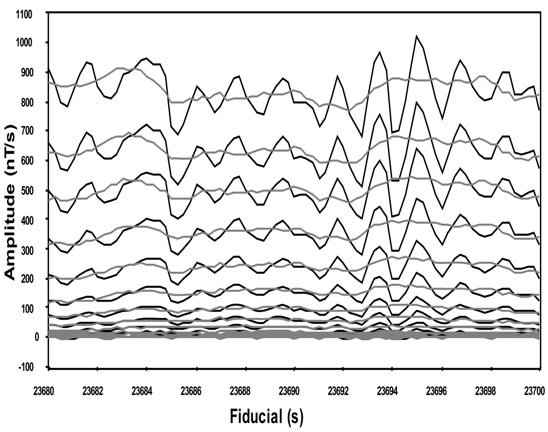

Fig 4. Example of sensor rotation correction of X component GEOTEM® data.

DIGHEM Resistivity Mapping Birds

The five frequency, coplanar bird shown in Figure 5 is uniquely focused on resistivity mapping, as the coplanar coils couple best to the layered earth resistivity. The five frequencies span a range of 380 Hz to 101 kHz, and all five coil pairs have a 7.9 m separation which we believe gives the highest data quality available.

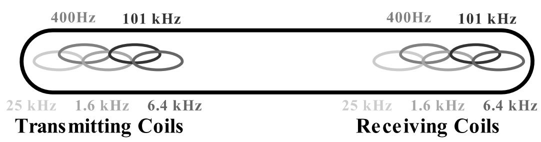

Fig 5. Coil configuration of the DIGHEM$^{V}_{RES}$ resistivity mapping bird.

Recognising the need for lower price EM surveys, Geoterrex-Dighem has designed the light-weight, all coplanar DIGHEM$_{COMPACT}$ bird shown in Figure 6. Four frequencies from 600 Hz to 75 kHz and a coil separation of 5.25 m allowed the reduction in size and weight while maintaining the high standards in quality of construction known from the larger birds.

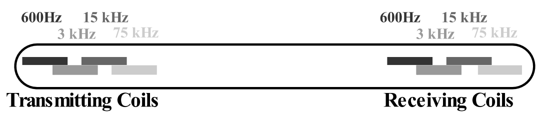

Fig 6. Coil configuration of the DIGHEM$_{COMPACT}$ mapping bird.

Mineral Discoveries

The Gindalbie Gold internet site provides a wealth of information on the Au-Cu-Ag Magnum deposit at Anketell, WA, and it states that *"The application of modern airborne electromagnetic surveying was directly responsible for the success at Magnum."* (www.gindalbie.com.au)

Figure 7 illustrates how the GEOTEM$_{DEEP}$® survey has detected the response from Mangum at late times and how the conductivity depth section aids in pinpointing the location.

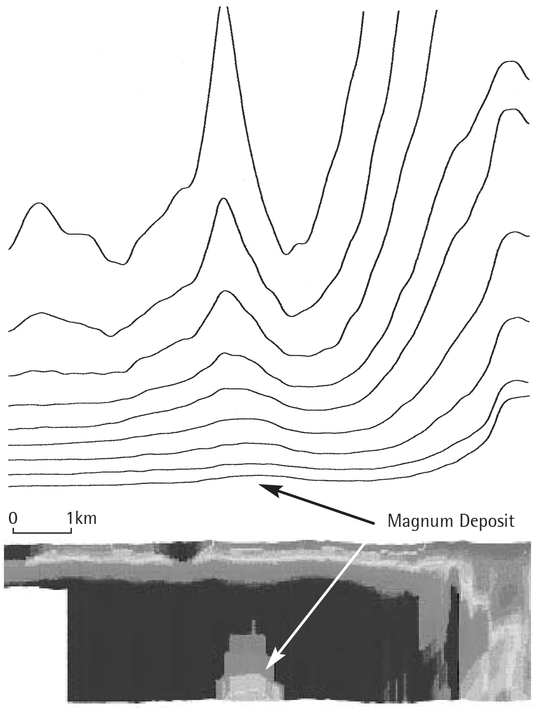

Fig 7. GEOTEM® profile with conductivity-depth section over the Magnum discovery.

The Storliden Cu-Zn deposit in northern Sweden has been acknowledged as a new GEOTEM$_{DEEP}$® discovery and the survey client has submitted a mine development application. The GEOTEM® anomaly on the discovery profile exhibits the typical shape of a moderately dipping plate-like conductor, and the interpreted dip and depth in Figure 8 illustrate how GEOTEM® has responded to the main ore body at depth as well as the (low-grade) stringer zone above it.

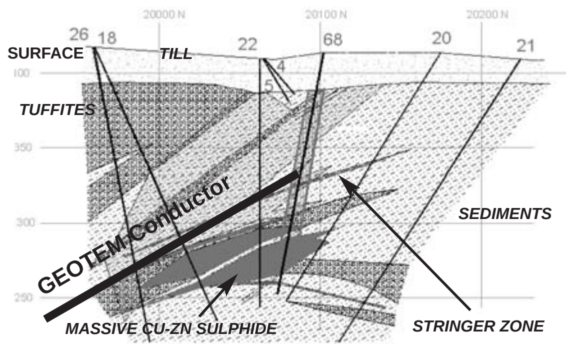

Fig 8. Storliden geological section. (Modified after Posey, 1999).

References and further reading

Geoterrex-Dighem Pty Limited is committed to continued education of professionals in order to help the company maximise the benefits from new AEM technology. More detail on the topics of this paper can be obtained from the sources shown below or by contacting us directly.

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Advances in AEM Software

Bruce Davies, James Macnae, Andy Green, Art Raiche, Don Hunter and Brian Spies
- Cooperative Research Centre for Australian Mineral Exploration Technologies

Key words:

Airborne Electromagnetics, interpretation and modelling AEM datasets

Abstracts

CRC AMET has developed three software suites that offer dramatic improvements in the processing and interpretation of Airborne Electromagnetic datasets. These programs complement the new acquisition systems which have recently become available. This paper describes the forward modelling programs, the rapid interpretation product (EM Flow) and some new image processing software.

Introduction

Software is the Cinderella of the airborne EM (AEM) world. While the 'Ugly Sisters' (new acquisition systems such as MEGATEM and TEMPEST) have hogged the limelight during the last year or so, few paid much attention to the hardworking girl at home who made their high life possible. However Cinderella has now slipped on the glass slipper and is beginning to attract the attention she has always deserved.

For many years it was recognised that the full potential of AEM data could only be attained through sophisticated computer processing. The problem, particularly in the Australian context, was how to find the needle in the huge and complex haystack of data, particularly if you had only a vague idea of what the needle looked like. Ten years ago data sets were cluttered with seemingly useless information. Efficient numerical methods for modelling complex 3D conductivity structures did not exist, and inversions took forever to run on the computers of the day.

In the early 1990s, the exploration industry, through AMIRA, identified AEM as an important new research priority. Fortunately this coincided with the availability of industry funds for exploration R&D and a new Commonwealth Government scheme to promote joint research between industry, government laboratories and the universities. The outcome was the creation of the Cooperative Research Centre for Australian Mineral Exploration Technologies (CRC AMET)* in 1992.

The new centre defined its mission as: Develop and deliver dramatically improved electromagnetic (especially airborne electromagnetic) methods for exploration in environments characterised by complex, conductive regolith. The CRC AMET's research objectives targeted both hardware and software, recognising that the advanced hardware systems being developed would make data processing and interpretation even more challenging by producing even larger and more complex data sets. Today, two of CRC AMET's research programs focus exclusively on modelling and interpretation software and a third, which is concerned with improving understanding of the effect of the regolith on AEM, also has a software component. The fourth research program focuses on hardware, and the development of the CRC AMET's TEMPEST AEM system, which has been commercialised by World Geoscience Corp Ltd, is described in Richard Lane's article on page 17.

CRC AMET has delivered three software suites that offer dramatic improvements compared to those available a decade ago, and which will ensure that full benefit is received from the new generation hardware systems which are now taking to the skies. This article covers the development, capabilities and potential impact on users of these three suites:

- the forward modelling programs Loki Air, Arjuna Air, Samair, Marco Air and Leroi Air
- the rapid interpretation product EM Flow (marketed by Encom Technology Pty Ltd) and
- the image processing software AEMIT

Forward modelling and inversion

The ability to model the AEM response of complex geology gives industry the tools to determine the likelihood of success of an AEM survey for a given target style before committing substantial funds to exploration.

Modelling is a vital tool to understand the nature of AEM data responses through both curve-fitting exercises and parametric studies. In addition to being the engine of full inversion methods, it is also a key tool in validating the results of approximate interpretation methods. Finally, it can also be a valuable tool in the design of new AEM systems.

Prior to the establishment of CRC AMET, the Mathematical Geophysics Group in CSIRO Exploration and Mining had developed a number of techniques that provided the starting point for the R&D required to produce software for modelling the time and frequency domain AEM response of structures at various levels of geological complexity. When CRC AMET was established the group, which formed the basis of the Centre's Mathematical Geophysics Program, continued this work with industry funding from AMIRA Project P223.

Many of the computer programs developed by the Centre have the capability to model topography, non-uniform regolith, multiple targets of arbitrary geometry, and complex conductivity or IP effects. The programs also incorporate system effects such as transmitter tilt, airframe currents, transmitter waveform and system geometry.

Figure 1 provides a partial summary of what the Centre has accomplished since its inception. Loki Air, a program due for release to AMIRA sponsors in October 1999, was developed to compute the AEM response of the 3D model

** CRC AMET is an unincorporated joint venture between CSIRO Exploration and Mining, Macquarie University, Curtin University of Technology, World Geoscience Corp Ltd, the Australian Geological Survey Organisation, the Geological Survey of WA, and the Australian Mineral Industries Research Association Ltd. It has research nodes in Sydney, Perth and Canberra, and offers geophysics education programs through both universities.*

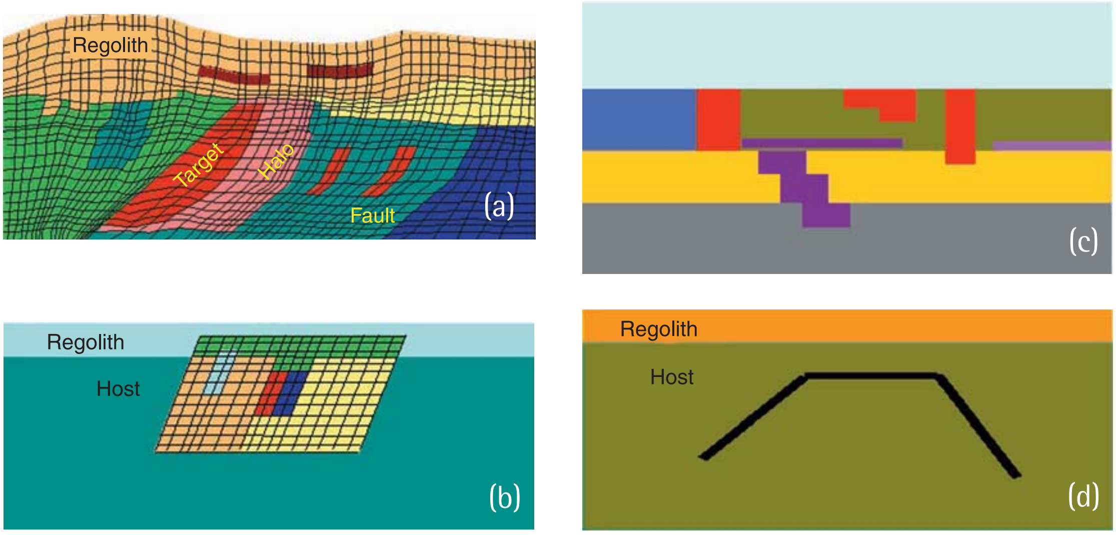


Fig 1. CRC AMET's Mathematical Modelling Program has progressed from modelling relatively simple structures (b - d) using programs such as Samair, Marco Air, Arjuna Air and Leroi Air, to structures with the full range of geological complexity modelled by Loki Air (a).

shown in Figure 1a which contains the full range of geological complexity. The program is based on the finite-element method, which, unlike finite difference methods, allows the user to drape the underlying mesh onto the rock unit boundaries rather than forcing the geological model to conform to a rectangular blocky mesh.

Loki Air allows the user to model conductivity contrasts of up to 1,000,000:1, more than a thousand times greater than those allowed by conventional 3D finite-element techniques. Although the edge-element approach of Loki Air represents a significant decrease in computation times as well as a major increase in accuracy over conventional 3D finite-element methods, computation times are still significant. In cases where full 3D geological model complexity is not required, it is possible to decrease computation times by one or two orders of magnitude through the use of simpler model classes developed by the Centre which allow trade-offs between model complexity and computation times.

Arjuna Air. When the geological cross-section does not change rapidly over strike lengths of 500 m or more, one can compute the response of a 2D cross section to a 3D airborne source using Arjuna Air. The program is particularly well-suited to airborne modelling because each airborne position means a separate source computation.

Samair, which was substantially developed before CRC AMET was established, addresses situations in which the host surrounding a heterogeneous region can be modelled as a two layered half-space (Figure 1b). Advances during the life of CRC AMET will be applied in the next year or two to make Samair ten times faster, as well as more accurate at higher contrast ranges (up to 10,000:1).

Marco Air computes the response of 3D prisms contained in a multi-layered host. Quite complex models can be constructed using combinations of prisms (Figure 1c). Marco Air is limited to situations where the conductivity contrast does not exceed 500:1.

Leroi Air. Figure 1d illustrates the Leroi Air class, which is designed to model structures composed of multiple, fully interacting thin sheets, encased in a uniform host overlain by a uniform overburden. This model can be used for very large conductivity contrasts.

Another product developed by the Centre is Airbeo, an AEM layered-earth inversion program for both frequency and time domain which is up to 20 times faster than conventional inversion techniques. Inverting to a two, three or four layer model can be useful in its own right or, alternatively, provide a very useful first look at AEM data before deciding on more complex interpretation techniques.

Programs are useful only if they are used. Speed and accuracy are important but programs such as Loki Air and Arjuna Air are very difficult to use without a GUI (graphical user interface) to set up the model and the system. Encom Technology worked with the Centre to develop Milsons, a GUI specifically designed for the 2D and 3D mesh programs. Using wizards, Milsons initially helps the user set up a simple mesh as illustrated in Figure 2. The user is then able to use the mouse based tools to develop the more complex structure illustrated in Figure 3. Milsons then supplies dialog boxes to set up system geometry, waveform and flight path as shown in Figure 4. The 3D option of Milsons, which will be released shortly, allows the user to rotate the 3D model to view it slice by slice, in chair mode, or as a wire frame where only those parts of the model with a specified range of properties are shown in colour.

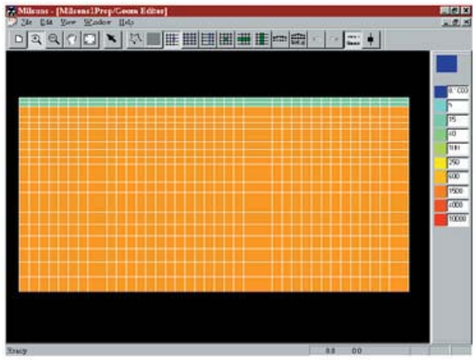
EM Vision, an EM modelling suite based on the Centre's research and marketed by Encom Technology, is presently limited to ground systems and does not as yet contain the 3D model functionality possessed by the programs described above. The Centre's next objective is the development of a unified graphical environment which can call, set up and run any of the airborne programs. The environment will allow model importation, survey design, and data importation and processing. The new environment would ideally contain artificial intelligence functionality to guide the user, and have the capacity to capture and combine the expertise of various expert users.

Rapid interpretation

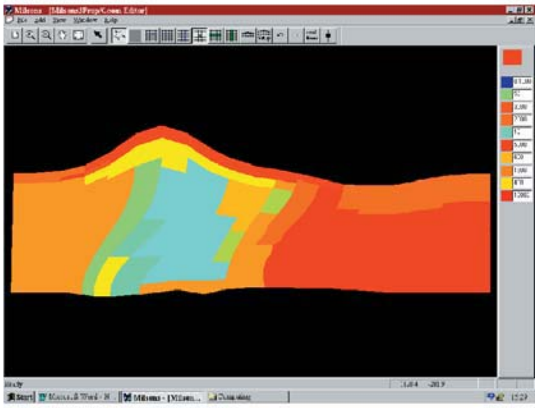
In the early 1990s AEM data was interpreted manually by a geophysicist who searched for desirable 'bumps' on data profiles. In areas such as Canada, where recent glaciation had left bedrock exposed or covered by a thin veneer of resistive glacial cover, anomalous bumps were often spaced kilometres apart, and interpretation was relatively straightforward. In Australia, with a bump every few hundred metres caused by regolith inhomogeneity, users found it extremely difficult to prioritise the bumps for follow-up exploration. With beauty in the eye of the beholder, it was rare for two interpreters to agree on which of the multiplicity of bumps were targets of interest for investigation.

Once a bump was selected, nomogram tools were used to predict dip, conductance and, occasionally, depth to target. Often, one particular time channel was contoured or imaged to make a map of amplitude variations, or data converted to an apparent resistivity using a uniform half-space assumption. This led to a multiplicity of maps without useful depth control on the information they contained.

One proprietary AEM system, SPECTREM, was using data in a far more quantitative manner: a process called conductivity-depth-imaging (CDI) had been developed to transform step-response data into a conductivity-depth section. This was achieved by stitching together vertical

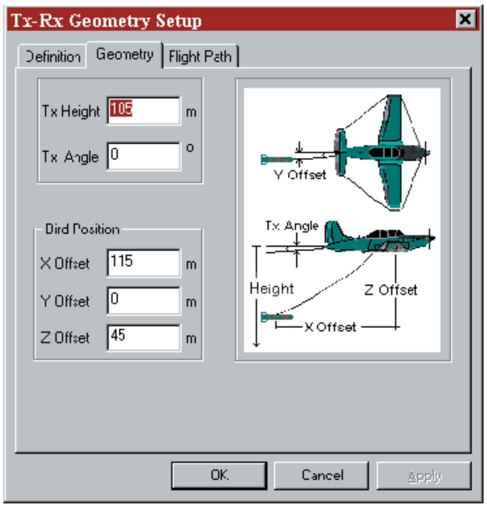


(a)



(b)

(c)



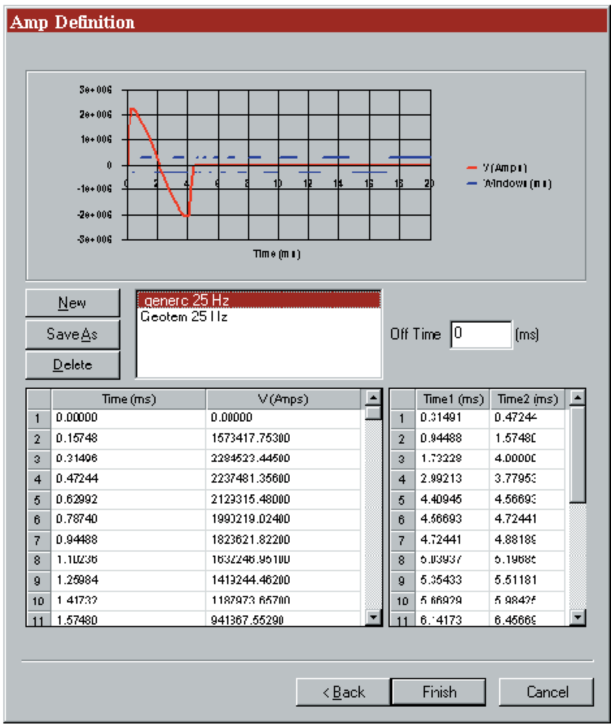


Fig 2. Graphical user interfaces (GUI) make AEM software much more user friendly. The Milsons interface was developed for CRC AMET's suite of modelling programs by Encom Technology Pty Ltd. The starting mesh (a) is manipulated using mouse-based tools to form the required geological structure (b). The GUI used to set up system geometry and waveform is shown in (c).

strips of conductivity derived under an assumption that the earth was quasi-layered. The process required calibrated step-response data to work. However, the commercial fixed-wing AEM systems available at the time, such as GEOTEM and QUESTEM, were largely uncalibrated systems, utilising a waveform nominally represented by a half-sine on-time current, followed by an off-time during which measurements were made. Such data could not be transformed to a CDI.

CRC AMET took up the challenge of developing CDI sections for commercial AEM systems, and of determining the electrical structure of the ground in detail even when uniform layering or isolated conductors

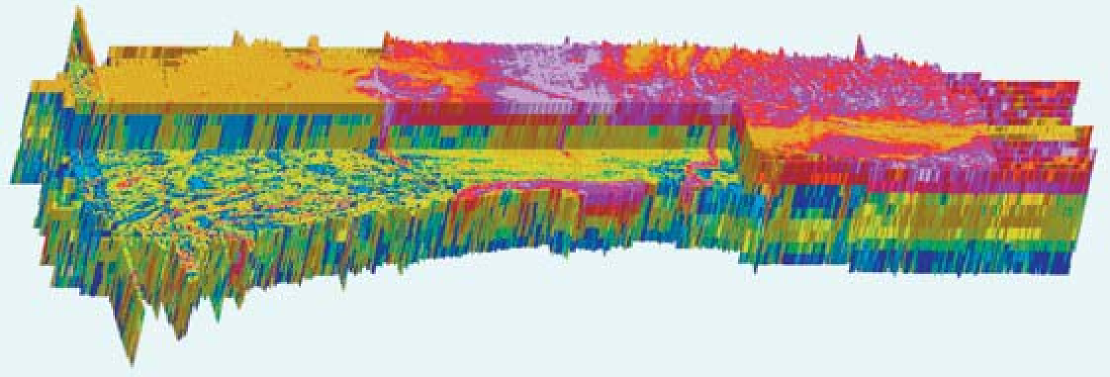


Fig 3. A 3-D image derived from 1996 QUESTEM AEM data from the Matchless greenstone belt in Namibia. The data was initially processed using EM Flow to produce a series of conductivity-depth images (CDI) which were reassembled in map form as a set of top-down slices of fitted conductivity. The final 3-D image was prepared using commercial graphics software. The red areas indicate extensive surface conductivity, and a paleochannel is evident towards the right hand end of the cut-out.

could not be assumed. The Centre's aim was to provide automatic and interactive tools that would allow geophysicists to transform EM data into accurate physical property maps and sections and facilitate incorporation of geological constraints in the process. Over $1 million was raised from AMIRA sponsors under Project P407, which began in July 1993. The outcome is EM Flow which was released commercially by Encom Technology in late 1998.

Features of the EM Flow software include:

- processing of data gathered by any digital system, including modern multi-component systems in either frequency or time domain. The software can also be used to reprocess old data sets to glean new information
- automatic processing of large data sets once parameters have been set using a representative section of the data
- rapid processing of preliminary data in the field, making EM Flow ideal for quality control by AEM contractors and clients and
- automatic picking of anomalous responses that might indicate the presence of ore bodies. This is accomplished by comparing the data against a mathematical model, specified by the operator, which simulates the geological features of the type of ore body being sought

Once an anomaly is selected, the data inversion facility in EM Flow can be used to extract more information about the potential target, such as its depth, size, shape, and conductivity, with the objective of establishing its priority for ground survey and drilling programs. EM Flow links to popular computer visualisation tools to produce three-dimensional images of the earth. The 3D image in Figure 3 was prepared from data processed by EM Flow using a commercial graphics program.

EM Flow is now providing fascinating and readily interpretable 3D pictures of ground conductivity structure, and has made it practical to process the 4 to 6 gigabytes of data per day gathered by a modern AEM system such as TEMPEST.

Since its commercial release, EM Flow has generated a high level of interest in the environmental, diamond exploration and mineral exploration sectors. The US Geological Survey has purchased a licence and requests for information or sample CD's have come from North America, South America, Europe, Africa, Asia and Australia. Feedback from users has been positive, although the extensive options to optimise and tailor the processing to specific targets may tend to overwhelm the novice user. As the ability to tailor the program is one of the strengths of the software, the Centre and Encom Technology plan to upgrade documentation and support, and make improvements to the user interface.

Future development will include data-adaptive processing and better imaging of localised structures. Another challenge is to further develop the program to take full advantage of 3-component data.

Image processing

AEMIT (Airborne Electromagnetic Imaging and Transformation) is a research tool developed in the Centre as part of AMIRA project P476. The project had two complementary themes - image processing and data interpretation. The AEMIT software was designed as a front-end to the suite of algorithms developed as part of the image processing component. In this respect, AEMIT is a vehicle for technology transfer.

The package provides a rapid way to image AEM data while retaining the original located, flight-line format. All processing is done on the profile data and the resulting products are gridded and imaged as needed. This enables a direct interaction between the image and original data by clicking in the image for information from the profiles.

The package has the following components:

- Data import for DIGHEM, SALTMAP, GEOTEM and QUESTEM
- Conversion of the above to step-response via exponential decomposition
- Data scaling via power law and other simple algebraic procedures

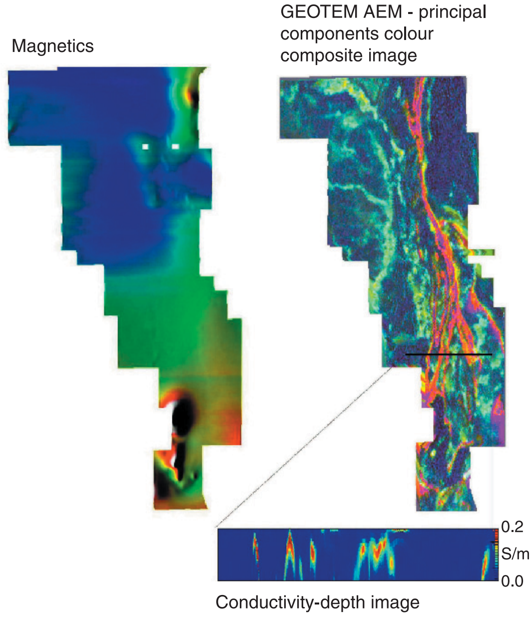


Fig 4. Magnetics (left) and principal components of GEOTEM airborne EM data (right) from the Lady Loretta area, Queensland, processed using AEMIT. While the area is magnetically quiet, the AEM image shows a wealth of information. A conductivity depth image (CDI) is also shown.

- Geophysical transforms, apparent dipole depths, apparent conductivity, conductivity depth images, and time constants
- Dynamic corrections for system geometry variations (altitude, bird position, etc)
- Selected multivariate transformations, principal components, MNF transform etc
- 1D histograms, 2D and 3D scatter diagrams in dataspace
- Image gridding and display and
- Export facilities to ArcView, ER Mapper and ENVI

AEMIT is not a 'stand alone' program, but requires the Interactive Data Language (IDL). It can run on both UNIX and Windows (95, 98, and NT) platforms. Currently AEMIT is available only to CRC AMET participants and sponsors of P476, but the Centre is considering making the source code publicly available when the AMIRA embargo expires. CRC AMET plans to continue to use the software as a development platform for research projects because it enables rapid delivery of research results to sponsors.

CRC AMET has plans to further develop AEMIT and, in particular, it will be modified to allow for export to MAPINFO, and the system definition file (the file that contains the AEM system specific information) will be made compatible with the file used in EM Flow.

The future

The Centre was formed in 1992 to develop and deliver advanced AEM hardware and interpretation tools to the Australian industry. Having achieved this goal, the Centre will close on 30 June 2000. Its legacy will be a new generation of hardware and software products, an improved understanding of the electrical properties of the Australian regolith, and a new generation of geoscientists skilled in the application of AEM for mineral exploration, geological mapping and environmental assessment.

Seismic Reprocessing

Mick Micenko, Consulting Geophysicist (micenko@bigpond.com)

Two commonly asked questions are:

Can this seismic section improve with reprocessing?

How often should I reprocess seismic data?

In many areas, seismic data will always improve with reprocessing as computer technology and processing algorithms improve. As a rule of thumb I would suggest that seismic data benefits from reprocessing every three years but there has to be a need for the improved section. This example from the onshore Taranaki Basin in New Zealand shows part of a seismic line across a large thrust fault (on the right). Both figures have a time range 0.8-2.7 sec and are about 2 km across. The Tikorangi Limestone reflection is at about 1.6 sec. The Kapuni group reflectors can be seen near the base of the section but it is difficult to see how the Kapuni sediments have been faulted on the original processing.

Drilling results suggested the overthrust beds are dipping much more steeply than the original section indicates - in fact the beds have dips which are greater than the original finite difference migration algorithm could handle. After reprocessing with a 'steep dip Kirchhoff' migration algorithm we see the steep dips that were not originally apparent. The reprocessing has also improved the continuity of the overthrust reflectors allowing a more reliable map to made of this gas field.

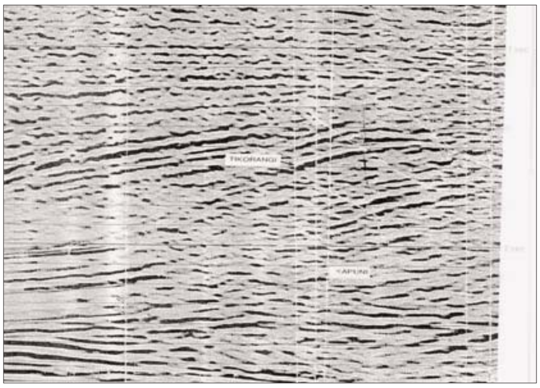


Fig 1. Original processing

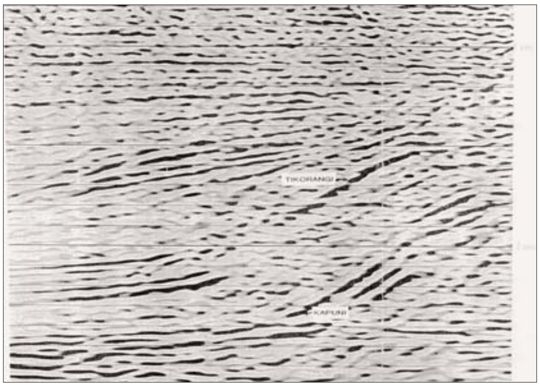


Fig 2. Reprocessed version

The Importance of Geophysics to the Geological Survey of New South Wales

Geophysical data and interpretation is an integral part of all programs of the Geological Survey of New South Wales (the Survey). These programs cover:

- *Regional Geology and Geophysics*
- *Coal and Petroleum Resource Geology*
- *Discovery 2000 Exploration Initiative*
- *Minerals Assessment*

Regional Geology and Geophysics

Geophysical data and resources are used to improve the current understanding of the regional geology in New South Wales. With the need to 'do more with less', the Survey periodically reviews the process of geological/ geophysical mapping. During the past decade significant strides have been made to improve this process.

In the early 1990's, Second Edition geological mapping of the State ushered in a new era. This started with the Bathurst 1:250,000 sheet area and for the first time, a high-resolution geophysical dataset was available for use the Dubbo, Forbes, Goulburn and Cootamundra 1:250,000 Sheet areas (Figure 2). Approximately 253, 000 line-km of airborne geophysical data and 2 000 gravity stations have been acquired through this program.

Since 1989 all airborne geophysical data collected over Exploration Licence areas have to be lodged, in digital format, with the Survey. Over 750 digital surveys are now archived and these can be accessed through the Survey's AEROFIND index using ArcView/MapInfo software.

In areas of significant exploration interest the Survey is compiling 1:250,000 map sheet areas with 'best-available'

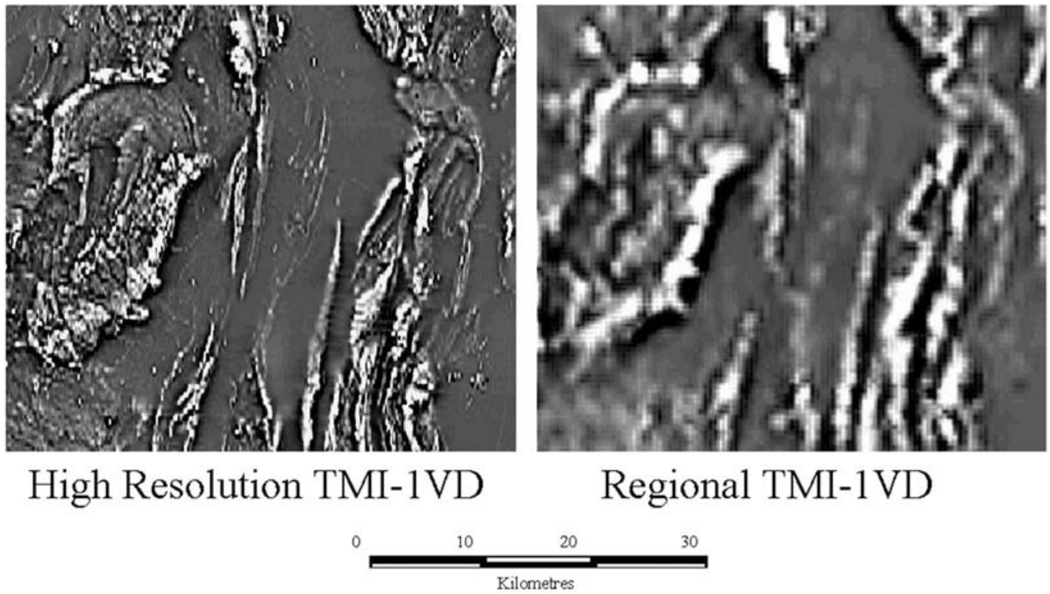


Fig 1. Comparison of the 'High Resolution' and 'Regional' TMI data.

in a regional mapping project. Previously, geophysical data were not used for mapping because the data were too coarse to map individual geological units. Figure 1 shows a comparison of the extra detail obtained by comparing the high-resolution total magnetic intensity (TMI) data with the regional 1.6 km TMI data.

The Survey and the Australian Geological Survey Organisation (AGSO), through the National Geoscience Mapping Accord (NGMA), have promoted acquisition of high-resolution geophysical data. Since the Bathurst survey was completed, the NGMA program has acquired data over

aeromagnetic data coverage. In many cases the 'open-file' surveys were micro-levelled before being merged using Engineering Computer Services' GPJOIN program based on the Lauf transform. An ER Mapper grid and image is available for the Dubbo, Forbes, Cobar, Nymagee, Wagga Wagga, Manilla, Coffs Harbour and Canberra Sheet areas.

Discovery 2000 Exploration Initiative

The main thrust of the Discovery 2000 program is to promote the development of the mineral and petroleum resources of the State by 'fast tracking' many core activities

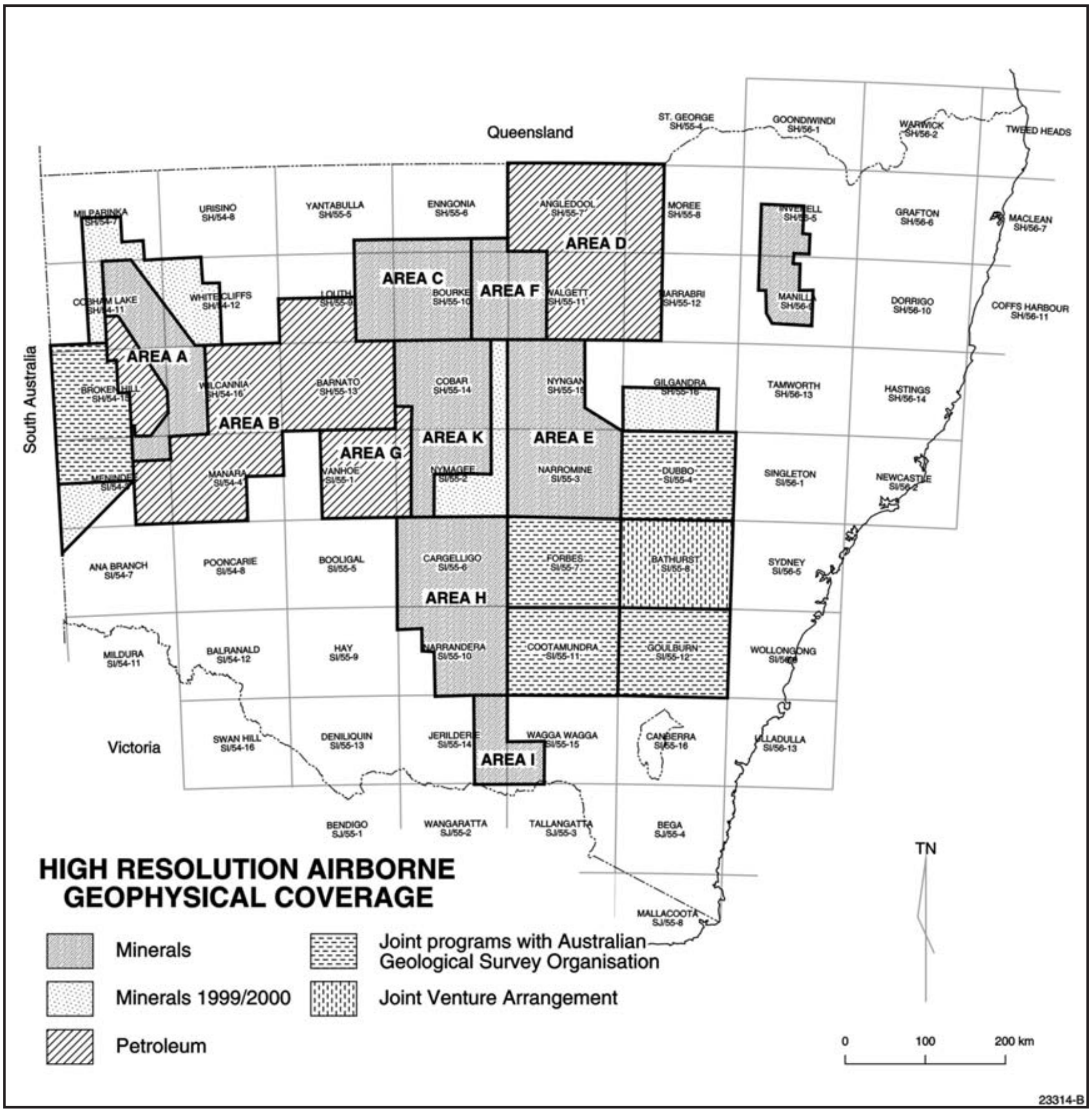


Fig 2. Outline of Airborne Geophysical Surveys in New South Wales

of the Survey. The focus of the program is to acquire and collate data over areas of shallow cover that were along strike of known mineralisation. Typically these areas have been poorly explored and a major part of this program was to acquire high-resolution aeromagnetic/radiometric and gravity data. Approximately 935,000 line-km of airborne data has now been acquired (Figure 2). In predominantly 'mineral' areas data were collected at an interline spacing of 250 m and a survey altitude of 60 m. Over predominantly 'petroleum' areas the interline spacing was increased to 400 m with a survey altitude of 80 m. Many of the airborne survey areas were covered with a total of 15,000 gravity stations. These were read on a regular 4 km grid, and although this station spacing resolved the outline and structure of sedimentary basins, it was too coarse to resolve lithologies in 'mineral' prospective areas. For the joint Survey/industry/AGSO sponsored Cobar Collaborative Gravity Survey, most of the 5,400 'new' stations were collected on a 2 x 1 km grid with significant infill to a regular 1 km grid.

As part of Discovery 2000, the Broken Hill Exploration Initiative (BHEI) has acquired an additional 142,000 line-km of aeromagnetic/radiometric data both north and south of Broken Hill (Figure 2). Approximately 1,800 gravity stations have also been acquired on a variable 1 and 2 km grid. These data have been merged and released with a review of over 12,000 open-file gravity stations. A review of 1,000 petrophysical samples has supported evidence for increased metamorphism and age emplacement of rock suites in the Broken Hill area.

In 1998, the Discovery 2000 Petroleum acquired 275 km of high-resolution seismic data. Eight traverses were completed with three Vibroseis® units vibrating for periods of between two and five seconds through a frequency range of 12-100 Hz. Results over part of the Eromanga Basin show a well defined trough with sediments onlapping to the south, and an overthrust to the north. Over the Murray Basin, results have identified faulted margins and sediments deepening to the south. Several deep stratigraphic drill holes are planned on the seismic traverses.

In collaboration with AGSO, AGCRC and more recently ANSIR, seismic traverses have been completed over mineral prospective areas of Broken Hill and over part of the Lachlan Fold Belt. Results support the preparation of more realistic and deeper geological cross sections and have implications for the 3D assembly and geometry of rock packets and fractures.

Additional airborne geophysical surveys are currently being acquired both northeast and south of Broken Hill and over the southern part of the Gilgandra Sheet area (Figure 2). Approximately 100,000 line-km of data are being collected with data releases planned for early 2000. For the first time, horizontal gradient magnetic data will be collected with the TMI magnetic data.

Fig 3. Dave Robson looking to the future.

Coal and Petroleum Resource Geology

One of the main roles of this group is to provide advice, information and identify opportunities for investment on coal and petroleum resources. An important part of this role is to evaluate 'new' coal reserves. Geophysical data have been used to define structure and identify volcanic intrusions and sills. Both fixed-wing and helicopter aeromagnetic and radiometric surveys have been completed over the Scone, Narrabri, Caroona (west of Quirindi), Maules Creek (northeast of Boggabri), Ulan and Rylstone areas. The Survey and the Japanese New Energy and Industrial Technology Development Organisation (NEDO) are researching advanced exploration technologies with particular emphasis on geophysical techniques. This research covers part of the Caroona area that lies within the Southern Gunnedah Basin. To obtain the high-resolution seismic data required for coal exploration, the survey used an innovative electromagnetic seismic source. This involved acquiring data using an electromagnetic vibrator that covered a frequency sweep range of 45-240 Hz that was received with highly-sensitive geophones (1.8 V/cm/s at 150 Hz). These data were integrated with detailed gravity, magnetic and transient electromagnetic data. The resultant interpretation showed the importance of using a range of geophysical techniques to help resolve the uncertainty of complex geological structure. This in-turn provides a higher level of confidence for effective mine planning and investment.

Minerals Assessment

To enhance the metallogenic mapping of the State, airborne magnetic and radioelement data and gravity data are routinely used for both local and district interpretations. To maximise access to land by promoting fully informed and balanced land use decisions, integration of geophysical data has assisted in delineating areas of high mineral potential in the Comprehensive Regional Assessments (CRA) of forest areas. There is an increasing need to provide and work with other State agencies in mapping the soil types and identifying areas of salinity. Statewide digital images of the magnetic and gravity data are included in the recently released NSW State Geoscience GIS Package.

Geological and Geophysical Mapping

The process of geological mapping is constantly evolving. Today, no mapping is undertaken by the Survey until high-resolution geophysical data have been acquired. Prior to field mapping and in a workshop environment, a preliminary interpretation of all available data is completed with both geologists and geophysicists. The next stage is to prepare a GIS Geoscience Data Package that includes the preliminary interpretation, known geology, geophysical images with historical titles, exploration drilling, mineral occurrences, petrological data, stream sediment data and cadastral information. Once the field mapping is programmed, field mapping teams, which include a geophysicist, go to the field with geophysical, geological and satellite digital imagery on notebook computers. Geologists and geophysicists jointly assist with day-to-day mapping by interrogating the digital data over specific areas. To facilitate field data acquisition, Window CE based palmtops are being trialed for the capture of outcrop data. To complete the process, cartographers periodically digitally scan geological line work that is then reviewed with geophysical and satellite imagery.

Future

For several decades, the Department, along with other government organisations throughout Australia has experienced regular funding cuts. Policies involving an annual four to five per cent staff reduction have serious implications over a five to ten year period. To 'do-more-with-less' the geophysics group periodically reassess their access to 'industry standard' computer hardware and software resources. In government, this is becoming an increasingly difficult situation.

With the Discovery 2000 program concluding in June 2000, the Department of Mineral Resources is preparing a submission to Government for another Exploration Initiative. If successful, this will further improve the framework for minerals and petroleum exploration in New South Wales.

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Chief Geophysicist
Email: robsond@minerals.nsw.gov.au
See also the website: www.minerals.nsw.gov.au

The Role of Geophysics in the Northern Territory's Exploration Initiative

In recent weeks, the Northern Territory's Minister for Resource Development announced the public release of a variety of geoscientific data as part of the NT Government's Exploration Initiative. The Exploration Initiative will see the injection of $16 million of additional Government funding over the next four years as a measure to stimulate resource exploration. These funds will enable the Department of Mines and Energy, through the Northern Territory Geological Survey, to collect, interpret, synthesise and disseminate modern geoscientific data for use by mineral and on-shore petroleum explorers well into the next century. This acknowledges the importance that mining makes to the NT economy, whilst recognising the steady decline in mineral exploration expenditure in under-explored terrains that are still regarded as highly prospective.

The aim of the Exploration Initiative is clear: to attract significant additional exploration investment into the NT that will bring its exploration expenditure proportion (currently estimated at around seven per cent of the nation's total) into line with its landmass (18 per cent of Australia's total area).

The Geophysics Section of NTGS is poised to play a major role in the Initiative.

NTGS's Geophysicists – Who Are We?

NTGS possesses a highly motivated and well-balanced team of four geophysicists. They are:

Richard Brescianini

Richard recently joined NTGS in Darwin after 12 years as an exploration geophysicist with BHP Minerals Discovery, based in various locations throughout Australia and North America. In his role as Chief Geophysicist with NTGS, Richard's responsibilities include co-ordinating all geophysical activities within the framework of the NT Exploration Initiative.

Roger Clifton

Roger has been with NTGS for seven years, based for the last four in Darwin. In 1990, he received a MSc for his work on processing methods for multichannel radiometric data with application to atmospheric radon. His current responsibilities include providing geophysical input to NTGS's Georgina Basin Project, and maintaining a watching brief on the development of new technologies of interest to the overall objectives of the NT Exploration Initiative.

Andrew Johnstone

Andrew also is a recent appointee to NTGS in Darwin after five years with BHP Minerals Discovery. During that time he was involved in precious and base metal exploration programs in both Australia and Africa, where his skills in regional geologic interpretation were put to effective use. He is currently involved in the joint production of an NT magnetic stitch (with Kerry Slater), and is a member of the Tennant Inlier Regional Geoscience Project team.

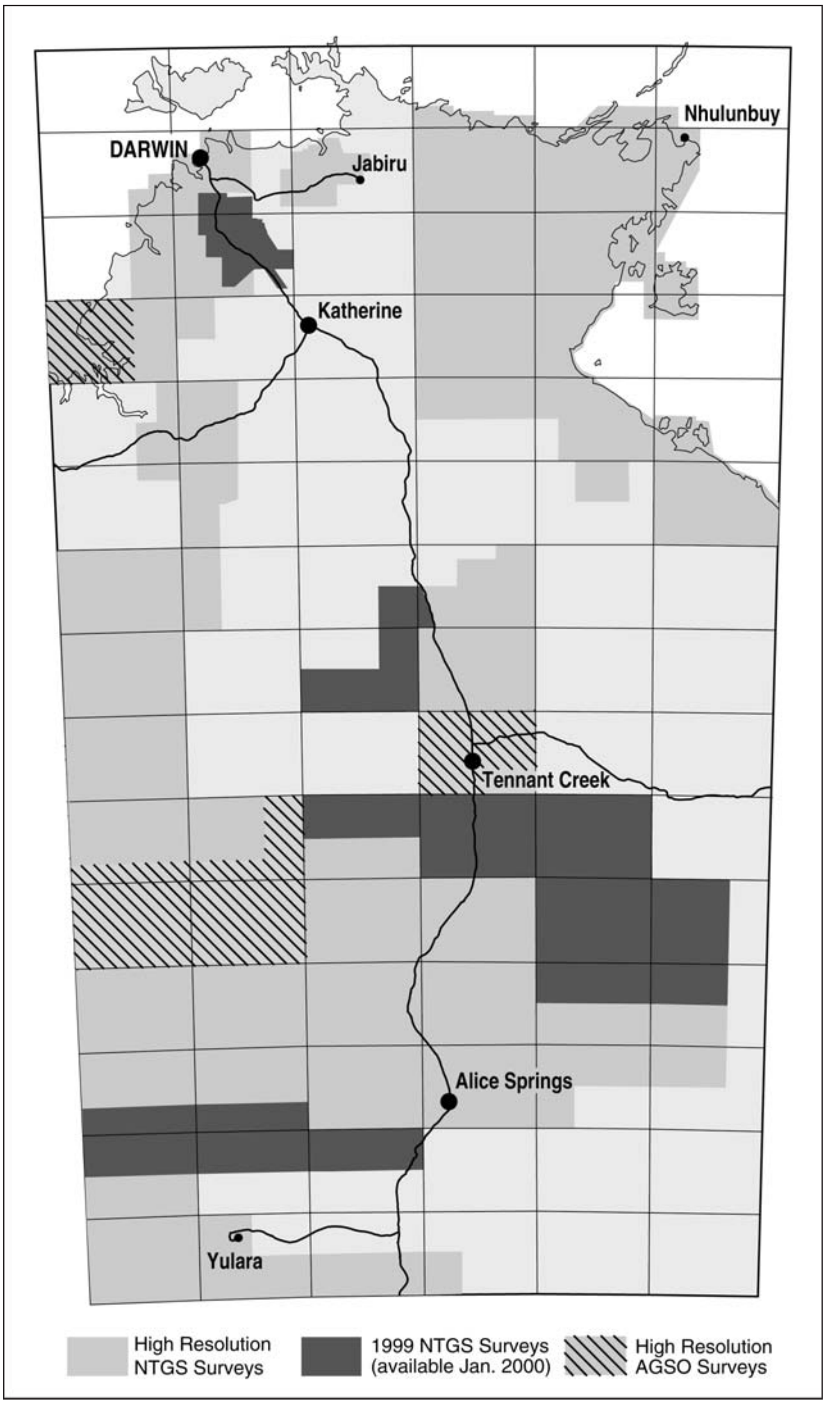

Fig 1. High-Resolution Government Magnetic and Radiometric Coverage of the Northern Territory.

Kerry Slater

Kerry has been based in the Alice Springs office since mid 1998. Kerry has had prior involvement with a state government exploration initiative through her employment with Geological Survey of Victoria (1995-8). Her expertise lies in the geologic interpretation of potential field geophysical data. She is responsible for geophysical input to the Tanami, Arunta North and Musgrave Regional Geoscience Project teams.

NTGS's Geophysical Programs

Since 1981, NTGS has been acquiring semi-detailed airborne magnetic and radiometric data on a prospectivity priority basis over mineral fields and basement terrains. Up until 1999, approximately 39 per cent of the NT had been flown (Figure 1) at line spacings of between 150 and 500 m. Where possible, open file company data were incorporated into the planned survey. In recent years, AGSO has increased the overall coverage to around 45 per cent.

Airborne geophysical surveys are the cornerstone of the Initiative. During the 1999 field season, the high-resolution magnetic and radiometric coverage of the NT is being increased to 55 per cent through the completion of five additional surveys. These surveys are designed to cover parts of the western Amadeus and southern Georgina Basins, concealed portions of the Tennant Creek and Davenport Provinces, and the Rum Jungle Block. Public release of the processed digital data is anticipated in early 2000. NTGS has taken the unprecedented step of providing these data free of charge in order to provide greater accessibility to explorers, both large and small.

Over the next four years, NTGS will progressively replace the old continental-scale BMR magnetic coverage with modern surveys. Choice of areas will be driven both by internal priorities, such as the focus of NTGS's Regional Geoscience Programs, and by industry requests. In addition, several exploration companies are being approached to submit extensive, non-strategic airborne surveys for immediate public release on a partial cost recovery arrangement. The intention here is to free up funds for use in other activities related to the Exploration Initiative, which would otherwise be earmarked for airborne surveys.

The strong historical and ongoing emphasis on flying high-resolution airborne surveys, coupled with the above-mentioned zero-pricing policy, is enabling NTGS to develop the most extensive coverage of uniformly high-quality magnetic data available in Australia.

NTGS has also commenced a program of semi-regional gravity surveys in selected areas to assist in the resolution of critical geological relationships in mineral fields. The first of these programs, in a joint effort with AGSO, covers the entire Tanami Goldfield on a 4 km grid. These data will help address the distribution of felsic intrusives and mafic rocks within this poorly exposed terrain, as well as elucidate the enigmatic boundary between The Granites-Tanami Block and the northern Arunta Province.

Through NTGS's Regional Geoscience and Mineral Resource Programs, new and existing data are being used in integrated multi-disciplinary geoscientific studies of under-explored geological regions of the NT, so as to enhance the perceived mineral and petroleum prospectivity of these regions. This will result in the production of digital bedrock geology and corresponding resource prospectivity maps. A current example focuses on the poorly exposed basement terrain that links The Granites-Tanami and Tennant Creek Blocks. If geological continuity can be established, primarily through the use of airborne geophysics, a potential new world-class goldfield may emerge.

It is an exciting time to be at NTGS, with the acquisition, interpretation and public release of high-quality geophysical information leading the charge to attract the attention of the exploration industry. I invite readers to visit NTGS's recently launched website at www.dme.nt.gov.au/ntgs to further whet their appetite.

Richard Brescianini
Chief Geophysicist NTGS
richard.brescianini@dme.nt.gov.au

The Geological Survey of Victoria (GSV)

in co-operation with the
Australian Society of Exploration Geophysicists

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Are You Using the Geocentric Datum of Australia?

The adoption of the Geocentric Datum of Australia (GDA) as a co-ordinate reference system for spatial data and map products is growing rapidly. The change is from the existing Australian Geodetic Datum (AGD), with its 1966 and 1984 variants, that were Australian-centred to the Earth-centred GDA with its origin at the Earth's centre of mass. Its adoption will lead to a homogenous national co-ordinate datum across Australia, and will ensure that co-ordinates are directly compatible with Global Positioning System (GPS) co-ordinate outputs, and with international mapping and charting standards. The Intergovernmental Committee on Surveying and Mapping (ICSM) resolved to adopt GDA at its November 1994 meeting, recommending that nation-wide implementation be achieved during 2000.

AUSLIG has already adopted GDA and is leading the Australia wide push for adoption of GDA through ICSM. All new topographic maps and geo-coded data products released by AUSLIG since 1996 have been based on GDA.

AGSO started the transition to GDA in February 1998 by migrating its National Geoscience Databases to GDA. Project data and field surveys were progressively moved to GDA such that AGSO is now GDA compliant. Any new datasets and maps are based on GDA. AGSO will convert old AGD datasets to GDA for clients, if requested, for a nominal cost.

Much of the current national mapping in Australia uses the Australian Geodetic Datums 1966 (AGD66) or 1984 (AGD84). The move to GDA from these datums involves a northeasterly horizontal shift of ground co-ordinates by approximately 200 m. This shift applies to both latitude and longitude geographic co-ordinates, or northing and easting grid co-ordinates. The new datum will better support modern survey and positioning technologies and will provide a more accurate mapping framework suitable for most practical purposes. Map users in Australia are becoming increasingly dependent on satellite-based positioning such as GPS. The use of GDA enables them to determine positions directly from maps, without the need for a series of co-ordinate transformations.

Being aware of Australia's adoption of GDA is important for businesses that produce maps or spatial data, describe locality in terms of co-ordinates and grids or use legislation which refers to co-ordinates and grids.

New maps released by AGSO now include a prominent message to the effect that the datum is GDA. The GDA logo and notes appear on MGA-based map products. For example, on 1:250 000 and larger scale maps the logo and declaration is displayed above the grid reference diagram. The co-ordinate shift for the centre of the map to AGD66 is given, and when appropriate, every tenth grid line, or grid tic mark, are shown in AGD66 in addition to the grid lines shown in GDA.

GDA

Horizontal co-ordinates on this map are based on the new Earth-centred GEOCENTRIC DATUM OF AUSTRALIA (GDA).

To convert GDA to AGD (around 10 m accuracy):

Geographicals (from GDA94 to AGD66/84) -add 5.58" to latitude (S) and subtract 4.38" from longitude (E).

UTM grid co-ordinates (from MGA94 to MG66/84) -subtract 184 m from Northing and subtract 113 m from Easting.

The following logo and notes appear on relevant map products where the scale or accuracy makes the datum shift insignificant.

GDA

Horizontal co-ordinates on this map are compatible with the Geocentric Datum of Australia.

The logo, released by ICSM, represents the curvature of the Earth's surface. The diagonal lines symbolise the old and the revised measurements of the centre of the globe. Combined, the image has attributes of a satellite dish and of a bow and arrow, both symbols of precision. The logo is intended to carry a feel of the space age, of looking upward and into the future.

All Australian State and Territory Geological Surveys are moving to GDA but have not completed their implementation strategy, and may not all meet the January 1st 2000 deadline.

The State Geological Survey organisations, as custodians of mining tenements and leases, have to decide how to manage and transform the co-ordinate descriptions of existing mining tenemnets, new tenements applied for and any transitional procedures from the old to the new. It is recommended that the reader contact the local Geological Survey office to obtain specific information for your state.

In respect of mining lease boundaries, the choice for State Geological Surveys are:

(1) move the lease boundaries 200 m, i.e. leave the coordinate values for the boundaries the same

(2) change the coordinate values for the lease boundaries 200 m so that the leases stay in the same position on the ground, or

(3) expand the size of the leases 200 m to the southwest, leaving the north and east lease boundaries in the same position, which is satisfactory if there is not another lease to the southwest

Users should be aware of these procedural issues when dealing with lease boundaries from State territory information systems.

Comment and requests for further technical information on AGSO's adoption of GDA should be directed to Geoff Lawford at AGSO (telephone +61 2 6249 9496 or email Geoff.Lawford@agso.gov.au).

Continued On Page 37

Paleoclimatology: Reconstructing Climates of the Quaternary

By Raymond S. Bradley, Volume 68 of the International Geophysics Series, Academic Press, A$130, ISBN 012124010X

The author claims in his Preface to provide a contemporary overview of the field of Quaternary paleoclimatology, while noting that some topics are not adequately reviewed. However, this is a remarkably detailed book that, in 511 pages, covers pretty much the whole gamut of evidence for, and climate changes in, the Quaternary. It details the phenomena that provide proxy data for past climates, which in turn provide the basis for testing hypotheses about the causes of climatic change. As the author points out, once this is understood, we will be able to forecast future climate variations, and point to possible results of human interference in the Earth's climatic systems.

Chapter 1, Paleoclimatic Reconstruction, is an excellent overview of proxy data sources for Quaternary climates. The author identifies 26 sources of proxy data, ranging from ice cores and marine and terrestrial sediments to biological and historical sources. The importance of dating is stressed, and there is discussion of the resolution of various data sources - some give a broad view of tendencies, while others give detailed, even daily, records of change.

Chapter 2 is about Climate and Climatic Variation. It covers the concept of climate as the statistical expression of daily weather, the present climatic system, and the nature and timing of climatic variation.

There are then two chapters on dating, a central part of reconstructing climatic change. In his discussions the author covers the methods, their uses and problems associated with their interpretation. Chapter 3 deals with radioisotopic methods, spending more space on radiocarbon dating that any of the others. This is reasonable in view of the central place that radiocarbon dating tends to have in studies of the late Quaternary. Potassium/Argon, Uranium series and thermoluminescence are also covered. Chapter 4 is about paleomagnetism, as well as chemical and biological methods.

There is then a series of seven chapters on various kinds of proxy data. Chapter 5, on Ice Cores, covers stable isotope analysis, ice core dating and paleoclimatic reconstructions from ice core data. These cores provide a great deal of high resolution data, especially the δO^{18} analyses. Chapter 6 (Marine Sediments and Corals) not only looks at the evidence for past climates contained in marine cores and corals, but also considers past ocean conditions in the context of the present oceans. The author points out that between six and 11 billion tonnes of sediment are added to the oceans each year, and that these sediments are an archive of data about the oceans themselves as well as adjacent land masses.

Chapter 7 deals with Non-marine Geological Evidence, considering loess and paleosols, periglacial features, snowlines and glacial features, and lakes, among others. Chapters 9 and 10 then discuss Pollen Analysis and Dendrochrolnology respectively. Chapter 9 is especially detailed on the sources, preparation and analysis of pollens. In Chapter 10 the impressive resolution of tree-ring data is highlighted.

Chapter 11 is about Documentary data, derived from historical records of various kinds. The use of old weather records is not surprising. More surprising is the report on a study of 12,000 paintings done between 1400 and 1967 that depict information about the weather, including cloudiness, visibility and the abundance of low and convective clouds. From this record, the period 1400-1549 is seen to be less cloudy and to have greater visibility than later periods. Another interesting source is the record of cherry blossom blooming dates in Japan.

Chapter 12 is about Paleoclimate Models. Perhaps the most important sentence in this chapter is 'Models are simplifications of reality.' However, for those who like models, this chapter presents a good overview of the ones that have been tried.

There is an Appendix that contains yet more information about radiocarbon dating, and a list of useful World Wide Web sites. The latter will undoubtedly become a more common feature in books.

The book concludes with 81 pages containing more than 1700 references! I didn't expect to find anything I have written in the list, but I did expect to find a lot of Australian work. I was disappointed. Very little of the extensive work on the Quaternary of Australia - or indeed of anywhere much in the Southern Hemisphere - is used in this book. This is its only real failing. However, on the bright side, this makes it an ideal book for workers in the Southern Hemisphere, in that it deals with much that we are not familiar with, while not presenting us with material we already know.

In reading this book I learnt a great deal about climate and its controls, and about the evidence for changing climates in the Quaternary, especially in the Northern Hemisphere. I strongly recommend it to anyone with more than a passing interest in the field of Quaternary studies.

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Other information is available at:
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