Preview

Australian Society of Exploration Geophysicists

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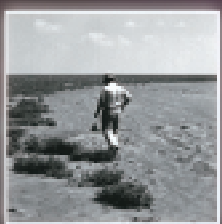
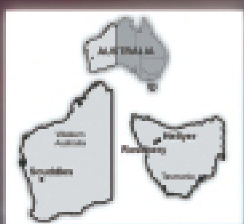
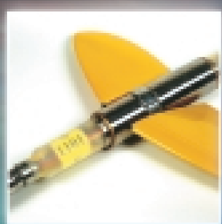
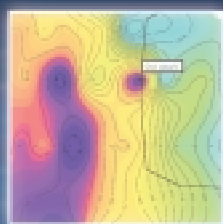
Ken McCracken awarded the Ian Wark Medal for 2001...

...and survives the NSW bushfires









Contents

Cover:

SPOT Image acquired 8 January 2002 by ACRES, Geoscience Australia (© CNES 2002) clearly showing the burnt out areas around Sydney and the fires still burning south of Jervis Bay.

In the image, healthy vegetation shows as bright red, forest as dark red, ocean and lakes as dark blue, burnt areas as black and smoke as white. This particular image is a mosaic of 9 "quick-looks" or sub-sampled images that provide a broad overview from the Hawkesbury River down to the Shoalhaven region and out to the Blue Mountains. Each quick-look covers an area of 60 km by 60 km. The full resolution data may be purchased from ACRES.

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In this issue

Once again we have a very varied fare. There should be something for everybody, with articles from the Mineral, Petroleum and Environmental Sectors. The notes on the Ian Wark Medal award to Ken McCracken and his bushfire experiences are poignant, in that one of Ken's main contributions to Australian science was his work on satellite remote sensing. He was instrumental in bringing sufficient pressure to bear on the government to authorise the establishment of the Australian Landsat Station in Alice Springs in 1979. In recognition of this and his experiences with the January bushfires, I have taken the liberty of including a SPOT image of the Sydney bushfires, taken on 8th January 2002, which show where his property was when the fire was at its peak. This image shows how key technologies can often be applied in a variety of areas of interest. I know this is not core exploration geophysics, but the picture shows an impressive image that would appeal to most image-processors. A good thing about the image is that it is available free from the ACRES website. As part of the policy introduced last September, of making core digital information freely available or at the cost of transfer, it now seems to be much easier to acquire these types of products that are clearly in the public interest.

AMF closes

In the Industry News section there is a news item about the closure of the AMF, which has served the mineral exploration industry since 1972. This event is yet another chapter in the story relating to declining exploration activity. The arrangements for liquidation had not been finalised at the time of writing, but steps have been taken to conserve the ASEG's holdings, formerly housed in the AMF's library. The ASEG Library comprises over 1000 items and has been moved to the Geology & Geophysics Department of Adelaide University. Graham Heinson has arranged the transfer and the collection can be accessed by contacting Graham on Tel: 08-8303-5377 or by Email at: Graham.Heinson@adelaide.edu.au.

Mergers and Rationalisation continues unabated

You can also read in the Industry News section that the spate of mergers and takeovers, which seems to have been with us for the last four years, is continuing unabated. In the last few months we have seen the US based Newmont take over Normandy in a $4 billion battle with AngloGold, Goldfields merging with Delta Gold to form a $1 billion company and Oil Search and Orogen Minerals merging to produce a $1.4 billion enterprise. On a smaller scale, Normandy NFM's has acquired Otter Gold Mines.

There could be more to come. AngloGold is all cashed-up after its windfall profit from the Newmont takeover of Normandy and there are still Newcrest and WMC as attractive targets. Ironically, the single most important factor in all these takeovers is probably the low Australian dollar. Australian companies are just soft targets when the predators are primed with US dollars.

There are now eleven billion dollar plus resource companies registered in the top 100 on the ASX. These range from BHP Billiton at $40 billion to Goldfields at $1.1 billion.

The net effect has been an apparent growth in the resource sector in the big end of town, but this seems to have been coupled with a decline in exploration expenditure and consequently, geoscience jobs in the industry. In the long run this will lead to problems as current mines are exhausted and petroleum becomes harder to find.

It turns out that in the mineral industry the discovery success rate has been very poor in the last 10 years or so, in spite of the huge exploration investment of the mid- to late- 1990s. Somehow or other we do no seem to be finding major new deposits. The Broken Hill area is a case in point. Although there have been huge exploration expenditure there by both the private and the public sectors, little of significance has been found, and Broken Hill will have to rely more and more on the tourist dollar to survive.

Call of Contributions

Preview is always ready to receive a range of manuscripts. We are particularly interested in soliciting the following types of contributions:

- Review articles of technique developments
- Mineral and petroleum case histories
- Conference reports
- News and views
- Letters to the editor
- News of people
- Historical accounts
- Photos or images suitable for the front cover, and
- Anything else of interest to members

Please let me know if you have any ideas, particularly if you can suggest suitable authors.

Good reading

David Denham

David Denham

Aims and Scope

Preview is published by the Australian Society of Exploration Geophysicists. It contains news of topical advances in geophysical techniques, news and comments on the exploration industry, easy-to-read reviews and case histories of interest to our members, opinions of members, book reviews, and matters of general interest.

Contents

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

Contributions

All contributions should be submitted to the Editor via email at denham@atrax.net.au. We reserve the right to edit all submissions; letters must contain your name and a contact address. Editorial style for technical articles should follow the guidelines outlined in *Exploration Geophysics* and on ASEG's website www.aseg.org.au. We encourage the use of colour in *Preview* but authors will be asked in most cases to pay a page charge of $440 per page (including GST for Australian authors) for the printing of colour figures. Reprints will not be provided but authors can obtain, on request, a digital file of their article, and are invited to discuss with the publisher, RESolutions Resource and Energy Services, purchase of multiple hard-copy reprints if required.

The text of all articles should be transmitted as a Word document. Tables, figures and illustrations should be transmitted as separate files, not embedded in the Word document. Raster images should be supplied as high resolution (300 dpi) tiff files wherever possible. Vector plots can be supplied using software packages such as Corel Draw or Illustrator. Illustrations produced in any other software packages should be printed to postscript files. Authors are encouraged to contact the publisher, RESolutions, for information to assist in meeting these requirements.

References

References should follow the author (date) system. When reference is made in the text to a work by three or more authors, the first name followed by et al. should be used on all occasions. References should be listed in alphabetical order at the end of the paper in the standard form:

Blackburn, G. J., 1981, Seismic static corrections in irregular or steeply dipping water-bottom environments: Exploration Geophysics **12**, 93-100.

Abbreviations and units

SI units are preferred. Statistics and measurements should always be given in figures e.g. 10 mm, except where the number begins a sentence. When the number does not refer to a unit of measurement, it is spelt out, except where the number is greater than nine. Confusing mathematical notation, and particularly subscripts and superscripts, should be avoided; negative exponents or the use of a solidus (i.e. a sloping line separating bracketed numerator and denominator) are acceptable as long as they are used consistently. The words 'Figure' and 'Table' should be capitalised (first letter) and spelt in full, when referred to in the text.

Deadlines

Preview is published bi-monthly, February, April, June, August, October and December. The deadline for submission of all material to the Editor is the 15th of the month prior to issue date. Therefore, the deadline for editorial material for the **April 2002 edition is 15th March 2002.**

Advertisers

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

Advertising copy deadline is the 22nd of the month prior to issue date. Therefore, the advertising copy deadline for the April 2002 edition is 22nd March 2002. A summary of the deadlines is shown below:

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97 Apr 2002	15 Mar 2002	22 Mar 2002
98 Jun 2002	15 May 2002	22 May 2002
99 Aug 2002	29 Jun 2002	13 Jul 2001
100 Oct 2002*	**15 Sept 2002**	**22 Sept 2002**
101 Dec 2002	15 Nov 2002	22 Nov 2002
102 Feb 2003**	**20 Dec 2002**	**22 Jan 2002**

**Centenary Edition*
***Conference Edition, abstracts of papers to be submitted by 2 December 2002*

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2002

April 14-16
Global Exploration 2002 - Integrated Methods for Discovery, Denver, Colorado, USA
Sponsor: The Society of Economic Geologists
Theme: The integration of geology, geochemistry, and geophysics, to discover new mineral deposits
Contact: The Society of Economic Geologists, Inc, 7811 Shaffer Parkway, Littleton CO 80127 USA
Tel: 720.981.7882
Email: SEG2002@segweb.org
Website: www.SEG2002.org

April 15-18
International Geophysical Conference and Exposition, Yogyakarta, Indonesia
Theme: Geophysics for Human Kind
Sponsors: The Indonesian Association of Geophysicists (HAGI), and the Society of Exploration Geophysicists (SEG)
Abstract Deadline: mid-August, 2001
Contact: Dr Wally Waluyo
Tel: 62 21 350 2150, ext.1434
Fax. 62 21 350 8032/351 0992
Email: wallywaluyo@pertamina.co.id

April 22-26
European Geophysical Society (EGS) XXVII General Assembly, Nice, France
Sponsors: EGS, American Geophysical Union (AGU)
Contact: EGS Office, Max-Planck-Str 13, 37191 Katlenburg-Lindau, Germany
Tel: +49 5556 1440
Fax: +49 5556 4709
Email: egs@copernicus.org
Website: www.copernicus.org/EGS/

May 12-17
International Association of Hydrogeologists, Australian National Chapter
International Groundwater Conference, Darwin, Northern Territory, Australia
Theme: Balancing the Groundwater Budget
Contact: Gary Humphreys
Email: Gary.Humphreys@nt.gov.au

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

May 28 - June 1
2002 AGU Spring Meeting, Washington, DC, USA
Sponsor: AGU
Contact: AGU Meetings Department, 2000 Florida Avenue, NW, Washington, DC 20009 USA
Tel: +1-202 462 6900
Fax: +1-202 328 0566
Email: meetinginfo@agu.org
Website: www.agu.org/meetings

June 30- 5 July
16th Australian Geological Convention
Theme: Geoscience 2002: Expanding Horizons
Adelaide Convention Centre, Adelaide SA
Contact: info@16thagc.gsa.org.au; Website: http://www.16agc.gsa.org.au

July 9-12
Western Pacific Geophysics Meeting, Wellington, New Zealand
Sponsor: American Geophysical Union (AGU)
Contact: AGU Meetings Department, 2000 Florida Avenue NW, Washington DC 20009 USA
Tel: +1-202 462 6900
Fax: +1-202 328 0566
Email: meetinginfo@agu.org; Web Site: www.agu.org/meetings

September 22-25
Applied Structural Geology for Mineral Exploration and Mining Symposium, Sponsor: Australian Institute of Geoscientists
Venue: WMC Conference Centre, WASM, Kalgoorlie, WA
Contacts: Julian Vearncombe at vearncom@iinet.net.au or Jocelyn Thomson at aigwa@iinet.net.au

October 6-11
SEG International Exposition and 72nd Annual Meeting, Salt Lake City, Utah, USA
Website: www.seg.org

October 20-23
West Australian Basins Symposium (WABSIII)
Burswood Convention Centre, Perth
Organised by PESA
Contact details: Peter Baillie
Tel: 0417 178764
Email: peterb@tgsnopec.com.au

2003

February 16-19
Australian Society of Exploration Geophysicists
16th International Conference and Exhibition, Adelaide, SA
Theme: Growth through Innovation
Contact: Rob Bulfield (08 8227 0252)
Email: rob@sapro.com.au
Website: www.aseg.org.au

April 7-11
Joint Meeting: European Geophysical Society (EGS) XXVIII General Assembly and the American Geophysical Union (AGU) Spring 2003 Meeting, Nice, FRANCE
Sponsors: EGS, AGU
Contact: EGS office, Max-Planck-Str. 13, 37191 Katlenburg-Lindau, GERMANY
Tel: +49 5556 1440
Fax: +49 5556 4709
Email: egs@copernicus.org
Website: www.copernicus.org/EGS

South Australia - by Andrew Shearer

The final two events for 2001 were the students' night and the Christmas party. Four presentations from representatives from the University of Adelaide, Flinders University, and the National Centre for Petroleum Geology and Geophysics (NCPGG) were given at the annual students' night held in November. The speakers and their topics were:

- Hashim Carey (Adelaide University): *Numerical modelling of the mise-a-la-masse method: The near-miss scenario.*
- Anthony Jervis (NCPGG): *Characterisation and mapping of stacking velocity and time effects of calcite-cemented zones, Cooper Basin.*
- Ivan Crabb (NCPGG): *A Petrophysical Investigation of Low Resistivity Hydrocarbon Zones in the Moran Field, Papua New Guinea.*
- Doug Weatherill (Flinders University): *Density-driven groundwater flow and solute transport: Issues in prediction.*

The best paper was won by Anthony Jervis (NCPGG) and Hashim Carey (Adelaide University) won the best presentation award.

The Christmas party was attended by approximately 50 people who managed not to destroy my house, for which I thank you all. The night went off with out a hitch and was enjoyed by all. As for who won the "fill the bin" competition, the judges are still deciding, a photo may be needed to solve the issue.

The first planned event for 2002 is the Annual General Meeting. Nominations for committee members are being called for and should be forwarded to Graham Heinson (Secretary Graham.Heinson@adelaide.edu.au, 08-8303-5377) as soon as possible. The AGM will be held in mid to late February, more details will be sent to members as soon as available.

Queensland - by Kathlene Oliver

The Branch held the annual Christmas dinner this year at My Thai, a popular Thai restaurant in Brisbane. The evening was well attended and enjoyed by everyone there.

In February the Branch will hold its Annual General Meeting with the positions of President, Treasurer, and Secretary open for nominations. If you wish to nominate yourself or a colleague for an office or be a general member of the Committee please send you nomination via email to either Troy Peters (tpeters@velpro.com.au) or Kathlene Oliver (ksoliver@optusnet.com.au). The date and location of the AGM will be announced during January via email and on the web site. A nomination form will be available on the web site from late January.

If any of our members have suggestions for Branch activities or wish to present at a one of the year's technical meetings please email either Troy Peters or Kathlene Oliver.

The Queensland Branch committee would like to wish all our members a Happy New Year and to thank them for their continuing support throughout the year. We look forward to receiving the continued support of our members during 2002

Western Australia - by Kevin Dodds

The Annual General Meeting was held in the pre-Christmas slot of December 19th along with wine and cheer.
The following officers were elected for 2002:

President: Kirsty Beckett
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Email: kirsty_beckett@uts.com.au

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Tel: (08) 6436 8727
Email: kevin.dodds@csiro.au

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Email: guy@encom.com.au

Treasurer: John Watt
Tel: (08) 9222 3154
Email: john.watt@mpr.wa.gov.au

Website: David Howard
Tel: (08) 9222 3331
Email: david.howard@mpr.wa.gov.au

Technical Meetings

November 2001

- Jerry Hooper: *Strategic Marketing of Innovations for Geoscientists*
- Klaas Koster: *Overview of time-lapse seismic reservoir monitoring - where do we stand today?*
- William French, Curtin Haydn-Williams Fellow: *New Technology Challenges*, ASEG lunch time seminar.

October 2001

Annual Students' night: presentations from Honours and Masters students from Curtin University. The following students presented:

Student	Thesis Title
Bronwyn Calleja,	Soil mapping using high-resolution radiometrics.
Tristan Campbell,	The role of geophysics in the monitoring of soil moisture and the zone of influence of trees.
Robert Galvin,	Calculation of correct compressional wave amplitudes for simple three-dimensional Earth models in seismic exploration using computer algebra.
Martin Kim,	Fluid and lithology prediction within a coal sequence using seismic attribute modelling and analysis.
Margarita Norvill,	A geophysical investigation of the relationship between gravity ridges and ironstone hosted gold/copper mineralisation in the northern Tennant Creek region of the

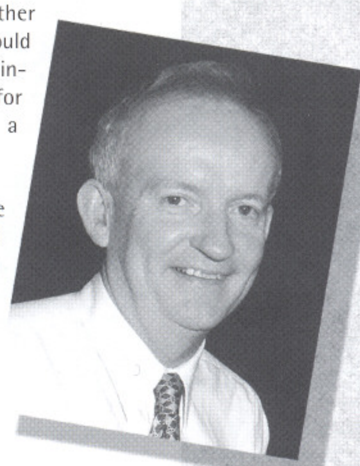
Continued On Page 7

State representatives at the Council Meeting held during the Brisbane Conference, endorsed the importance for the Executive to have national representation. It is felt that the positions of President, Secretary and Treasurer need to be based in the host city, but that the positions of Vice Presidents and Committee Members could be either Branch Presidents or their nominee from outside the host State. Currently, the Executive is moved from State to State every 3-years and in April 2002 at the Annual General Meeting, the current Sydney-based Executive will hand over to a new Executive hosted by our Perth members. With the current Vice Presidents based in Perth and Melbourne, tele-conferencing has and will continue to facilitate the monthly Executive meetings.

During the period that the Executive has been in Sydney, Brian Spies and now Suzanne Hayden have been the champions of a Procedures Manual. This manual documents most of our procedures with proforma notices/letters, and descriptions of the responsibilities and duties of the Executive, Standing Committee Chairs, Secretariat and Accountant. It is expected that this will become an important document in the change over to the new Executive.

The Brisbane Conference was a great success both technically and financially. Thus at the end of 2001, the Society is in a reasonable financial position. With 2002 being a non-conference year, the 2002 budget predicts a deficit that is consistent with previous non-conference years. Of continuing concern is the reduced advertising income and increasing costs for our publications and a publications budget in 2002 has a forecast deficit of $76 000. The Federal Executive and the Publications Committee are very aware of this situation and are working with the publisher (RESolutions) to keep costs in check. Ways of further reducing the cost of publications are constantly being reviewed. The CD produced with the Conference Edition of Preview was a great success, both in containing costs and increasing the amount of information to members. This is an example of the changes and innovations that have to be considered to keep our Society financially viable.

A proposal being considered is for the Secretariat to email Notices of Branch Meetings that are linked to the ASEG web site. This would save yet another attachment on members' email and would facilitate more hits of our web site that in-turn would make it more attractive for advertisers. Another proposal is to form a Bulletin Board for jobs on the web page.



With to need to book ahead, our conference venue, after Adelaide in February 2003, will be the Sydney Conference and Convention Centre at Darling Harbour, which has been booked for September 2004.

David Robson
Honorary Federal Secretary

Continued From Page 6

	Northern Territory, and the implications for further exploration.
Karen Pittard	The contribution of magnetite to the induced polarisation effect of the Centenary orebody.
Christopher Salti	The development of wireline logging in analogue reservoir models.
Mitchell Tomlinson	Seismic imaging on Barrow Island.

Bruce Hobbs, Deputy Chief Executive CSIRO:
A Strategy to get Australia to 2025, ASEG Earthscience Week, Key Note Seminar, sponsored by Woodside Energy, Shell, Schlumberger and WMC.

Ken McCracken Awarded the Ian Wark Medal for 2001......

The Ian Wark Medal and Lecture recognises the contribution by the late Sir Ian Wark to the application of science to industry. His principal contributions to science and Australia were in the electrowinning technology used at the Electrolytic Zinc Company at Risdon, Tasmania, and his creation and development of the CSIRO Division of Industrial Chemistry.

The 2001 Ian Wark Medal was awarded in December, at the Australian Academy of Science, to Dr Ken McCracken for his "substantial and sustained contributions to the prosperity of Australia, through the development of the scientific basis for new technologies for mineral exploration, in the highly weathered Australian continent".

Ken McCracken is Managing Partner of his business Jellore Technologies. He received his BSc and PhD from the University of Tasmania and his DSc from the University of Adelaide for research in astronomy and space physics. He has won several prestigious awards including the CSIRO medal in 1988 and he was a joint recipient of the Australia Prize in 1995.

In 1970, Ken was approached by CSIRO to develop a planning brief for a new research unit to undertake R&D into the application of geophysics in the Australian mining industry. He developed a research rationale and a notional program that contained five elements - electromagnetic geophysics; satellite remote sensing; mathematical geology and geophysics; and active and passive nucleonic geophysics. The unit attained the status of a Division in CSIRO in 1972.

At the time, exploration geophysics for the mineral industry was dominated by R&D in Canada and the USA, and by Canadian manufacturers. The research and instruments they developed were designed for the glaciated Canadian terrain and little attention was given to the deeply weathered terrains common in Australia and elsewhere in the world. The research program established by Ken in 1970 was totally focused on the needs of deeply weathered terrains.

His strong links with the Australian Mineral Research and Development Association (AMIRA) provided an exceptional ability to understand the attitudes and needs of industry. Using funding obtained from companies through AMIRA, major research programs were developed in conjunction with industry. By 1980 Ken had built his Division to a strength of 120, more than 50% being supported by industry funds. By this time the Division was regarded as a major source of geophysical innovation worldwide and Australian industry had rapidly pressed their R&D into operational use.

Ken's achievements include:

The commercial manufacture of the exploration instrument SIROTEM built on his Division's expertise in electromagnetic geophysics and the study of the effects of noise on the EM measurements. This instrument had been designed around the microprocessor - years before it became commercially available. As with much new technology in the 1970s, there was no Australian interest in manufacturing an instrument based on the CSIRO research. The market was too uncertain. Through an AMIRA project the capability of SIROTEM was demonstrated to the mining industry and five companies committed to purchase enough instruments to minimise the risk. SIROTEM has been a contributor to many major mineral discoveries in Australia during the past 25 years.

By 1976 Ken's team had established that satellite remote sensing was of substantial value to the Australian mining industry. There was no facility in Australia capable of receiving the satellite data from space and the totality of the data used by industry was from Ken's Division, using digital imagery stored on a tape recorder on the satellite; received by radio transmission over Alaska and transported to Australia by computer tape. As a result of the work in his Division, the Australian mining industry brought sufficient pressure to bear on the government to authorise the establishment of the Australian Landsat Station in Alice Springs in 1979.

By 1982 the first generation of Landsat satellite had been replaced by a second generation that was incapable of reception by the Australian Landsat Station. It was through Ken's efforts in establishing an alliance between AMIRA, individual companies and CSIRO that funds and support were provided to construct "The Signal Processing Experiment" which received and processed the second-generation Landsat data obtained over Australia. These data became an indispensable part of the mining industry's technology and were used extensively in environmental management, agriculture and hydrology. It was for this work and other R&D into remote sensing that Ken shared the 1995 Australia Prize.

After CSIRO

Ken provided the technical oversight of the SALTMAP airborne survey tool developed by the Australian company, World Geosciences Corporation. This instrument pioneered many new innovations.

In 1991 he assisted BHP in research directed towards the provision of the means to map the Earth's gravitational field from a low flying aircraft. His most important contribution to the program (with Mike Asten and Graham Creer) was in recognising the potential (that no one else had seen) represented by a military technology that, at face value, appeared to be inadequate for the industrial task. He remained associated with the program until two systems entered operational service in 1999/2000. Airborne gravity is expected to fill a pivotal role in mineral exploration similar to that of airborne magnetics. Already these two instruments have provided a degree of geological insight far in excess of the initial expectation.

To touch on Ken's solar and space research interests. Since 1959 he has had an international reputation in solar system and space research. He was a technical advisor to NASA during the Apollo moon program and a member of the Australian Space Board. He developed a mathematical model of the 'optics' of the high energy ionising radiation in the Earth's magnetic field that is still in use and which will be used to protect the astronauts on the International Space Station from radiation sickness. He is also a Visiting Senior Research Associate at the University of Maryland. His work there will have a practical outcome in the area of climate change.

......and survives the NSW Bushfires

Email 2 January. "The bushfires started on 24 December and initially we were not threatened. However, the fires spread, until there was a 700 km fire front on the 27th. By the 28th our area went on full emergency alert.

Jellore farm is surrounded on three sides by a national park and state forests and the bush is thick and will burn strongly. However, the farm itself is largely all paddocks, so it provides its own protection, except from wind blown burning debris that can land up to 10 km ahead of a fire front. That's what we need to watch. We have lawn sprinklers installed along the ridge of the house roof to keep it wet, and the gutters full of water.

We all got highly organised and the houses and farms are now as prepared as possible. There are fire crews here from all over Australia and they have no local knowledge, so the gates of all farms have prominent signs indicating number and names of people there, how much water available etc. Bulldozers are cutting control lines and renewing fire breaks all over the place.

Ken McCracken (right) holds his Ian Wark Medal, presented by Brian Anderson (left) President of the Australian Academy of Science.

The fires were about 8 km from us by 30th. That night, and on New Years Day, 300 people were evacuated from Hilltop, a small village 8 km from us. The winds on 1 January were very gusty, and that did much mischief. Today (2nd) is predicted to be one of the worst in the whole period. Luckily for us, the fires are to the east and north of us, and the winds are from the west. They still move toward us against the wind, but slowly.

Our cattle are in the paddocks around the house. They were most thankful when I moved 50 of them from one of our more remote paddocks, through dense smoke. Their general demeanour suggested they were thinking "about bloody time".

Email 7 January. The uncertainty is getting to everyone. All the preparations have been made and the waiting is most unsettling. Often the smoke is such that we cannot see 100 m. Everything is covered by a layer of quite large bits of burnt leaves. There is dense smoke around the house for at least 50% of the time, depending on the wind vector.

The fire has worked its way against the wind towards us. By the 4th a long bright fire front was visible from the house. I misread the map and thought it was 2 km from our bottom paddock. I was wrong by one valley, it was about 4 km away. That was the most uncertain time for us. A neighbouring farm was evacuated that night. I told the local fire brigade to bring a pair of handcuffs if they were going to try to evacuate me. Much wildlife was voting with its feet, moving into our paddocks and our garden.

One night, a wombat broke a water outlet pipe in the garden and we lost 40 000 litres or more that night. Our comments about wombats were not charitable.

Our volunteer fire brigade was very active cutting a 20 km long fire containment line and back burning from it at night to produce a wide firebreak to protect the towns of Mittagong and Bowral. Our farm was one of the few outside the containment line, so a bulldozer was sent here to cut a protection road on the hillside to the west of the

This text is a shortened version of Ken's accounts of his and Gillian's experiences during the recent bushfires. The originals were despatched at the dates indicated to their friends in Australia and overseas during the crisis.

farmhouse, to allow backburning there. This was by far the most dangerous direction, so this was a very welcome move. Also it gives us a really fine access road into a part of the farm it was very hard to get a vehicle or tractor to, so it has lasting value to us, other than for fire fighting.

About the 6th, backburning started in earnest near the farm. There was fire all around us, but an enormous number of rural fire trucks from all over Australia to keep it under control. We had trucks from near Melbourne patrolling near our front gate. They managed to burn out one of our fences, but that is a small price to pay for the protection the burn will give.

Last night (6th) we had a 14 mm fall of rain. Not enough but, with the backburning, means a greatly reduced risk. The following day was very quiet and with little smoke, we could even see several km.

Email 15 January: The 8th was different. A warm day and the fires that had survived the rain in stumps, etc, livened up. One in particular was about 2 km away from us to the west. It built up a real run, heading for the northern part of our farm. The wind direction meant that it was going to miss the farm buildings, or so I thought.

That night our neighbour called to say that there was fire on an unexpected part of our farm. On investigating I found a line of fire just 10 m from the "old cottage" 400 m north of the farmhouse. This, and the other fire seen by our neighbour were spot fires due to burning debris blown ahead of the main fire front. I called fire control, lifted a garbage can full of water and 2 buckets into the VW, and raced over to the cottage. The volunteer fire brigade was only seconds behind me. They did a remarkable job and no damage was done to the cottage.

The next day there were about 8 fire crews on our farm. They were burning back into the bush around the farm, and were very successful. The smoke was very thick, visibility of 100 m at the most, and frequent crashes due to trees falling in the forest all around us.

During this time the volunteer fire brigade was patrolling the farm in their large fire trucks about every 2 hours, day and night. They brought a bulldozer in to remove several trees that were going to fall and possibly demolish the old cottage. They did a superb job looking after us, while attending to their primary task of eliminating the risk that a big fire would get to Mittagong and Bowral.

The fires subsided over the following days, but we would hear a tree crashing to the ground roughly every 5 minutes. This continues still, but much less frequently. However, there will be a real risk of falling trees until we have had a really good windstorm.

The fires are now over (15th) and the weather is cloudy. There has been an almost 100% elimination of the fuel on the forest floor for many kilometres around Jellore. The fires were mainly "cold" fires, i.e., not burning the canopy but singeing it in some parts. The kangaroos and birds have moved into our paddocks and particularly our garden. The bees are active today so at least some of their hives (which are often in old, dead eucalypts) have survived."

Beethoven's "Pastoral Symphony" is very applicable as a description of our past 3 weeks, with the fires substituted for his storm. And the peaceful section after his storm says it all.

SPOT Image acquired 8 January 2002 by ACRES, Geoscience Australia (© CNES 2002) clearly showing the burnt out areas around Sydney and the fires still burning south of Jervis Bay.

New Members

We welcome the following new members to the ASEG. Membership was approved by the Federal Executive at its October 2001 meeting.

Name	Affiliation	State
Tracy Campbell	Teck Exploration.	Canada
Nicholas Holding	Western-Geco	Qld
Wayne Mogg	Santos	Qld
Turgut Ozdenvar	Geocenter	US
Jovan Silic	Flagstaff	VIC
Alan Webb	Anglo American	Chile
Toshiyuki Yokota	Geological Survey Japan	Japan

Obituary

Wilfred Dudley Parkinson, 1919-2001

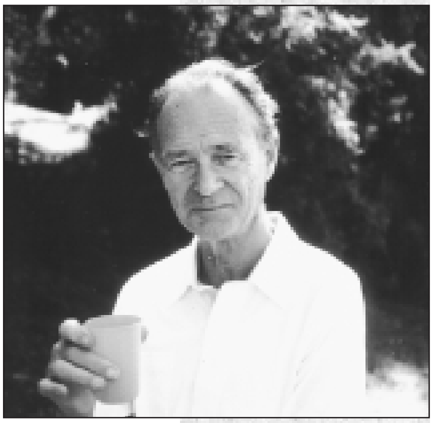
Wilfred Dudley Parkinson was born in Perth, Western Australia in 1919, during the time his father, Wilfred Charles, was working for the Carnegie Institution of Washington (CIW) as assistant observer at the Watheroo Observatory. One of Dudley's earliest boyhood memories was of bouncing around in the back of an ox-drawn cart accompanying his father to and from the remote Watheroo Observatory. As a youngster, Dudley travelled extensively with his family, accompanying his father on magnetic surveys to many parts of Australia, southwest Pacific islands, New Zealand, Papua New Guinea, south east Asia, and finally to the Huancayo Observatory in Peru. Dudley's early exposure to observatory and field survey work was to mould much of his later career.

The need for a formal education took Dudley to a boarding school in Sydney, and thence to the University of Western Australia. His education was disrupted by World War II, during which time he served in the Royal Australian Air Force - posted to Watheroo to provide predictions of ionospheric conditions. He was able to complete his degree in Mathematics (with honours) externally. After a brief spell with the CIW supervising the science program at the Huancayo Observatory during its hand-over to the Peruvian Government, Dudley won a scholarship to undertake a Ph.D. at Johns Hopkins University. There he was to complete the early work on the behaviour of helium gas in discharge tubes. It was at this time that he met and married his wife, Mary, who had left her native Peru and was also studying in Baltimore.

The following three years were spent working at Fordham University, New York with Victor Hess, who had received a Nobel Prize for his discovery of cosmic radiation. Here, Dudley was to discover the phenomenon of radioactive fall-out caused by nuclear tests (in Nevada), but was not allowed to publish the results.

The draw of Australia was finally too strong, and Dudley joined the Bureau of Mineral Resources (now called Geoscience Australia) in Melbourne. At BMR he undertook pioneering work in airborne radiometric and magnetic surveys for identifying mineral deposits, carried out ground magnetic survey work in Australia and Antarctica, developed the first 3-component regional magnetic field charts of Australia, identified the global pattern of the daily variation of the Earth's magnetic field (work carried out with Vestine at Rand Corporation), and started a series of laboratory experiments to simulate the effects of electromagnetic induction in the Earth. It was at this time that Dudley developed the now-standard induction vector method of analysing electromagnetic crustal induction data - a technique for which he became famous. The induction vector is now commonly referred to as the "Parkinson Vector".

After the move of BMR to Canberra in 1965, Dudley stayed for only two more years before taking up, early in 1967, a senior lectureship in the Geology Department, University of Tasmania under the headship of the charismatic Prof. Sam Carey. He was promoted to Reader in Geophysics early in 1968 and remained at the University for the remainder of his professional life, teaching and continuing his research into the electromagnetic properties of the Earth's crust. He was a successful, possibly outstanding, teacher who interested undergraduate students in further studies in geophysics and then stimulated them to carry out research into his own and other fields of geophysics. Many of those who studied with him have achieved prominence in their profession. His investigation, with students, of the electrical conductivity of the Tasmanian crust resulted in the recognition of a zone of anomalous currents in a zone extending south-southeast from beneath the mouth of the Tamar River almost to Maria Island. One of his proudest achievements was to devise a method of using a single magnetometer to obtain the same results as an expensive array of instruments - an approach entirely in keeping with Dudley's love of applying intelligence and innovation to seek simple solutions to difficult problems. His well-known text "Introduction to Geomagnetism" was published in 1983 and was the first comprehensive scholarly monograph about the Earth's magnetic field since Chapman and Bartels classical two-volume work "Geomagnetism" (1940). The monograph was an immediate success with students and researchers alike and remains the most authoritative modern general textbook on geomagnetism.



Dudley's interest in geomagnetism was reflected in his involvement in the Bicentenary of the establishment in 1792 of a magnetic observatory on the shores of Recherche Bay, southern Tasmania, by officers of the D'Entrecasteaux Expedition. He was much involved in the associated meeting and a ferry excursion to the site in 1992 for the emplacement of a commemorative plaque. He was also involved in reviewing and assessing the results of magnetic observations made at the Rossbank Observatory over a period of a decade or so after it was set up at Hobart in 1840 by officers under the direction of Captain James Ross, commander of the "Erebus" and "Terror" expedition to the Antarctic, with the active help of Sir John Franklin.

Dudley's gentle nature and self-effacing modesty, characteristics that endeared him to both students and colleagues alike, belied a penetrating intellect, rigorous analytical abilities, and a propensity for original and innovative thought. Dudley was a wonderful test bed for new ideas; if it passed the Parkinson scrutiny, you could be confident an idea was worth pursuing. He never lost a boyish delight in discovery that was one of his most endearing characteristics. Dudley's interests were not limited to science - he was an accomplished musician, and an authority on the Esperanto language. He is survived by his wife Mary, sons Charlie and Richard, and four grandchildren. Dudley will be greatly missed by his colleagues, not only for his scientific wisdom and knowledge, but also as a role model as a gentleman and a gentle man.

Charles Barton (Geoscience Australia), Max Banks (University of Tasmania)

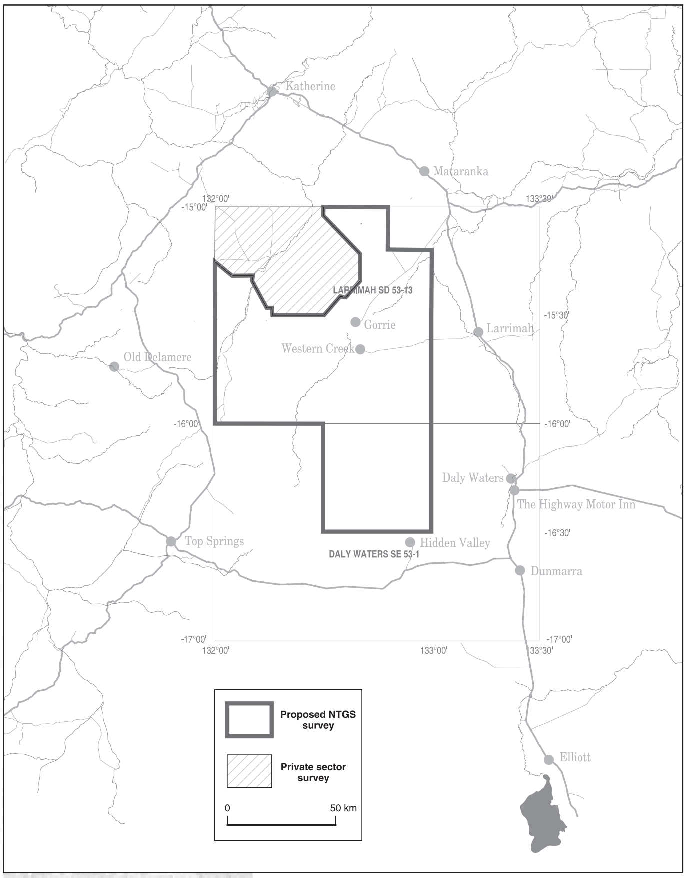


Fig. 1. Sturt Survey.

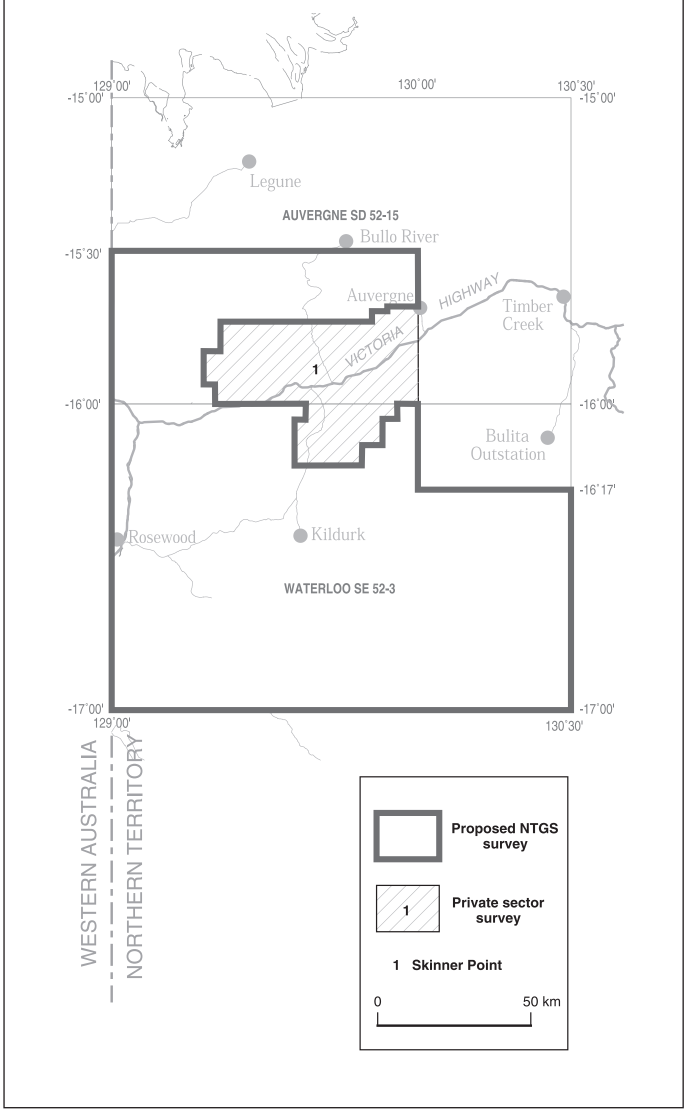


Fig. 2. Waterloo Survey

NTGS

Sturt and Waterloo survey data released

NTGS has released 67 300 line-km of located and gridded magnetic, radiometric and elevation data from the Waterloo survey, flown on behalf of NTGS by Kevron Geophysics during 2001. The survey was flown at 80 m MTC along 400 m spaced N-S flight lines using a 33 l spectrometric crystal. The new flying occupies approximately 80% of the Waterloo survey area. Reprocessed existing private sector airborne data (250 m line spacing; 1997 vintage) has been incorporated over the remaining 20%. The survey is located on the western edge of the Victoria-Birrindudu Basin, immediately adjacent to the Halls Creek Orogen, and incorporates the Waterloo and south-western part of the Auvergne 1: 250 000 sheets. The raw 256 channel radiometric located data are also available upon request.

The NTGS has also released 48 600 line-km of located and gridded magnetic, radiometric and elevation data from the Sturt survey, also flown on behalf of NTGS by Kevron Geophysics during 2001.

The Sturt survey was flown at 80 m MTC along 400 m spaced N-S flight lines using a 33 l spectrometric crystal volume. New flying occupies approximately 80% of the Sturt survey area. Reprocessed existing private sector airborne data (300 m line spacing; 1993 vintage) has been incorporated over the remaining 20%. The survey is located in the Dunmarra Basin, south of Katherine. It incorporates the western portions of the Larrimah and Daly Waters 1: 250 000 sheets.

The raw 256 channel radiometric located data from both surveys are also available upon request.

Survey location, specifications and located images for the Waterloo survey are now available on the NTGS Image Web Server at:
http://www.dbird.nt.gov.au/ntgs/geophysics/air_map/survey_specs/new_surveyspecs/new_surv_map.html.
The figures to the above show the locations of the surveys.

Environment China - Ground EM for Mapping Soil Salinity in China

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[1] The Geo-Eng Group is an Australian consultancy firm with a growing presence in China's water industry. It has recently been involved in providing innovative, Australian developed geophysical systems to tackle China's salinity and groundwater problems.

China and the Environment

China is one of the most significant nations on planet Earth, with a population of approximately 1.2 billion, which is expected to peak at 1.8 billion in the next 20 years. Traditionally an agriculture based society, China is also an industrial powerhouse undergoing rapid modernisation and economic growth. This growth of the population and the economy has come at a price to the environment in China. China faces major environmental issues and the better known of these are air and surface water quality, as well as regular flooding, the legacy of past land clearing and depletion of wildlife. Perhaps less known are China's groundwater and salinity problems.

Groundwater

With the rapid industrialisation, population density and consequent issues of surface water quality, and also with the implementation of major surface water transfer projects (eg transferring Yangtze River water to the North of China), still many years away, pressure is being applied to groundwater systems especially on the fertile floodplains of coastal China. In the north around Beijing and the Haihe River Basin, for example, groundwater systems are increasingly under management pressure. Seawater intrusion into coastal aquifers, over-pumping and salinisation of aquifers, plus ground subsidence around large cities are the consequences of increased groundwater extraction.

China's arable lands and the salinity problem

Agricultural land also is heavily exploited as feeding the population of China is a major challenge and food is such an important part of the Chinese culture and enjoyment of daily life. China has 137.6 million hectares (MHa) of arable land but with its large population has less than half the world average of arable land in Ha/person. Even with this major disadvantage China still manages to largely support its populace. This is done by heavily working any available arable land (at least two crops per year with no rest for the land). Of the 137.6 MHa of current arable land, 23.1% is irrigated paddy fields and 76.9% is dryland. Of the dryland agricultural area (105.8 MHa), 21.5% has surface water irrigation and 88.5% is rain-fed agriculture.

The current and future threat to the China's arable land and food self sufficiency is salinity, either from abandonment of agriculture in salty soils or reduced crop production due to salt toxicity of the soil (Wang et al., 1993). There are 35 MHa of salt affected soils in China, 14.7 million Ha of these are in arable land (almost 11% of the arable land). It is estimated that China is losing between 1 and 3 MHa of arable and potentially arable land per year to salt and construction of new dwellings, often the more valuable irrigated land. If potentially salt affected land is taken into account an estimated 99 MHa of land is under threat from salt.

Given the importance of land and food in China, and the preceding statistics, Australia's salinity problems seem milder in their effects, compared to China's salinity problem. Figure 1 shows the salt affected lands in China. Like Australia, China's salinity is either dryland salinity (exacerbated by high evapotranspiration/precipitation ratios over much of China) particularly in the north of China, or secondary salinisation of irrigated lands.

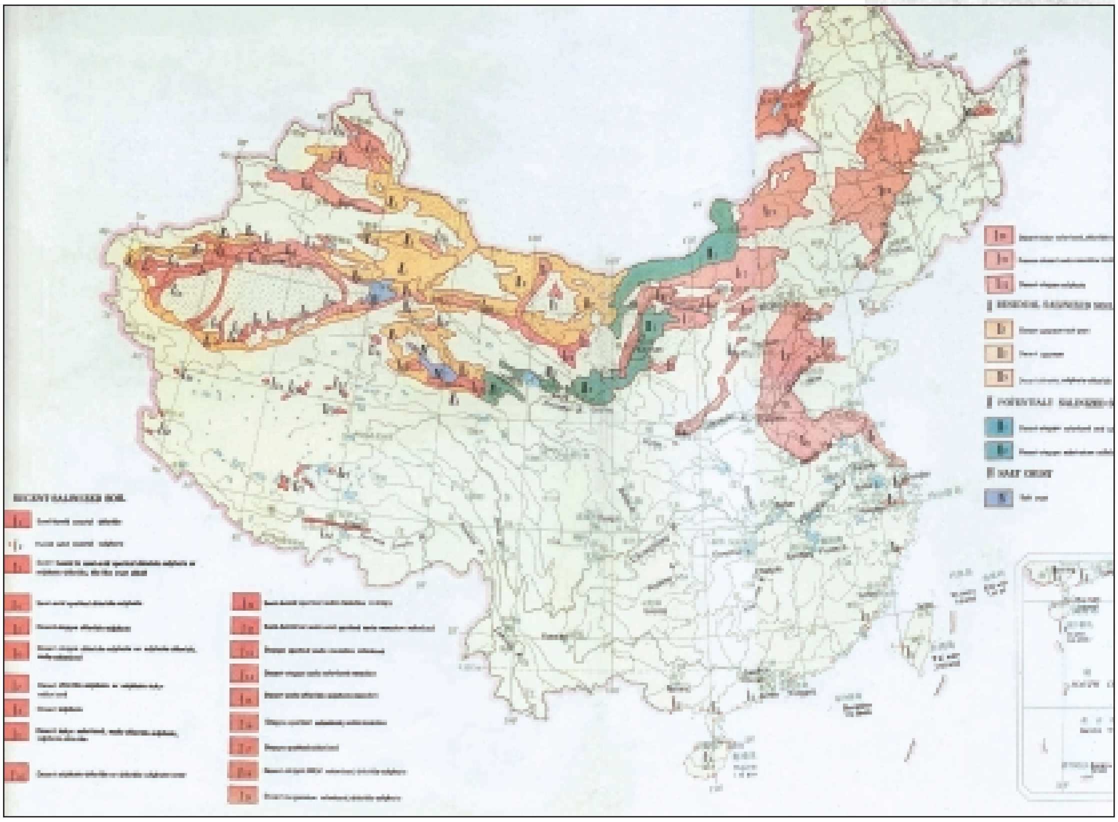

Fig. 1. Salinised soils in China (source Yang Jingsong). The map shows Recent salinised soils (red-brown); Residual salinised soils in the western deserts (yellow), Salt Crust Soil areas (blue-purple) and Potential salinised soils (green-blue). In the southeast of China there is little or no salinity problem.

Soil Salinity	Yield Reduction	Crop Growth	Soda type	Chloride type	Sulphate type
			Salt content of 0-60cm layer (g/kg)	Salt content of 0-100cm layer (g/kg)	
Non salinized	0	Normal	<1.0	<1.5	<3.0
Slightly salinized	10-20%	Slightly restrained	1.0-2.0	1.5-3.0	3.0-6.0
Moderately salinized	20-50%	Moderately restrained	2.0-3.0	3.0-5.0	6.0-10.0
Severely salinized	50-80%	Severely restrained	3.0-5.0	5.0-8.0	10.0-20.0
Solonchak	Near 100%	Mostly dead	>5.0	>8.0	>20.0

Fig. 2. Effect of salinised soils on crop production in China (source Yang Jingsong).

Soil alkalinity is a problem also. Figure 2 shows the effect of salt toxicity (expressed in grams of salt per kilogram which is equivalent to 1000 ppm or mg/l in Australian salinity parlance) on crop production efficiencies in different types of soils (sodic and acidic).

ISSCAS and Salinity in China

The Soil Physics and Soil Salinity Research Department of the Nanjing based Institute of Soil Science, Chinese Academy of Science (ISSCAS), is one group that is leading the fight against salinity in China with a variety of applied and research approaches including:

- Groundwater table control and encouragement of fish aquaculture pond relocation,
- Land levelling and improved irrigation/drainage methods,
- Reduction of surface evaporation around crops,
- Mapping and monitoring soil salinity and soil/salt associations,
- Introducing salt tolerant crops, and
- Enhanced fertiliser management

ISSCAS have found drainage and improved water engineering methods have worked well and China could teach Australia much in this area. Salt tolerant crops are being actively pursued with research crops able to tolerate soils of up to 10 g/kg (and more) in salinity.

A centuries old solution of the arable land problem is to rehabilitate and use rich silt lands reclaimed from the sea between the mouths of the Yangtze and Yellow Rivers in China, even though these lands are initially very salty. With the large silt loads from these rivers the land is growing seawards at up to 200 m/year, providing tens of thousands of hectares of new land per year (see Figure 3). Within 5-10 years (or less) with drainage and flush irrigation, which the Chinese agriculturalists are very skilled at, this land can be growing rice and other crops.

Sydney University EM System

ISSCAS have looked to Australia recently though to learn from Australia's use of ground electromagnetics for mapping and monitoring of salt in soils, as this will be particularly useful for optimal use of the new reclaimed and other salt affected lands. ISSCAS were particularly interested in the dual EM system (Geonics EM31 and EM38 with GPS navigation and computer data acquisition), devised by a team from the University of Sydney Cotton Research CRC, lead by John Triantifilis (Triantifilis et al, 2001). This system (Figure 4) had a purpose built vehicle with a front mounted EM31 and an EM38 mounted in a rear sleeve with hydraulics to raise, lower and rotate (vertical and horizontal coil orientation) the EM38. ISSCAS wanted this system to be adapted to a Chinese tractor and the flexibility to be used in a variety of modes of operation of the instruments with and without the GPS and the tractor.

EM system design and construction

The State of the Art EM system was assembled and supplied to ISSCAS using two Geonics instruments: EM38RT for shallow (1 m) soil and EM31SH for intermediate depths (5-7 m), plus a Trimble ProXRS / TSC1 GPS unit.

The key design features of the ISSCAS EM system[2] are:

- System operational flexibility for a variety of field requirements and conditions,
- operating on any tractor with a 3 point linkage,
- Tractor mounted rear (self-contained, independent of tractor) hydraulics system,
- Expandable serial data combination box (several RS232 inputs; 1 RS232 output),
- Data recording system redundancy,
- Simple manually activated vertical (V) or horizontal (H) EM dipole operations, and
- Prototype walking frame for dual EM sensor and GPS mounting.

For the main configuration of the system (see Figure 5), the EM instruments are mounted on a small Chinese tractor with the EM31SH (V or H dipole orientation) at the front and the EM38RT (V or H dipole orientation) at the rear. The EM data are recorded (via the serial data combination box) into a Trimble ProXRS GPS and TSC1 data logger for sub-metre positional accuracy. The Trimble TSC1 accepts only one serial data stream from an external sensor, so a serial data combination box and software had to be built. This has two (expandable to six) RS232 serial data inputs and one serial data (combined data stream) output to the TSC1 (which accepts data at between 0.5 to 5 s, and typically 1 s recording intervals).

The rear mounted EM38RT is in a sleeve inside a PVC cylinder fitted to a self-contained hydraulics system to raise and lower the instrument for various ground clearances. Manual rotation of the sleeve provides for V or H dipole orientation.

In addition to the Trimble ProXRS TSC1 data logger, two other optional data loggers (HP1000CX palmtop and Geonics DL600 Polycorder) were also provided and a 2-person prototype walking frame to mount the dual EM sensor and GPS instrumentation on, where tractor access was not feasible. The system provides 16 different system configurations giving total flexibility of configuration and operation, plus some data recording system redundancy, to meet a variety of data recording needs and field access constraints. This configuration flexibility is made possible by combinations of the three data recording options and the ability to use the system with dual or single EM sensors on a tractor or on foot and with or without the GPS. The ability to record in either vertical V or H dipole mode with both (or either) EM systems, with the 16 configurations, gives a total of 40 possible different modes of EM data acquisition. Post processing and mapping of the EM and GPS data is by a variety of configuration (and mode) dependent XL spreadsheets for data pre-conditioning and then by Geosoft OASIS Montaj for 2D and 3D mapping, profile display and data imaging.

[2] The Geo-Eng Group, working closely with ISSCAS, was 'chosen for the design, supply, testing and commissioning of the EM system. Geo-Eng was sub-contracted to JiangAu International Pty. Ltd who was contracted to supply the EM system along with other soil salinity research and salt modelling technologies. The EM project was lead by Geoff Pettifer of Geo-Eng assisted by Professor Yang Jingsong of the Soil Physics and Soil Salinity Research Unit. Dr Ju Maosen (JiangAu/Jiangsu Water), provided project management.

Geo-Eng adapted and augmented the Sydney University EM system design, supervised the design and construction of specialist components by sub-contractors, purchased and tested the equipment and software, helped assemble it in China and provided training and a comprehensive system manual. The final design of the tractor system and configuration options, negotiated with Professor Yang, was not in-place to early May and the system had to be assembled in record time for shipment in the first week of June. Previous systems like this one have taken usually several months to prepare. Good support under tight deadlines was provided by Geo-Eng sub-contractors and equipment suppliers who included:

- David Gamble of Mindata (RS232 combination box and programming and HP1000CX EM data acquisition software),
- Latrobe Valley Engineering (rear EM38RT steel mounting frame and hydraulics),
- D.E.P.S. (PVC threaded frame engineering),
- Simon Best and Paul Andrews of Ultimate Positioning (assistance with GPS interfacing and training),
- John Peacock and Rob Johnston of Fugro Ground Surveys and other Geonics, Canada staff (Geonics EM equipment), and
- Nick Bideau and Levin Lee of Geosoft Australia (OASIS Montaj software).

Construction of the EM system was also was helped by Australian experience with EM systems notably that of John Triantifilis (University of Sydney) and LeeAnne Mintern (NRE Victoria EM31 system).

The EM system was delivered in China to the ISSCAS field team of Liu Guangming, Xu Ligang and Li Dongshun (Figure 6), who worked closely with Geoff Pettifer, during acceptance trials.

Field Trials

The EM system successfully underwent field trials, in the various modes, at Dong Chuan the Jiangsu Water operated research farm on the coastal reclaimed land east of Nanjing and north of the Yangtze River. This was despite typhoon build-up weather limiting fieldwork and a few equipment gremlins that are to be expected in a complex system such as this. In-situ EM conductivities of between 90 and 700 mS/m (1.4 to 11 Ωm) were measured, indicating mild to very saline conditions. Rice was already being grown on this land (1 km behind the current sea-wall).

Interestingly, the place where the field acceptance trial was carried out is 35 km east of Dong Tai city, which in the time of the Ming Dynasty (~1600 AD) was a coastal port. This fact signifies the importance of the rapid build-up of land in the growth (literally) of coastal arable lands in this area. The EM system will be used initially, by Liu Guangming and ISSCAS colleagues, to map salinity in these rich silt lands reclaimed from the sea, but is designed to operate all over China and will soon be used in the north to tackle the massive dryland salinity problem there. Hopefully this will be the first of many geophysical systems in use in China for mapping salinity and soils.

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Fig. 3. (Top) Typical reclaimed coastal silt flats in China, before rehabilitation.

Fig. 4. (Middle) University of Sydney/Cotton CRC EM Salinity mapping system (after Triantifilis et al., 2001) was used as a basis of the ISSCAS system.

Fig. 5. (Above) The completed ISSCAS EM salinity mapping system. Note the GPS console and antenna, front mounted EM31SH and rear mounted sleeve, with separate hydraulics system, containing the EM38RT.

Fig. 6. (Right) Proud owners of a new salinity mapping system (from left) ISSCAS staff: Li Dongshun, Xu Ligang and Liu Guangming.

Physical Properties of Zinc and Iron Rich Volcanogenic Massive Sulphides: Laboratory Scale Measurement Results

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Abstract

Volcanogenic massive sulphide (VMS) deposits are an important source of zinc. These deposits are commonly of a moderate size (<30 Mt), and are iron rich. The whole mineralised assemblage usually presents good physical property contrasts to host metasediments and metavolcanics, mainly from iron sulphides and oxides. Conductivities in the economic ore zones are not particularly high, being of the order of tens of S/m. These and other aspects of VMS deposits are discussed with reference to three Australian deposits: Hellyer, Rosebery and Scuddles.

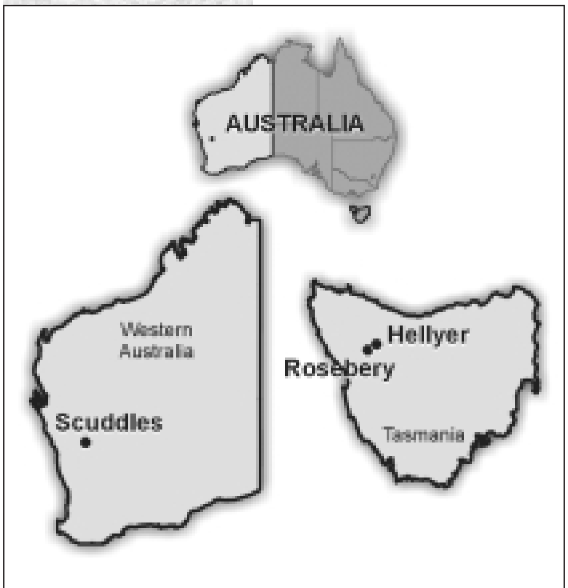

Fig.1. Location map for the three volcanogenic massive sulphide deposits discussed

Introduction

Some submarine volcanic accumulations of acid (rhyolitic) to intermediate (andesitic) composition host important stratiform exhalative deposits of Fe, Zn, Pb, Cu with lesser Cd, As, Sb, Bi and trace Au, Ag. Typically such banded and zoned ores occur in rhyodacitic environments comprising lavas, clastics, and associated (flanking) sediments, andesites and basalts. The deposits tend to be of moderate size, 5 to 30 Mt. For the Bathurst region in Canada, Lydon (1988) gives an average tonnage of 8.7 Mt for 29 Zn-Pb-Cu volcanogenic massive sulphides (VMS) with grades averaging 5.4%, 2.2%, 0.6%, 62 g/t, 0.5 g/t, for Zn, Pb, Cu, Ag, Au, respectively. Within Australia 16 deposits have an average resource of 8.5 Mt with grades averaging 3.77%, 1.18%, 1.29%, 48 g/t, 0.79 g/t, for Zn, Pb, Cu, Ag, Au, respectively. Using the average US dollar commodity price for the last decade and average metal recoveries we derive an approximate average in situ value for Australian VMS deposits of US$1.8 billion.

Around mineralisation the original host mineral suite of quartz, alkali plagioclase, biotite and hornblende (typically) is now quite altered. In the sulphide suite: pyrite is dominant; sphalerite, galena, chalcopyrite, arsenopyrite and tetrahedrite are subordinate, and pyrrhotite is variable but usually minor. The iron oxides magnetite and hematite may also be present. Iron is usually the major metal in the deposits, which often have ~20% Fe, mainly as pyrite. Associated or gangue minerals include quartz, chlorite, carbonates, sericite, barite, and gypsum.

The deposits can be richly textured. Grainsizes generally are fine, but coarsen with metamorphic grade. Sulphides may occur massively and/or as stringers or disseminations. The mineralisation may be rubbly, brecciated, colloform, banded, layered or laminated. Vertical zonation in chemistry, mineralogy and texture is a VMS characteristic (see Figure 2 in Lydon, 1988). The Cu/(Zn+Pb) ratio usually decreases upwards and outwards i.e. the base can be a zone of Fe and Cu (cupriferrous pyrite) and the top can be a zone of Fe and Zn/Pb (pyritic sphaleritic and galena). Further details on VMS characteristics may be found in Stanton (1990), Lydon (1988), and Davis (1977).

From the geophysical point of view, VMS deposits, although quite heterogeneous, should be good targets. They can reasonably be expected to be dense, conductive, and variably magnetic and therefore to present good physical contrasts relative to the host sequence. However, little has been published on directly measured physical properties. In this article mesoscale physical property data are presented for three of the larger, pyritic, zinc-rich Australian VMS deposits: Hellyer, Rosebery, and Golden Grove, all important underground mines. The data were collected as part of AMIRA Project P436 on the application of geophysics to mine planning and operations (Fullagar et al., 1996a). The locations of the deposits are shown in Figure 1 and a summary of features given in Table 1. Information on the detailed geology of these deposits may be found in McArthur and Dronseika (1990), Lees et al. (1990), and Mill et al. (1990), respectively. Comparisons of the previously mentioned average resource size and associated grades with the values quoted in Table 1 indicate the economic significance of these three deposits.

Hellyer, Rosebery, and Scuddles have been included in previously published discussions on the geophysical responses of VMS deposits. Bishop and Lewis (1992) concluded that electromagnetic (EM) techniques were particularly relevant to exploration for the conductive VMS ore types. However, they noted that iron poor, zinc rich, fragmented or silicified ores would not respond to EM, while extensive, near ore, black shale horizons (as at Rosebery) could act as a screen and mask any ore response. Bishop and Emerson (1999), in a review of zinc deposit geophysics, noted that zinc-rich VMS deposits generally are conductive, some highly so, even though zinc ore itself is resistive. Their ranking of prospecting methods, in order of decreasing utility, was: electromagnetics, IP/resistivity, gravity/magnetics. They also remarked on the paucity of physical property data.

Eadie et al. (1985) discussed the application of geophysics to Hellyer; Bishop and Lewis (1985) carried out underground IP measurements at Rosebery; and Craven et al. (1985) compared EM techniques at Scuddles.

Samples and Measurements

Fifty-three samples of ores and associated rocks were collected from the three mines: Hellyer 17, Rosebery 17, and Scuddles 19. Mine geology lithological designations are summarised in Table 2. Mesoscale (core, hand sample) physical property measurements were carried out on cores and shaped prisms to determine density/porosity, magnetic susceptibility, induced conductivity, galvanic resistivity (DC, 1 kHz), and ultrasonic P wave velocity (Fullagar et al. 1996b, c, d). The techniques used are outlined in Emerson (1990, 1969), Yang and Emerson (1997), and ISRM (1978)/Wyllie et al. (1958). Visually representative offcuts were selected for geochemical and petrological analysis. These data will be the subject of a future article.

Results

A summary of measurement results is given in Table 3.

The tabulated data show the rock suites to be hard (high P wave velocity) and tight (generally low porosity). Densities are sulphide dependent, with the barren country rocks having background values of ~2.8 t/m^3 while the sulphide horizons range up to 4.77 t/m3. The background density is higher than that of most silicate minerals and suggests additional ferromagnesium content. Magnetic susceptibilities depend on sparse magnetite in the ores at Hellyer, and on plentiful country rock magnetite and ore environment monoclinic pyrrhotite at Rosebery and Scuddles where the richest zinc ores are not necessarily especially magnetic.

Galvanic resistivities generally are quite high in the country rocks although some minor porosity development at Hellyer results in a few moderate resistivities contiguous to the ore. Below the water table macrofracturing could diminish these high resistivities significantly to present moderate bulk resistivities (100's Ω.m) to large measurement arrays (Emerson and Yang, 1998).

The textured nature of the mineralised zones leads to differences in inductively measures (EM) conductivity and galvanically measured (inverted) resistivity (Yang and Emerson, 1997). EM testing favours conductive bands that may be isolated in a resistive matrix. Nevertheless, most of the sulphide mineralisations are, in either sense, clearly more conductive than the host rocks. The contrasts are moderate for Hellyer, and extreme for Rosebery and Scuddles, except for their sphalerite rich zones.

Induced polarisation responses show good contrasts between the mineralised zones and country rocks at the three sites. However, minor sulphide occurrences in the country rocks give rise to quite measurable responses. The mineralised zone responses are somewhat exaggerated for the more massively sulphidic specimens owing to surface or electrode polarisation effects in the water bath measurement procedure (Emerson, 1969). Bishop and Lewis (1985) distinguished "target" material at Rosebery on the basis of higher chargeability and longer time constant.

Anisotropy can attain quite high values when resistivities perpendicular and parallel to foliation are considered, exceeding 10 000:1 for one Rosebery metasediment. Velocity anisotropy generally was moderate. [Compressional wave velocities were measured under load with an energising source frequency of 500 kHz].

		Mineralogy (main)							
Deposit	Resource	sulphides	gangue	grain size	Host	Ore Body	Discovery	Weathering	Comments
	(initial)	(zoned)		texture	(now highly altered)	(all roughly tabular)			
						(all dimensions approx			
						est. maxima)			
HELLYER	17 Mt			very fine grained					
Tasmania	13.8% Zn	py	qtz		Cambrian (520 Ma)	complex zone	1983	minor	Zn:Pb = 1.9
	7.2% Pb	sph	bar			800 m strike	UTEM anomaly		
long: 145.72	0.4% Cu	gal	calc		Mt Read Volcanics	200 m wide	(IP failure)		pyritic
	167g/t Ag	aspy	chl			43 m thick			
lat: -41.58	2.5 g/t Au	cpy	ser		andesitic volcanoclastic				mtt present
		tetr.	sid		h/w, overlain by pillow				
	[26% Fe]	po. (tr)	mtt		lavas; r. basalt basement	depth to top:			
				laminated	vesic.	90-500 m			
				& banded	met grade: prehnite-pump	(plunges)			
ROSEBERY	28 Mt			very fine grained					
Tasmania	14.2% Zn	py	bar		Cambrian (520 Ma)	complex sheeted zone	1893	minor	Zn:Pb = 3.3
	4.3% Pb	sph	carb (Mn)			1500 m strike	(prospectors)		
long: 143.56	0.7% Cu	gal	mtt		Mt Read Volcanics	100 m wide			pyritic
	155 g/t Ag	po	qtz			700 m depth extent			
lat: -41.78	2.9 g/t Au	aspy	chl		tuff shale horizon between	variable ore lenses			mtt & po present
		cpy	ser		h/w & f/w pyroclastics in	av. 6 m thick in			
	[14% Fe]	tetr.			dacitic-andesitic lava env.	this zone			po zones extremely
				laminated					conductive
				& banded	met. grade: chlorite	surface outcrop			
SCUDDLES	26 Mt			fine-coarse grained					
Western	8.2% Zn	py	mtt		Archaean (2950 Ma)	two lenses in zone	1979	extensive	Zn:Pb = 13.7
Australia	1.0% Cu	sph	qtz			600 m strike	120 nT mag	to 100 m	
	0.6% Pb	cpy	ser		Gossan Hill Group	50 m width	anomaly	-> clay	pyritic
long: 116.80	65 g/t Ag	po	talc			600 m depth extent	(corrob. by		
	1.1 g/t Au	gal	chl		h/w: rhyodacties		geochem)		mtt & po present
lat: -28.50		tetr	carb		f/w: andesitic/basalt volc.				
	[30% Fe]	aspy		laminated	seds.	depth to top:	subsequent D/D		po zones extremely
				& banded		~140 m	(200 m) IP and		conductive
					met. grade: mid/upper		various TEM		
					greensch		tests successful		

Table 1.

Discussion

The physical properties are better appreciated in crossplots. Approximate values for reference minerals are indicated on these plots in Figures 2 to 6. Rock texture and condition (brecciation, fracturing, alteration) can and will shift measured data away from the nominal values even when a rock is virtually monomineralic.

HELLYER	ROSEBERY	SCUDDLES
HE01 Chert	RB01 Silicified black slate	SC01 HW metasediment (magnetite)
HE02 Basaltic pillow lava	RB02 Chlorite sericite pyritic schist	SC02 Silicified metasediments
HE03 Hanging wall volcanic sediments	RB03 Massive po	SC03 Stringer zone pyrite + cp
HE04 Pyritic rich ore	RB04 Banded magnetite pyrite	SC04 Low iron sphalerite
HE05 Massive sulphide breccia ore	RB05 Massive pyrite + sphalerite	SC05 High iron sphalerite
HE06 Barite ore	RB06 Massive sphalerite	SC06 Footwall sediment
HE07 Banded massive sulphide ore	RB07 Banded B lens ore	SC07 Massive sphalerite+pyrite
HE08 Stringer zone	RB08 Banded J lens ore	SC08 Massive sphalerite
HE09 Stringer zone	RB09 Massive po + cp	SC09 Dolerite dyke Xcutting SC08
HE10 Massive sulphide magnetite rich	RB10 Massive banded pyrite minor silicifcation	SC10 Transitional ore
HE11 Sez weak alteration	RB11 Chlorite schist + diss pyrite	SC11 Flat lying dolerite dyke
HE12 Stringer zone moderate alteration minor py	RB12 Massive pyrite	SC12 Banded ore
HE13 Stringer zone strongly altered sil+py+sp	RB13 Massive magnetite + chlorite	SC13 Massive pyrrhotite
HE14 Massive pyrite breccia	RB14 Massive pyrite + sphalerite	SC14 Massive sulphide py+sp+cp(poikolitic)
HE15 Hanging wall volcanic sediments faulted	RB15 Massive banded pyrite + sphalerite	SC15 Silicified metasediment py minor po, cp
HE16 Massive sulphide breccia	RB16 Massive banded ore sp minor py, ga	SC16 Massive sulphide (py:sp, 97:3)
HE17 Silicified pyritic ore	RB17 Massive banded ore sp, ga, py	SC17 Massive sulphide (py:sp, 75, 25)
HE18 Massive sulphide breccia		SC18 Massive sulphide (py:sp, 60 40)
HE19 Barite rich ore		SC19 Massive sulphide (py:sp, 8, 92)

Table 2.

Figure 2 shows magnetic susceptibility against density for all rocks tested. There is a wide spread of values, from low to very high, in susceptibility/density space. The silicate, carbonate, and sulphate gangue reference minerals have not been plotted; they are either diamagnetics (negative susceptibility e.g. quartz, barite) or low to moderate paramagnetics (i.e. Fe dependent e.g. siderite ~500 x 10^{-5} SI). Pyrite is the dominant sulphide in the three deposits but it is practically non magnetic. The susceptibilities result from disseminated magnetite (not previously reported for Hellyer) or concentrated magnetite (Rosebery magnetite-chlorite zone) or concentrations of monoclinic pyrrhotite (Scuddles massive zone).

The ultrasonic compressional wave velocity plot against density for all samples in Figure 3 shows velocities ranging from moderate to very high. The data indicate two trends, with overlapping compressional velocity ranges, that are consistent with the VMS zonation (Lydon 1988). The first trend spans the high strength Quartz +/- Feldspar to the moderate strength sulphides (Chalcopyrite +/- pyrrhotite) of the disseminated and stringer lower zones. The second trend encompassing the sulphides represents the vertical zonation from the lower chalcopyrite +/- pyrrhotite stringer zone, through the economically important

Basic Physical Properties Summary - Laboratory Samples & Subsamples, AMIRA P436: Mean Values (range in brackets)										
rock property		mass		inductive (EM)		galvanic elec.			acoustic (ultrasonic)	
deposit & lithology	main sample i.d. nos.	DBD t/m^3	P_A percent	EM cond σ S/m	mag k $SI\times10^{-5}$	resist (lkHz) Ωm (air dry) (ρ_{max})	resist aniso ρ_{max}/ρ_{min}	IP charge ms	Pwave vel Vp m/s (max)	Pvel aniso V_{max}/V_{min}
Hellyer										
	(total 17)									
chert, basalt	1, 2	**2.66**	**2.5**		**45**	**875625**		**8**		
		(2.61-2.71)	(1.2-3.8)		(20-70)	(1250-1750000)		(4-12)		
h wall volc seds	3, 15	**2.73**	**2.2**		**40**	**263**	**1.5**	**35**	**5077**	**1.09**
		(2.68-2.78)	(0.6-3.8)		(30-50)	(88-438)	(#15 only)	(8-61)	(#15 only)	(#15 only)
stringer zones	8, 9, 11, 12, 13	**2.89**	**1.9**		**36**	**3408**	**2.1**	**46**	**4979**	**1.21**
		(2.74-3.41)	(0.5-3.9)		(10-70)	(33-10056)	(2.0-2.1)	(8-164)	(4243-5627)	(1.04-1.34)
barite ore	6	**3.91**	**0.8**		**35**	**5357**		**12**		
massive $S^=$/bx ore	5, 7, 16, 18	**4.44**	**0.3**	**43**	**964**	**10**	**2.2**	**208**	**5046**	**1.07**
		(3.47-4.77)	(0.2-0.5)	(9-110)	(60-2650)	(0.09-40)	(2.1-2.3)	(113-328)	(4745-5346)	(1.05-1.09)
py/py ore/bx	4, 14, 17	**4.36**	**0.3**	**11**	**137**	**113**	**288**	**178**	**5643**	**1.05**
		(3.76-4.71)	(0.1-0.4)	(2-23)	(20-300)	(0.06-338)	(1.6-574)	(37-375)	(4847-6438)	(1.03-1.06)
Rosebery										
	(total 17)									
slate, schist, mtt/py	1, 2, 4, 11	**3.08**	**0.7**		**6403**	**57075**	**2635**	**75**	**5726**	**1.07**
		(2.84-3.52)	(0.3-1.3)		(10-28600)	(7620-169674)	(2.7-10521)	(14-149)	(5635-5862)	(1.05-1.09)
mtt/chlorite	13	**4.81**	**0.4**	**20**	**250000**	**1.19**	**8.8**	**164**	**5950**	**1.26**
massive py (+ZnS, + banding)	5, 10, 12, 14, 15	**4.46**	**0.2**	**74**	**4103**	**1.73**	**9.7**	**283**	**6086**	**1.07**
		(4.10-4.77)	(0.1-0.2)	(0-360)	(60-15000)	(0.13-5)	(1.7-25)	(104-457)	(5350-6600)	(1.02-1.10)
massive po (+cpy)	3, 9	**4.34**	**0.8**	**52333**	**7500**			**324**	**4432**	**1.08**
		(4.3-4.38)	(0.5-1.0)	(45000-60000)	(2598-17500)			(107-540)	(4414-4450)	(1.06-1.10)
massive sphal	6	**3.89**	**0.2**		**101**	**6059**	**367.2**	**32**	**4958**	**1.03**
					(46-160)					
banded polymet ores	7, 8, 16, 17	**4.39**	**0.2**	**3.5**	**383**	**25.3**	**4.2**	**204**	**5102**	**1.3**
		(4.21-4.63)	(0.1-0.3)	(2-5)	(21-1100)	(0.2-115)	(3.63-4.77)	(43-326)	(4651-5912)	(1.16-1.44)
Scuddles										
	(total 19)									
metased	1, 2, 6	**2.9**	**0.5**		**10040**	**29413**	**6.6**	**80**	**6286**	**1.16**
		(2.76-3.04)	(0.2-1.0)		(30-40000)	(1460-98901)	(#6 only)	(10-153)	(#6 only)	(#6 only)
dolerite	9, 11	**2.77**	**0.5**		**44**	**275527**	**17.2**	**3**	**6231**	**1.15**
		(2.75-2.78)	(0.5-0.6)		(32-55)	(236133-314921)	(4.0-30.5)	(3-3)	(6226-6235)	(1.07-1.22)
massive po	13	**4.27**	**0.4**	**13200**	**73333**			**198**	**5460**	**1.03**
					(36000-104000)					
py ores (cpy, mtt, po)	3, 7, 10, 14, 15, 16, 17, 18	**4.16**	**0.3**	**280**	**8959**			**220**	**6263**	**1.07**
		(3.45-4.44)	(0.1-1.0)	(3-2246)	(300-32360)			(125-433)	(4927-7076)	(1.00-1.15)
sphalerite ores (po)	4, 5, 8, 12, 19	**3.81**	**0.6**	**2**	**5038**	**6000**	**254**	**70**	**5236**	**1.08**
		(3.31-4.04)	(0.1-1.4)	(#4 only)	(73-12000)	(509-21245)	(2-455)	(24-147)	(5021-5356)	(1.06-1.10)

Table 3.

Conductivity	Hellyer (S/m)	Rosebery (S/m)	Scuddles (S/m)
geometric mean of all sulphidic samples	9	52	55
geometric mean of a sample subset with assays similar to resource grade	4	3	11
inferred from exploration data	6	n/a	7

Table 4.

sphalerite zone and up to the very high strength pyrite magnetite upper or fringe zone.

For the sulphidic rocks, maximum-recorded conductivities, from either inductive EM or DC galvanic measurements, are plotted against density and magnetic susceptibility in Figures 4 and 5, respectively. The pyrrhotite rich, very conductive Rosebery and Scuddles zones plot as outliers, near the reference (monoclinic) pyrrhotite. The other mineralised lithologies are not very conductive with conductivities ranging from about 1 to 100 S/m. Such values are typical of pyrite dominated sulphide systems. Maximum conductivity and density are poorly correlated, but there is a weak correlation between conductivity and susceptibility for the pyrrhotite poor samples (<200 S/m). For Rosebery and Scuddles, away from the pyrrhotite rich zones, it is thought that magnetite enhances the conductivity of the pyritic units. Half of Hellyer is pyrite; pyrrhotite occurs only in trace amounts. Any rise of conductivity with increasing mag k is thought to be a textural effect in the pyrite (e.g. improved grain suturing) associated, not necessarily causally, with more disseminated magnetite and/or paramagnetics such as siderite.

For all samples the density chargeability crossplot in Figure 6 indicates a very weak positive correlation. The data can be segregated into two clusters, each displaying a more positive correlation and having a similar slope. The lowest density cluster (2.5 to 3.5 t/m^3) contains all the measurements on host samples and some of the weaker mineralised ore samples. As sulphide minerals are the dominant cause of conductivity in all samples it seems reasonable to speculate the two clusters broadly represent different mineral texture groups. The two clusters have overlapping chargeability ranges with the less dense biased towards the low end and the denser biased towards the high end.

It is interesting to consider the conductivities further, as summarised in Table 4. An analysis of the published TEM responses for Hellyer and Scuddles suggests conductances of 118 S and 110 S, respectively, from which effective conductivities of 5.7 S/m and 7.3 S/m are inferred, respectively, given the mineralised lens' likely thicknesses. These conductivities are similar to the geometric mean of the economic ores' conductivities as shown in Table 4. It seems that the effective conductivities of the economically important zones of VMS deposits (or at least for the three deposits considered here) are not high, being of the order of a few S/m to a few tens of S/m. The most important mineralisation in VMS deposits is unlikely to be the most responsive, geophysically.

In establishing a petrophysical database from hand and core samples, the geostatistical representivity of the sample set is a key concern. The 3D sampling density is a crucial issue since it determines whether the variability within the volume of interest is adequately represented. For resource and reserve estimation, variography of assays data can characterise the spatial variability within a deposit/lens, providing an indication of the number of samples required to capture the petrophysical variability. Ultimately, time and availability of appropriate samples (more than dollar cost) limit the number of rock samples which can be submitted for comprehensive petrophysical analysis. The small data sets considered here by no means completely define the ranges of physical properties at Hellyer, Rosebery, and Scuddles but they do give a useful indication of the physical characteristics of VMS deposits.

Conclusions

The polymetallic mineral assemblage precludes the detection and measurement of compressional velocity as an exploration targeting tool. The remaining physical properties examined all show a range in contrasts and suggest that geophysical surface responses, related to mineralisation, should be recorded in careful surveys. The ability to define the economic portion of a deposit is problematic as the iron sulphides dominate the density and conductivity, while the iron oxides dominate the magnetic susceptibility. Chalcopyrite, sphalerite and galena have physical properties in between those of the iron oxides/sulphides and the host minerals. Clearly the use of this information to help an exploration program also requires an understanding of the weathering profile, the degree of lithological variation within the host rock, degree of variation and sharpness to the alteration halo surrounding the ore and the economic content of the ore.

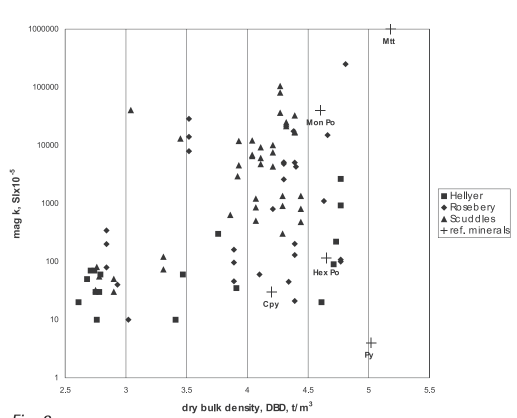

Fig. 2.

Fig. 2. Crossplot of magnetic susceptibility against dry bulk density for the VMS sample suites. Ref. minerals are plots of the nominal "textbook" values for the important mineral components in their crystalline form. Given the natural variations that can occur (e.g. very minor doping of a pyrite crystal can change its conductivity) they are to be regarded as indicative only.

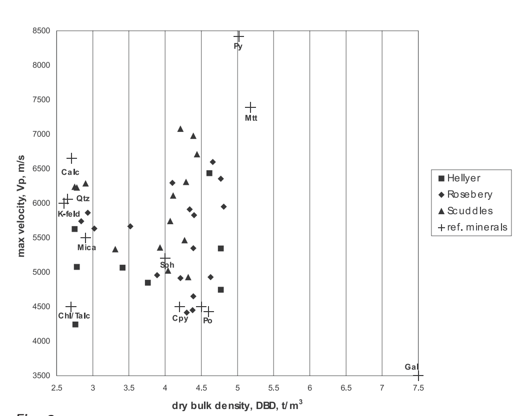

Fig. 3.

Fig. 3. Crossplot of ultrasonic velocity against dry bulk density for the VMS sample suites. See caption for Fig. 2 for ref. minerals explanation.

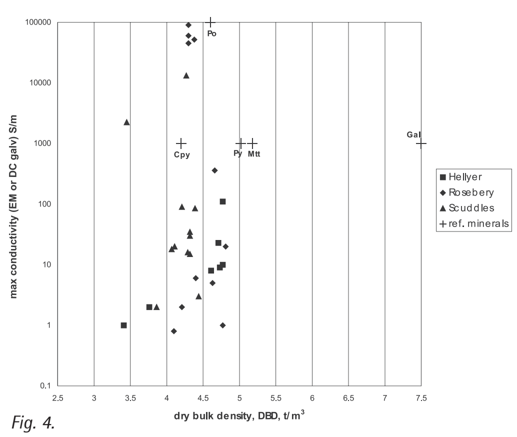

Fig. 4.

Fig. 4. Crossplot of maximum conductivity against dry bulk density for the VMS sample suites. See caption for Fig. 2 for ref. minerals explanation.

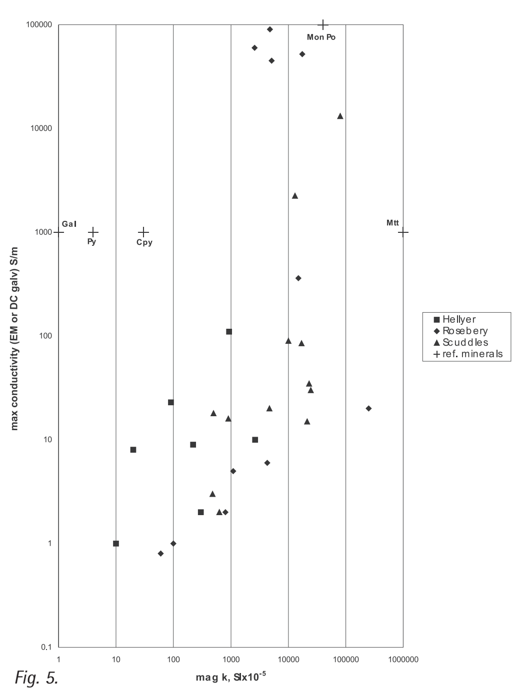

Fig. 5.

Fig. 5. Crossplot of maximum conductivity against magnetic susceptibility for the VMS sample suites. See caption for Fig. 2 for ref. minerals explanation.

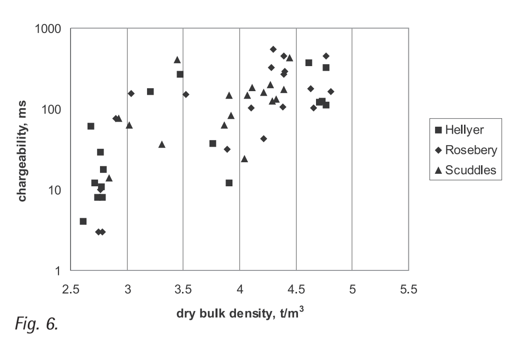

Fig. 6.

Fig. 6. Crossplot of chargeability against dry bulk density for the VMS sample suites.

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Perturbations in 4D Marine Seismic

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Keywords

Calibrated seismic data, perturbations, Q-Marine, 4D seismic, single sensor recording, Notional Source Method, steerable streamers.

Summary

A new concept for acquiring calibrated towed streamer seismic data is introduced through a new acquisition and processing system. The specification of the new system has been defined by rigorous analysis of the factors that limit the sensitivity of seismic data in 4D studies and imaging. New sensor and streamer technology, new source technology and advances in positioning techniques and data processing have addressed these limitations.

Sensitivity analysis revealed that the most significant perturbations to the seismic signal are swell noise and sensor sensitivity variations. Conventional analog groups of hydrophones are designed to suppress swell noise, however, a new technique for data-adaptive coherent noise attenuation delivers even greater noise suppression for densely spatially sampled single-sensor data.

Although modern source controllers provide accurate airgun firing control, the signature of an airgun array may vary from shot to shot. This can be due to factors such as changes in the array geometry, air pressure variations, depth variations and wave action. A method for estimating the far-field signature of a source array is the Notional Source Method (proprietary to Schlumberger), which has been steadily refined since its first disclosure. A recent development compensates for variation in source array geometry by monitoring the position and azimuth of each subarray using GPS receivers mounted on the floats.

New calibrated positioning and streamer control systems are part of the new acquisition system. Active vertical and lateral streamer control is achieved using streamer steering devices called Q-fins and positioning uncertainty is reduced through an in-built fully braced acoustic ranging system.

Calibrated marine seismic data are achieved through quantifying the source output, the sensor responses and positioning uncertainty. The consequential improvements in seismic fidelity result in better imaging and more reliable 4D analysis.

Introduction

Reservoir monitoring using time-lapse or 4D seismic has demonstrated its effectiveness for understanding the dynamic behaviour of the reservoir and its value for reservoir management. 4D seismic studies can:

- Map fluid movements, pore fluid saturation changes and pressure changes,
- Identify unswept oil and infill drilling opportunities,
- Identify flow units and flow barriers,
- Monitor the performance of enhanced recovery programs, and
- Quantify and constrain the spatial properties of the reservoir model.

Most time-lapse survey interpretations have been made for reservoirs with highly porous sands where fluid replacement has the greatest effect on seismic response. The largest time-lapse signals are induced by the replacement of either oil or water by gas; the replacement of oil by water generally leads to a smaller time-lapse signal. Altering the pressure regime within a reservoir will induce time-lapse anomalies within the data, and the period between surveys will also affect the magnitude of the time-lapse signal.

The method has a yet unrealized potential that will open for wider use if higher repeatability and greater sensitivity can be obtained. Wider applications could be more quantitative interpretations, monitoring over shorter time intervals and application of the technology to smaller, tighter and more complex reservoirs. However, the time-lapse signal, like all signals, is only detectable if it is not masked by noise. Perturbations (errors and differences) between different phases of a 4D seismic study create noise when datasets acquired at different times are analysed for changes. This noise can mask the subtle variations in the seismic response of the reservoir that indicate changes in pore fluids. The sources of the perturbations can be internal or external to the acquisition system. Examples of internal perturbations are hydrophone calibration variations and positioning errors. External perturbations include environmental effects such as rough sea and tidal variations. We can divide the perturbations (internal and external) into:

- Those that affect the received signal such as sensor sensitivity variations and ambient noise like swell,
- Those that affect the emitted source signature such as shot-to-shot variations in the source output and the array directivity, and
- Those that affect positioning accuracy and reliability such as sea currents and positioning network.

The effects of these perturbations have been studied using both modelled and real data examples and the impact on seismic data quality quantified. It was with these factors in mind that Schlumberger developed a new marine acquisition system called Q-Marine. The design features of this system, which differentiate it from 'conventional' marine acquisition systems may be summarised as follows:

- Calibrated sensors individually recorded,
- Calibrated positioning with streamer steering capability, and
- Calibrated sources.

These features are intended to address the sources of perturbation that impact on the quality of seismic data both for high-resolution imaging and repeatability in 4D studies.

Control of Perturbations

Calibrated receivers

The two most significant perturbations to the signal received by a towed streamer are swell noise and sensor sensitivity. Conventional streamers contain hard-wired

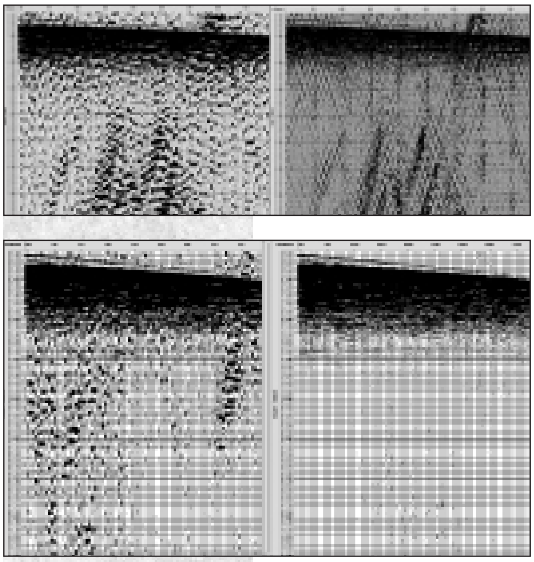


Fig.1. (Top) Comparison of shot domain data recorded simultaneously on conventional analog group-forming streamer (Nessie 4 left) and a point-receiver streamer (right).

Fig. 2. (Above) Comparison of shot domain shown in Figure 1 after digital group forming using the data adaptive coherent noise filter.

spatial arrays of hydrophones designed to suppress noise, these arrays also act as a spatial filter for non-vertical seismic ray paths. Connecting the outputs of individual receiver elements forms receiver groups, however, there are drawbacks associated with the nature of the analog array. The outputs of these elements are simply summed without any processing applied, as the group forming is hard-wired in the acquisition system. The ideal would be to record each individual receiver element into its own seismic channel (single sensor recording) so that a dense grid of receivers samples the wavefield alias-free, however, this has been prohibited by cost and equipment limitations. The Q-Marine system is able to record data from each single sensor in the streamer and can record more than 4000 individual hydrophones on each of up to 20 streamers giving a total of up to 80 000 channels. Onboard computer processing systems perform sophisticated noise attenuation much more effectively than hard-wired arrays, while preserving signal amplitude. The processing system compensates for individual hydrophone sensitivity variations and dropouts. New proprietary high fidelity tubular hydrophones are used; each delivered with its own aging profile and sensitivity certificate. These values are stored in the streamer electronics for automatic data calibration.

Recording individual sensors allows more effective removal of noise caused by the movement of the equipment through the water. The principal noise source affecting marine towed streamer data is the flow of water across the streamer. Vertical cross-flow can be introduced by wave action and is often termed swell noise. Horizontal cross-flow is introduced by the towing of the equipment and local water currents. All sources of cross-flow generate vibrations in the streamer in a number of characteristic modes, appearing completely chaotic and impossible to handle in data from conventional streamer groups due to inadequate spatial sampling. The same noise will, however, from single sensor records appear coherent and removable, utilizing adaptive noise attenuation methods (Figures 1 and 2).

A new technique for data adaptive coherent noise attenuation has been developed (Özbek, 2000) which delivers greater noise suppression for densely sampled point receiver data than conventional arrays. The method works by searching for coherent low frequency, low velocity noise fields across groups of adjacent traces. A suitable multi-channel filter is then defined to attenuate the noise while leaving the reflected signal. The result is a significant improvement of the signal-to-noise ratio (in the region of 6-12dB) of the seismic data, and increased robustness against noise during data acquisition in marginal weather (Figure 2).

Calibrated positioning

Repeatability of the acquisition footprint is regarded as the key requirement for 4D surveys. Some of the most successful 4D studies have been those conducted using the same acquisition configurations between successive surveys. This means identical streamer lengths, separations and depths. The source arrays should be identical with the same tow depths, sailines should have identical directions and shot locations to those of the baseline survey. With a conventional towed streamer system it is very difficult to exactly replicate receiver positions due to the effects of current on streamer feathering.

Variations in the acquisition footprint from survey to survey also depend on positioning accuracies. Relative positioning accuracies across a spread depend on a combination of GPS nodes, acoustic range-finders and compasses and the performance of a network solver. Crossline accuracies are poorer than inline and conventional systems have crossline errors which may be as high as 12 m. Archer *et al.* (1999) studied the effects of positioning errors and Morice *et al.* (2000) analysed the impact on 3D imaging as functions of dip and frequency. In broad terms they suggest a target accuracy of 2-3 m is required to reduce non-repeatable noise in a 4D signal below other sources of error.

The new system provides lateral steering of the streamers in addition to depth control. Utilising this, it is now possible to steer several degrees laterally from the natural streamer feather angle. This ability is coupled with a new positioning system based on a fully braced acoustic network from the front to the tail of the streamers, providing greatly improved relative and absolute accuracy. Using the new steering system, streamers can be towed with crossline separations of as little as 25 m.

Streamer steering devices (Q-fins) are mounted inline with the streamer to avoid noise and provide the desired mix of horizontal and vertical force with their two independently operating wings (Figure 3). The ability to steer horizontally provides close and constant streamer separation giving improved crossline sampling and the ability to steer for optimal sub-surface coverage and repeatability from survey to survey.

The new accurate positioning system provides a full streamer acoustic network, independent of streamer length. The acoustic positioning sources generate a robust broadband signal with each acoustic source having its own signal code enabling simultaneous shooting. The positioning signal can be received by any seismic hydrophone in the streamer and a super-fast acoustic network-solver performs correlation and range calculations. The result is an absolute positioning accuracy better than 3 m anywhere along the streamers.

Streamer steering and accurate positioning improves the safety of seismic operation in busy oil fields as the streamers can be steered around potential hazards such as surface installations.

Calibrated sources

The signature of an airgun source array is known to vary from one shot to the next depending on variations in the individual airgun firing times, airgun chamber pressure, sea conditions and array geometry. These shot-to-shot variations reduce the accuracy and resolution of the seismic data, and can mask subtle effects due to reservoir pore fluid changes in time-lapse studies. Figure 4 shows how modelled changes in fluid contract can be masked by source and receiver variations.

Removal of these shot-to-shot variations may be accomplished by signature deconvolution for which the far-field signature is required. This is the signal that would be recorded by a hydrophone placed directly below the source array. The distance from the source array needs to be sufficient such that the array output appears to the hydrophone as a single pulse rather than a number of pulses from the individual airguns. As this distance is in excess of 100 m, it is impractical to record the far-field signature during production.

Fig. 3. Inline streamer steering device called a Q-fin. The two wings operate independently to allow vertical and lateral steering. Tests show that these devices generate less noise than conventional depth control birds.

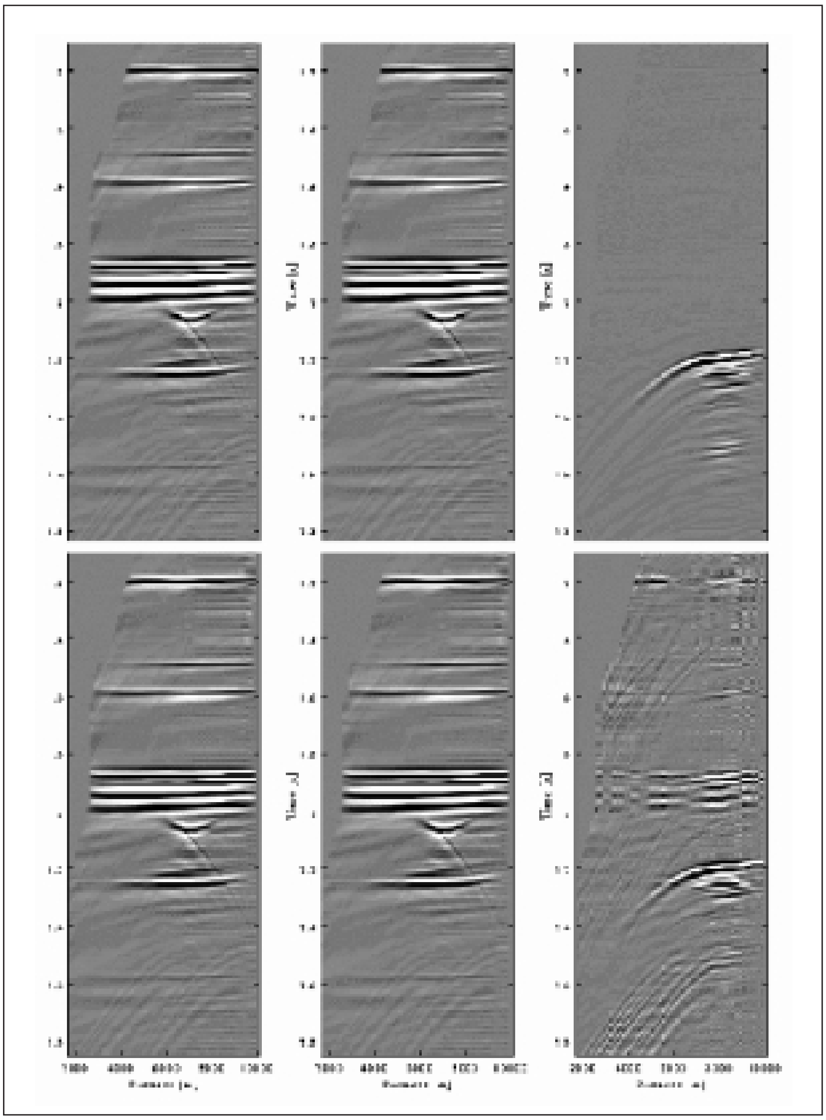
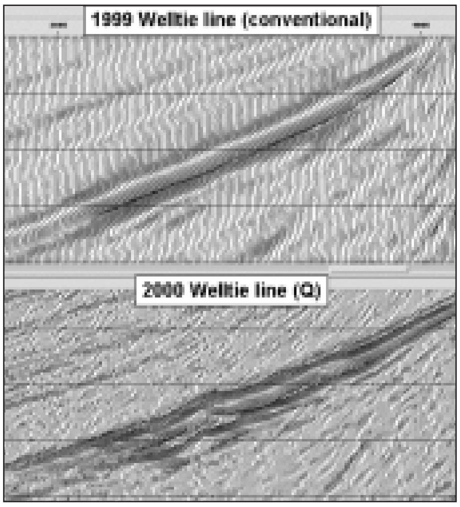


Fig. 4 (Right) The upper three plots show modelled data with a 5 m change in the oil/water contact. The time-lapse change (right) is as much as 25dB lower than the seismic response of the reservoir. The lower three plots illustrate how the 'noise behind the signal' from random shot amplitude variations and random receiver sensitivity variations can mask the seismic differences. The variations of 5% in each case are realistic ranges for conventional technology.



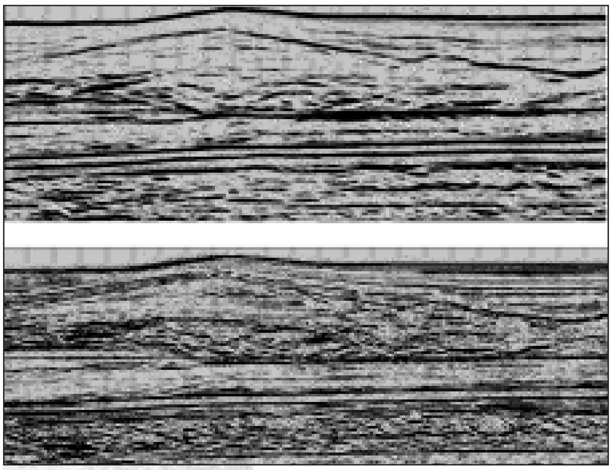


Fig. 5. (Top) Conventional and Q data examples showing the improved resolution in the Q data.

Fig. 6. (Above) Conventional (top) and Q data (bottom). Data recorded by conventional arrays smear energy across CMPs; improved lateral resolution results from recording single sensors.

The far-field signature can be estimated from the combination of array components. One approach is to use a static gun signature from a library of previously recorded gun signatures and combine these using special source modelling software to calculate a far-field signature. The downside of this method is that the estimate does not include shot-to-shot variations caused by timing, air pressure changes and varying depths etc.

A better approach is to use a real signature for a gun recorded during the shot, by a near field hydrophone (NFH), which is placed directly next to each gun. However, each NFH not only receives the acoustic pulse from its own gun but also its ghost arrival bounced off the sea surface, signals from all other guns in the array and their ghost elements. Thus the NFH is not a pure measure of the gun signature. The new system takes the recorded NFH signals and computes an 'uncontaminated' near field signature in real time. This is done using the Notional Source Method of Ziolowski *et al.*, (1982) which takes into account the various pressure wavefields and the relative movement of the bubbles to generate a notional source signature. The notional sources are calculated by subtracting scaled and time delayed signatures of the adjacent airgun hydrophones from each respective airgun reference hydrophone. The source geometry is used to calculate the travel path distance and time delays of the adjacent interfering energy and accurate measurements of the source geometry are derived from dGPS units on the subarray floats. The far-field signature is then derived from the notional source signatures, raw NFH signals, notional source signals and the computed far-field signature estimate are recorded on auxiliary channels on tape for each shot. The far-field signature is then used for accurate source deconvolution during processing. A further refinement is that by combining the notional source signatures offline, far-field estimates with operator selected azimuth, angle or surface reflection coefficients can be generated.

Experiments using a hydrophone towed deep below the source showed excellent agreement between the measured far-field signal and the estimate arrived at by the notional source algorithm. Compensation for the shot-to-shot variations improves the bandwidth of the seismic data and enhances the accuracy of advanced analysis such as AVO. Measurement and compensation for variations in the source signature between phases of a 4D study removes a major perturbation from the time-lapse signal.

Conclusions

Data recorded with the new generation of acquisition system will minimise the impact of the acquisition footprint on time-lapse interpretations. The amount of ambient noise in the data will be greatly reduced through the use of single sensor recording and digital group forming. The quality of the final image and frequency content of data will be improved (Figures 5 & 6) and the accuracy of interpretations will improve to enable the detection of weaker time-lapse signals. This will allow periods between monitoring surveys to be reduced giving greater control of the reservoir management.

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Improved Near Surface Mapping in Groundwater Studies: Application of Fast-Sampling Time-Domain EM Surveying Methods

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Introduction

There are a limited number of methods currently in use to gather information on the various hydrogeological/environmental problems that are part of "everyday" life. Traditionally, groundwater problems have been evaluated and then monitored using a carefully designed network of wells where water depth and quality are measured on a regular basis. In recent years, some of the various mining and petroleum oriented geophysical techniques have been modified from their deeper applications to sample at shallower depths (Poeter et al., 1997). Often the goal of these surveys is to help geologists and engineers determine whether their assumptions on well location and water flow are correct. Techniques that have been used include shallow seismics (Bachrach and Nur, 1998), DC resistivity (Benson et al., 1997), ground penetrating radar (Hagrey and Muller, 2000), frequency domain electromagnetics (FDEM) (Acworth, 2001), and time domain electromagnetics (TEM) (Yang et al., 1999).

Recent advances in sampling speed, circuitry speed, and data recording have allowed the development of TEM techniques where data can be taken faster (and therefore start closer to the surface), and with better resolution of the top 15-50 m. These techniques include the Zonge Engineering NanoTEM system and the fast sampling modifications to the SIROTEM-3 system.

This paper briefly summarises the TEM results from three separate study areas encompassing a range of hydrogeological and environmental problems, each of some immediate importance in Australia at this time. The first study, at the Stockyard Plain Disposal Basin (SPDB) near Waikerie, South Australia, examines the changing hydrological environment around a groundwater disposal basin in the Murray-Darling system. The second study, in the Willaura Catchment in Victoria, examines water mobility in an evolving dryland salinity system. The third study, at an abandoned mine site in New South Wales, attempts to delineate the extent of acid-mine drainage in the area around the mine.

Aims

Some of the long-term aims of these types of geophysical surveys are to:

(a) Develop relationships between downhole geophysics and revised, local stratigraphy, so that downhole methods can be used to "map" the occurrence or absence of formations on a broader, regional scale. Regional mapping may help in borehole site selection.

(b) Use geophysical techniques to map the spread of groundwater mounds beneath irrigation areas, the alluvial groundwater quality, the water quality within mounds (variation of salinity with depth), and revise/expand the hydrostratigraphy based on the results of this type of work.

(c) Use geophysics to monitor the efficiency of various schemes that are aimed at improving water quality to help determine their effectiveness.

Methods

All of the time domain data in this paper were taken using a Zonge Engineering and Research Organization NanoTEM system. In each case the transmitter loop had 20 m sides, with a centrally placed horizontal receiver loop of 5 m sides. For each study the transmitter turn-off time was approximately 2 μs, while the turn-on time was less than 2 μs. The sampling rate was set either to 1.2 or 1.6 μs (depending on the depth and resolution desired). Assuming a 5 Ω.m ground, and the first sample taken within 4 μs of the top of transmitter turn-off ramp, information for the first data window is shallower than 4 m.

Although field-data acquisition is not as fast as some FDEM techniques (such as Geonics EM34), several line-km of TEM data can be collected in a day. For example, in the Willaura survey 120 measurement sites separated by 20 m were obtained in less than 15 hr (i.e. 1 line-km of data in 6.25 hr). Data quality for all of the sites reviewed here was exceptionally good. As with most electrical geophysical surveys, larger distances from roads, powerlines and urbanisation leads to better data quality. Both the Stockyard Plains data set and the Acid-mine Drainage data set were taken at remote locations, fairly distant from noise sources. Although half of the Willaura data were collected within 50 m of a small powerline, they were also of very good quality.

All the data displayed in this paper were inverted using Zonge Engineering's smooth-model inversion program STEMINV. Smooth-model inversion is a robust method for converting TEM measurements to profiles of resistivity versus depth. Observed TEM dB/dt magnitude data as a function of time for each station were used to determine the parameters of a 1-D layered-earth model. Layer resistivities were then adjusted iteratively until the model TEM response was as close as possible to the observed data, consistent with smoothness constraints. Lateral variations in resistivity were determined by "stitching" together inverted 1-D profiles from successive stations along a survey line to create a 2-D section (MacInnes, 2000). Results were contoured using the Geosoft geophysical contouring package: warm colours in the NanoTEM sections displayed below indicate conductors and cold colours indicate resistors.

Stockyard Plain Disposal Basin

Background: Intercepted saline groundwater and drainage-effluent from irrigation are commonly stored in both natural and artificial saline disposal basins throughout the Murray-Darling Basin. Concerns have been expressed about the possible environmental impacts these disposal basins

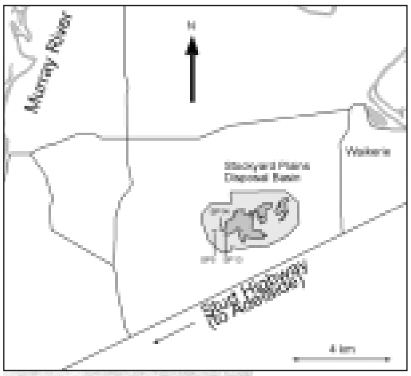


Fig. 1. (Top) Approximate location of Stockyard Plain Disposal Basin, near Waikerie, South Australia (Australian Water Environments).

Fig. 2. (Above) Location of Stockyard Plain Disposal Basin, and traverse. Note that Waikerie (and therefore the source wells for the water dumped here) is approximately 15 km to the northeast of the traverse (modified from Australian Water Environments). The boreholes MW2 and SP14 are situated within a few cm of each other.

may have, particularly on underlying groundwater systems and subsequently on surrounding low-lying land and river systems. Their continued use as wastewater evaporation sites therefore requires a detailed understanding of the groundwater dynamics beneath them. Of critical importance is leakage into underlying aquifers and the potential for salinisation of surrounding land, groundwater, streams and rivers. This study examined the use of non-invasive geophysical techniques to determine extent of saline plume migration and efficacy of saline groundwater disposal at Waikerie, South Australia.

Saline groundwater interception schemes have been in place along the River Murray at Waikerie and Woolpunda since the late 1980's. Saline ground water is intercepted before it enters the river and is then pumped to a natural depression approximately 15 km southwest of Waikerie, known as Stockyard Plains. Figures 1 and 2 are maps that show the approximate location of the field area.

Early in 2001, Adelaide University approached Australian Water Environments to test whether geophysical techniques could be used to help monitor the flow of groundwater in the area. A 500 m transect on the western side of the lake was run as a pilot study. A number of methods were tested at that time including TEM, FDEM, GPR and DC Resistivity. This paper concentrates only on the results of the TEM; full results of the study are provided in Barrett (2001).

NanoTEM Results and Discussion: Figure 3 shows inverted 1-D models contoured as a 2-D section of all data to the limit of data resolution between 45-70 m depth. Resistivities vary from > 50 Ω.m at the westernmost site (next to borehole SP5), to < 1 Ω.m adjacent to the lake (next to borehole SP13). The approximate water table depth (from boreholes SP13, SP14, MW2 and SP5) is shown by the solid black line. The prominent low resistivity layer is most likely clay.

Figure 4 shows the inversion for the top 15 m from the surface. The approximate water table depth (from boreholes SP13, SP14, MW2 and SP5) is shown by the solid black line. A thin clay layer (of resistivity < 2 Ω.m) is evident in the eastern section over depth range 3-8 m beneath SP13, SP14 and MW2. It is interesting to note how the shallow resistive layer in the east deepens to the west, apparently following a perched water table.

Willaura Catchment

Background: The Willaura catchment is located on the southeastern side of the Grampians Ranges in western Victoria (Figure 5). Much has been learned about the Willaura catchment from a series of investigations carried out starting in the early 1990s. It is clear that there is much more surface and sub-surface water now mobile within the Willaura catchment. Such increase in water prominence has major implications to landholders who depend on the land for their livelihoods. It is not only the obvious increase in water that is important, but also the serious implications as to the mobility of salt in the near-surface that is critical. The quantification of the mechanisms giving rise to this increase in water-flow is still a significant challenge. A number of scenarios have been put forward that act individually or in combination.

These include:
- Altered drainage and lake management practices,
- Excessive recharge occurring on the Grampians colluvial slopes,
- Increased local rainfall since the 1940s,
- Increased runoff and recharge across the landscape generally, and
- Increased runoff and recharge concentrated in the cleared Stavely Hills,

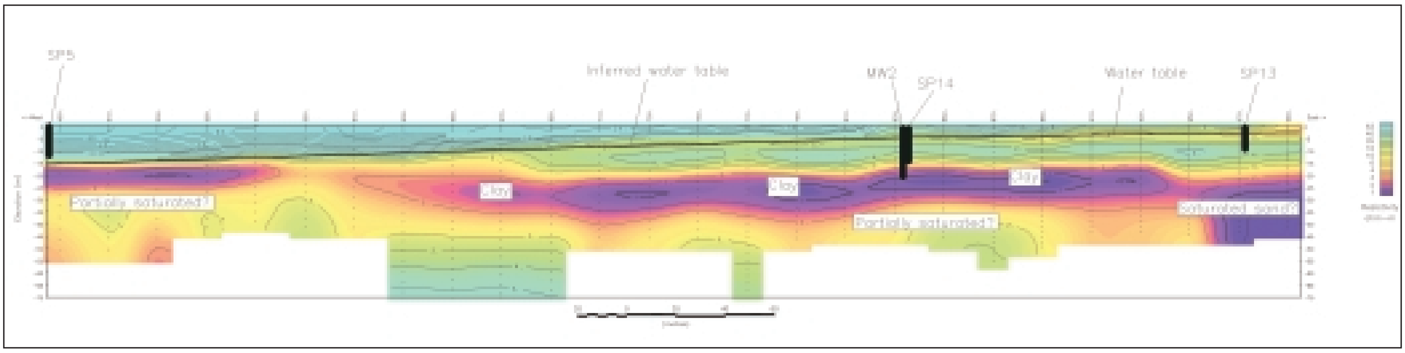
The survey transect reported in this paper follows Helens Rd (approximately 5 km west of Willaura Township) along gently sloping topography from north to south.

For most of the area there is a shallow layer of Pleistocene basalt quite close to the surface (within 4 m at Bore 103350). North of Wedding Lane three basalt flows are evident in bore logs and are inferred from airborne magnetic data. South of Wedding Lane the airborne magnetics indicate that a thin flow is present (Street et al., 1998). Below the basalt, at approximately 65 m depth, are Ordovician sandstones and shales. Soils are noted to be ~3 m thick. Figure 6 shows a schematic view of the interpretation of the area based on evidence available before 2001.

Strong features in airborne magnetics on the southwestern margin of Lake Muirhead have been interpreted as greenstone axes with associated bedrock faulting (Street et al., 1998). Heislers (1998) suggested that although such greenstones structures usually act as a barrier to groundwater flow from the north, they can also act as a conduit for preferential groundwater flow (e.g. leakage from Lake Muirhead) that may ultimately seep into underlying basalt aquifers (and therefore mix with surface waters in local creeks). Strontium and tritium isotope analyses reveal that younger, fresher basaltic water is mixing with older, more saline Ordovician sandstone and shale water (Bennetts, 2001).

NanoTEM Results and Discussion: Figure 7 shows inverted 1-D models contoured as a 2-D section for the top 100 m of ground. Resistivities vary from > 25 Ω.m to < 1 Ω.m adjacent to Boggy Creek and other saline features.

Deeper resistive units have been interpreted from aeromagnetic data as linear greenstone units (Street et al., 1998). The resistive unit labeled as fresh basalt matches well with occurrence of basalt in Bore 327 and Bore 103350. There is water in Bore 103350 at <2m depth, suggesting the existence of a perched water table over the fresh basalt (correlating with the slightly more conductive unit apparent above the basalt). Resistivity of this unit decreases markedly at 15 to 30 m depth, suggesting that this is the "true" water table over the northern half of the survey area.



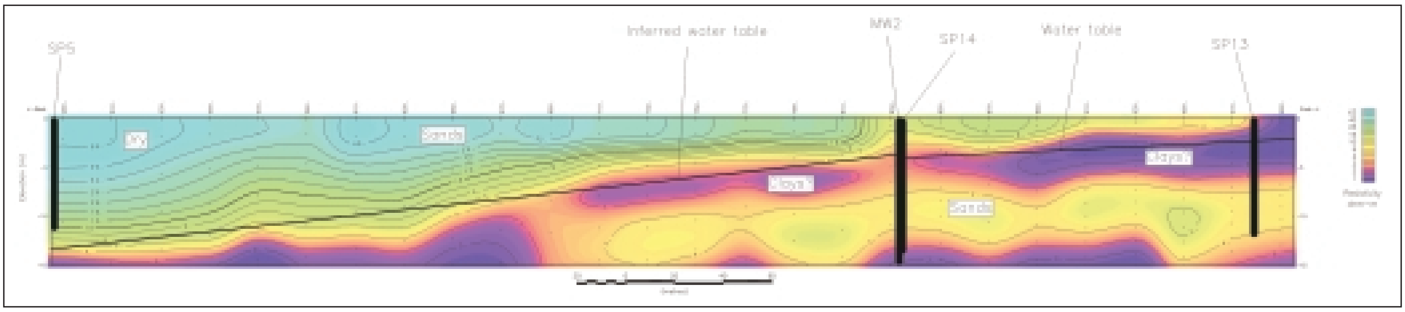


Fig. 3. (Top) Stockyard Plain Disposal Basin; 2-D section (from 1-D inversions stitched together) of all data to the limit of data resolution between 45 and 70 m depth. The solid black line shows the approximate water-table depth. The prominent low resistivity layer is probably a clay region. Resistivities vary from > 50 Ω.m to < 1 Ω.m adjacent to the lake.

Fig. 4. (Above) Stockyard Plain Disposal Basin; 2-D section (from 1-D inversions stitched together) for the top 15 m below the surface (note that the vertical scale has been exaggerated by a factor of four). The solid black line shows the approximate water-table depth. Note how resistivities increase to the west near the surface of the inverted section, apparently following a perched water table.

Fig. 5. (Right) Approximate location of Willaura Catchment study area (Bennetts, 2001).

Examination of Figure 8 suggests that the more resistive (greenstone?) unit is acting as a barrier to deeper flow in the area, forcing deeper water toward the surface to mix with the shallower perched water. It is interesting to note that Boggy Creek (further to the south - see Figure 7) occurs over one of these resistive units, and that a similar zone (although less intense) occurs south of Blue Gum Road. On Figure 8 it is also interesting to note the shallow resistive zone associated with the tree line. Which came first - the trees or the resistive zone? Does the resistive zone reflect the presence of less saline ground water? In this scenario NanoTEM can provide a pinpoint location for groundtruthing this feature, and may in fact help reveal the influence of trees on groundwater movement and salinity.

Acid-mine Drainage

Background: Acid-mine drainage in older mine sites around the country poses a significant threat as a potential groundwater pollution source that can extend for many kilometres beyond the mine sites. It is believed these fluids are more conductive than surrounding geology, and therefore may be detectable with shallow sounding EM techniques.

The study area is an acid-mine drainage site in central New South Wales . At this site 3500 t of copper were recovered from strongly pyritic ore in the early 1900's. A heap leach plant operated intermittently from the 1950's to the 1970's and recovered a further 500 t of copper (Craig Roberts, Personal Comm., 2001).

This field area slopes slightly to the south and east (suggesting that the groundwater gradient is similar). The topography on each line is generally gentle, although on most of the lines, at the edge of the waste dump, the topography can drop nearly 10 m vertically over a distance of 20 m horizontally.

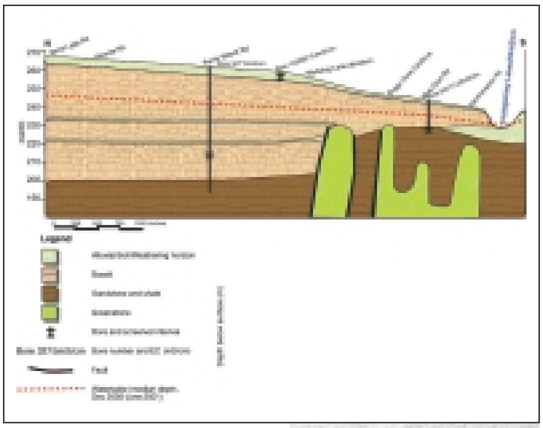
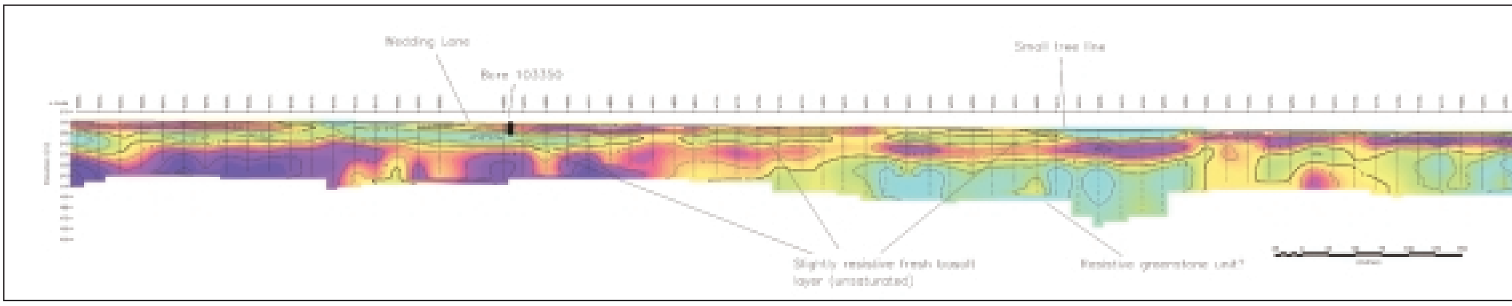


Fig. 6. Schematic interpretation of the Helen's Road transect in the Willaura catchment. This interpretation is based on information available before 2001 (Bennetts, 2001).

In an effort to track drainage from the mine site, TEM measurements were made along five east-west lines across the site.

NanoTEM Results and Discussion: Two figures are shown here to summarise the results from the five lines of data. Figure 9 shows the results of the inversion of line 53210N. This line is located over the waste dump, extending past their western margin. Note the shallow conductive zone at the west end of the line, apparently extending to depth. We have interpreted this as possible acid runoff. The survey line was extended to the west in an attempt to



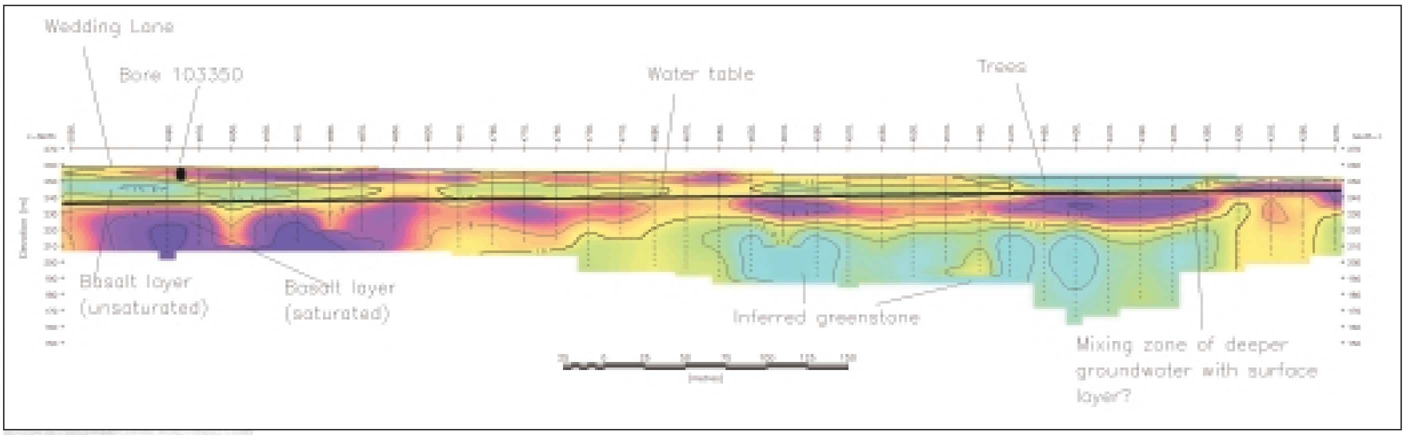


Fig. 7. (Top) Two-dimensional section for the top 100 m of ground along Helen's Road, Willaura Catchment. Resistivities vary from > 25 Ω.m to less than <1 Ω.m.

Fig. 8. (Above) Two-dimensional section along Helen's Road, looking with more detail from Wedding Lane to south of the small tree line. The more resistive (greenstone?) unit appears to be acting as a barrier to deeper water flow in the area, forcing this deeper water toward the surface to mix with the shallower perched water.

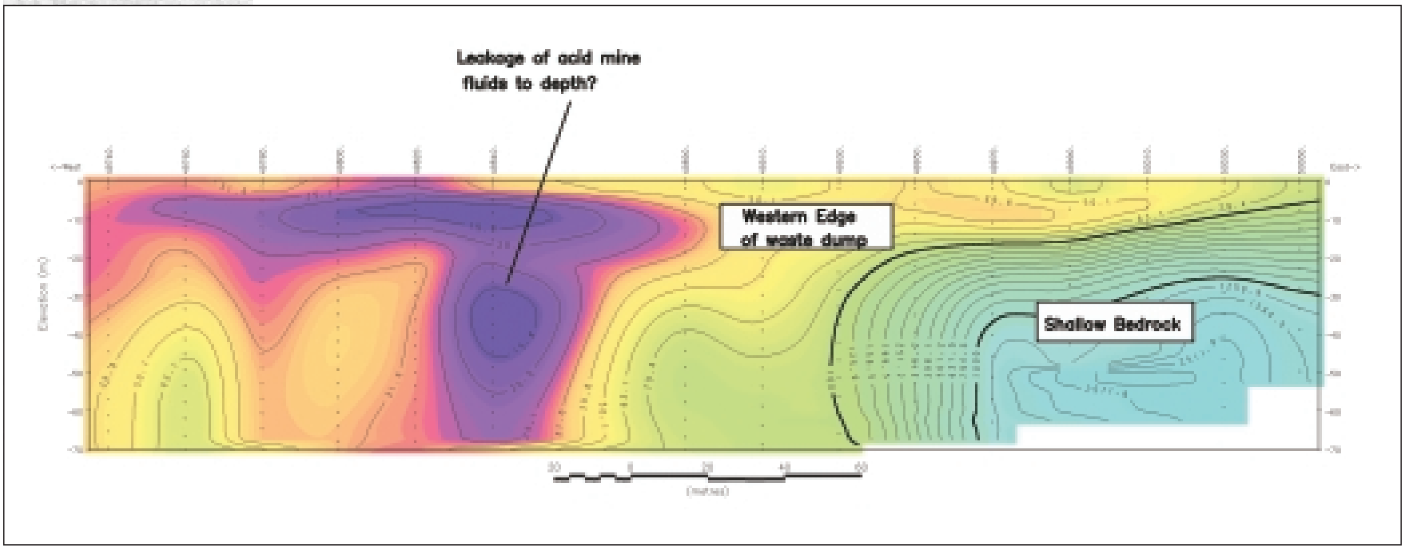
quantify the extent of the runoff, and as contours appear to close, it suggests that leakage is limited.

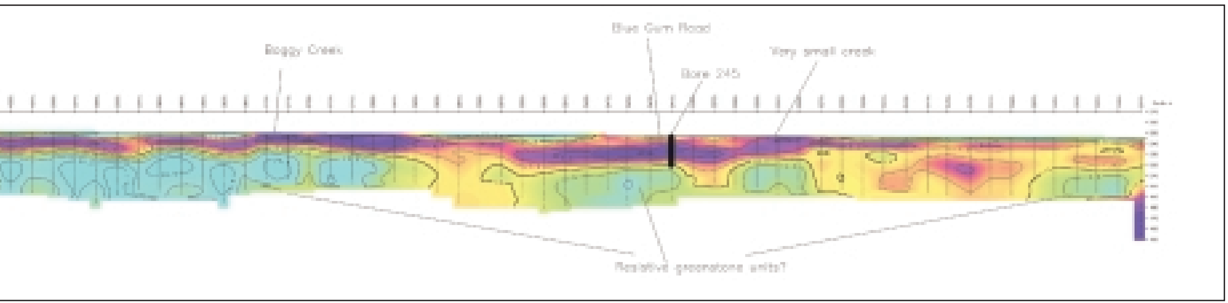
Figure 10 is a contoured "depth slice" created from the inversions of all of the lines. This plot was "cut" at a depth of 30 m. Again, it is worth noting the more conductive zone extending to the west and south of the waste dump. We have interpreted this as acid-mine runoff. A quick summary of the five lines follows.

- Line 53410N was located ~70 m north of the waste dump. It is believed that this is minimally affected by runoff from the mine.
- Line 53350N was located over the waste dump, extending west past the western margin of the dump.
- Line 53290N was located over the waste dump, extending west past their western margin. Note that an old mineshaft has disrupted readings at station 49930E.
- Line 53210N is presented in this paper in Figure 9.
- Line 53110N is located just to the south of the waste dump, running approximately through a small drainage along the south edge of the waste dump.

We believe that the thin, near-surface conductive zone extending over the west end of the four southern lines, at a depth of 10-25 m is partially related to the acid-mine drainage from this old mine site. Local topography suggests

Fig. 9. (Below) Acid Mine Drainage; 2-D section along line 53210N. This line starts in the waste dump, extending to the west well past their western margin. Note the shallow conductive zone at the west end of the line, apparently extending to depth - possible acid-mine runoff. This line was extended to the west in an attempt to quantify the extent of the runoff. The contours appear to close, suggesting that the lateral extent is limited.





that groundwater movement in this area should increase to the south and west. This correlates well with the apparent thickening of the inferred acid-mine drainage layer in the NanoTEM cross-sections also to the south and west. It is interesting to note that on Line 53110N at station 49830E and Line 53210N at station 49840E this conductive zone appears to extend to depth, suggesting a possible accumulation of the acid waters along fractured rock.

Conclusions

Fast sampling, fast turn-off EM methods (such as NanoTEM) are highly effective at mapping small-scale (<100 m) changes in shallow conductivity. Studies suggest that these changes are related to changes in lithology and fluid composition. Surveys can be carried out rapidly, about 500 m in just over three hours at 20 m station spacing.

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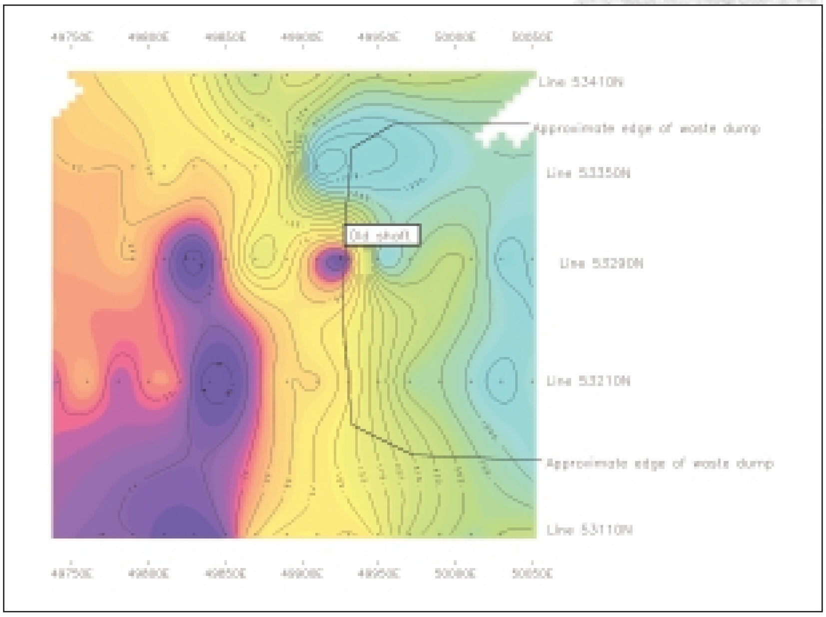


Fig. 10. (Right) Acid Mine Drainage; contoured "depth slice" at 30 m depth created from the one-dimensional inverted sections of all five lines. Note the more conductive zone extending to the west and south of the waste dump - possibly acid-mine runoff.

Oil Search and Orogen agree to $1.4 billion merger

The Boards of Oil Search Ltd and Orogen Minerals Ltd have announced a proposed merger of the two companies to create an enlarged upstream oil and gas company with an aggregate market capitalisation of $1.4 billion. This will put the new company, which will be called Oil Search, in the top 100 companies registered on the ASX. The PNG government, which controls 51% of the shares in Orogen, has indicated its support for the merger.

Under the terms of the proposal, Orogen's shareholders will be entitled to receive for each Orogen share, $0.45 cash (to be distributed by Orogen by way of a capital return) and 1.2 Oil Search ordinary shares. The $0.45 cash capital return will be reduced by the aggregate amount of any dividend should Orogen decide to declare a final dividend relating to the year ended 31 December 2001 before completion of the merger.

On completion of the merger, Orogen's shareholders would hold approximately 34% of the expanded Oil Search, with the remaining 66% held by current Oil Search shareholders. The largest shareholder would be the PNG Government, which will own approximately 18%.

The Directors of Orogen intend to unanimously recommend that Orogen shareholders support the merger, in the absence of any higher offer.

The new company will be one of the region's largest independent oil and gas companies and PNG's largest listed company.

It will have assets combining:

- Production - Kutubu, Gobe, Moran and Hides (majority interests), totalling ~12 mmboe/yr, Misima and Porgera gold mines,
- Development - PNG Gas Project (with 37% equity), Moran and Saunders, Ramu nickel project, and
- Exploration/Appraisal - Bakari and NW Moran.

The mineral assets are small but provide positive operating cash flow.

It is proposed that on completion of the merger, Oil Search's Board of Directors will be expanded to include Martin Kriewaldt and Clive Hildebrand who currently serve on the Board of Orogen. In addition, the PNG Government will be asked to propose one nominee to join the Oil Search Board. Lindsay MacAlister, currently the Chairman of Orogen plans to retire from the Board of Orogen in early 2002 and has therefore elected not to accept an invitation to join the Board of Oil Search upon completion of the merger.

Five conditions have to be met before the merger is completed. These are:

1. Orogen shareholder approval at a meeting planned for March 2002(75% of shares voting),
2. PNG Court approval,
3. No material adverse change or prescribed occurrence in either company,
4. PNG Central Bank and regulatory approvals, and
5. Oil Search arranging a US$25M standby credit facility for the merged company.

If the merger is successfully completed, it will provide a significant new player in the resource sector of the Australian region. Perhaps more importantly, the merger will speed up the PNG/Queensland gas pipeline because the operator, Exxon Mobil and Oil Search will now hold a 74% interest in the project and they will be able to make progress without any delaying tactics from recalcitrant partners.

Turbulent times for Santos

Falling Profits

As a result of a review of its Proved and Probable reserves, Santos now estimates that its profit for 2001 will be about 10% lower than the 2000 result, which delivered a record profit of $478M.

The results, as announced in its January statement are as follows:

"Proved (1P) reserves are estimated to be 316 million barrels of oil equivalent (mmboe) at year end 2001.

Proved and Probable reserves (2P) at the end of 2001 are estimated to be 724 mmboe, 13 years of reserve life based on 2001 production. 2P reserves have been adjusted downwards by 169 million barrels of oil equivalent (mmboe), a reduction of 18% on the 2000 year-end level.

Of the 460 fields reviewed, 2P reserve estimates for 77 fields increased, 255 fields remained the same and 128 fields declined. Revisions mostly reflect drilling and seismic results, technical reviews and production performance.

Notwithstanding the reduction, the review identifies over 1,750 petajoules of proved and probable gas (net to Santos) available for new contracts, over and above gas dedicated to covering existing contracts.

Around three-quarters of the reduction in 2P reserves is being reclassified as Possible reserves or Contingent Resources. Proved plus Probable plus Possible reserves (3P) have increased by around 200 mmboe to 1,438 mmboe at end 2001. Additionally, Contingent Resources have increased by over 500 mmboe, to 1.2 billion boe at end 2001.

Preliminary unaudited indications are that Santos' 2001 trading results arising from production of 55.7 mmboe (56.0 mmboe in 2000) will be approximately 5% lower than the record 2000 results as a consequence of lower product prices and higher operating expenditure in 2001.

The downward revision of 2P reserves will increase the depletion charge, a non-cash charge to operating profit, by approximately $40 million. Principally, due to the lower trading results and higher depletion charge in 2001, the net profit after tax is expected to be approximately 10% lower than the record 2000 result. This will still be

Continued On Page 31

Australian Mineral Foundation closes

Australian Mineral Foundation (AMF), which was established in 1972, closed its doors on 21 December 2001 and ceased trading on that date.

The Australian Mineral Foundation provided a single point of contact for the resource sector through:

- Maintaining a specialist library,
- Managing and developing AESIS - the national geoscience database,
- Operating one of Australia's largest technical bookshops,
- Providing quality professional development courses and conferences,
- Offering a unique program of international study tours to the world's most significant mineral deposits, and
- Developing the Data Metallogenica ore deposit collection to deliver electronic images and data worldwide

At the time of its closure, it had a listed staff of 20 people and an office in Perth as well as the main office in Adelaide. Prentice, Parbury and Barilla has been appointed liquidator to deal with the closure.

In recent years, the AMF has made significant contributions to Australian geoscience, particularly through the Data Metallogenica collection, the AESIS database, the AMF Library collection, the specialist Bookshop and its training courses. The likely future of these resources and services is discussed below.

Data Metallogenica collection

AMIRA and the AMF secured this renowned mineral deposit collection in 1999, and it is currently housed in a custom refurbished wing of the AMF headquarters in Adelaide with building funds provided by the South Australian Government. Money to acquire and develop the collection is being provided by AMIRA Project P554, which has nearly sixty contributors, who will have exclusive access to the collection until March 2002

Data Metallogenica is the lifetime achievement of Professor Peter Laznicka and his wife Sarka. It contains more than 65 000 representative rock samples from 3500 deposits in over 100 countries. On Peter's retirement from the University of Manitoba in 1999, the Laznickas moved to Adelaide, where he and Sarka worked at the Data Metallogenica Centre, to extend, enhance and curate this unique resource.

The plan is to extend and enhance the collection and make it accessible to worldwide users through electronic imaging, CD-ROMs and the Internet. Rock and mineral samples, PIMA mineralogy, thin-sections, deposit descriptions, maps, photographs, videos, bibliographies and much more, representing mineral deposits and settings from around the globe, are assembled in one dynamic workspace. A major value of the collection is that it is representative and non-genetic in concept, and provides a record of the total geological environment of any given deposit, not only of the ore material.

A searchable digital database supports the collection. Systematically derived graphical legend sheets provide a summary of each deposit setting and the location of representative sample materials. It is also planned to progressively add brief descriptions, accurate but simplified maps and sections, and scientific bibliographies for each deposit.

With the demise of the AMF, AMIRA is likely to take over the full responsibility for the operation of this facility but this has yet to be finalised.

Australian Earth Sciences Information System (AESIS)

AESIS is the national earth sciences, minerals and petroleum reference database. It includes both published and unpublished literature and was coordinated and maintained by the AMF.

At present AESIS contains in excess of 200 000 records, including 6000 references to Australian university postgraduate and higher degree theses, and is updated on a monthly basis.

It would seem logical for Geoscience Australia to take on this facility in the post-AMF era, but the disposal of assets and facilities depends on the Administrator.

Library and Bookshop

At the time of writing the future of these resources is uncertain.

Continued From Page 30

substantially higher than any earnings achieved by Santos prior to 2000."

Withdrawal from PNG Gas project

Santos also announced in January that it has quit the $6 billion project to build a gas pipeline between Papua New Guinea and Queensland, after a problem over the commercial terms of the partnership.

Santos said that it was unhappy with the terms of a new agreement, which did not require all partners to agree on commercial decisions. However, the Santos Group, through PNG subsidiaries, still holds a 31 % interest in Petroleum Development Licence No.1. This contains the Hides Gas Field, which is expected to be a major source of gas for the Project. The project operator, Exxon Mobil said the proposal would continue under a new heads of agreement.

The PNG gas proposal has been delayed partly because of the PNG government's inability to raise funds for an expected one-third share of the project, as well as slow uptake of gas sale agreements with customers in Queensland.

The current low price of gas in the global market place is probably another contributing factor to the delay in getting the project off the ground.

AngloGold loses battle for Normandy

AngloGold has given up its six-month fight for Normandy Mining, clearing the way for the US based Newmont Mining to assemble the second largest gold producer (after the recently merged Barrick/Homestake group) with an output of 283 t/yr.

"It is not possible for AngloGold to obtain majority control of Normandy, as it has become too expensive", AngloGold's CEO Bobby Godsell said in a statement in January this year. As of 18 January, AngloGold had obtained only about 7% of Normandy's capital.

The AngloGold bid was effectively worth $1.99 per Normandy share, while Newmont's offer was close to $2.05 per share. Since September, both AngloGold and Newmont have made three offers in a bidding war to take control of Normandy. AngloGold's offer was 2.15 AngloGold shares for every hundred Normandy shares held as well as 30c per Normandy share. Newmont was offering 50c cash and 0.0385 Newmont shares for each Normandy share held.

AngloGold offered immediate acceptance, but shareholders planning to accept the Newmont offer will have to wait until mid-February to receive cash and scrip. The Newmont offer is also conditional on it gaining control of more than 50% of Normandy and it will also need to assume $1.18 billion of Normandy's debt.

However, the production figures for Normandy are very good. In the 4th quarter of 2001 it produced 19.0 t gold at a price of $10/g and sold the gold at $19/g. This brought the total gold production for the 2nd half of 2001 up to 38.9t, not a bad outcome and indicates why Normandy was such an attractive target; low production costs and a low value of the Australian dollar.

The future of AngloGold may be somewhat uncertain. Opportunities in South Africa are limited because of the depth of the gold deposits, which are often expensive and dangerous to mine. So there may be even further consolidation as the bigger boys, like Gold Fields, AngloGold and Barrick continue to sort themselves out.

Normandy NFM takes over Otter Gold Mines

Normandy NFM's acquisition of Otter Gold Mines was agreed to in January 2002. The formal offer was made in November last year and only took two months to succeed. Otter's primary assets are a 60% interest in the Tanami Joint Venture (the other 40% is held by AngloGold), owner of the Tanami mill, significant exploration properties held in the Tanami region of Central Australia and an interest in the Waihi Operations in New Zealand.

This acquisition will provide Normandy NFM with management control of the Tanami mill which is well located to process future discoveries made on either Normandy NFM's or Otter's exploration tenements in the Tanami. Otter holds exploration permits and applications covering approximately 20 000 km^2 in the Tanami region and Normandy NFM holds permits and applications covering about 56 000 km^2. The acquisition will increase Normandy NFM's gold resources by approximately 17.0 t and annual production by nearly 1.2 t.

Goldfields completes merger with Delta Gold

The merger of Goldfields and Delta was finalised on 17 December 2001.

Under the terms of the merger, Delta ordinary shares were transferred to Goldfields, with Delta shareholders receiving 187 Goldfields ordinary shares for every 200 Delta ordinary shares held. This brought the total number of Goldfields shares to over 440 million. The total market capitalisation of the new company is $1.1 billion and it currently ranks 94th in the largest companies listed on the ASX.

As part of the re-organisation, Goldfields has arranged a US$170 million four-year revolving credit facility, provided by twelve financial institutions. These funds will be used partly to refinance the existing debt of Goldfields and Delta, and partly to provide capacity for growth opportunities. It will now be the second largest Australian based gold producer with an annual output of about 30 t.

Goldfields was formed in 1995 from the Porgera, Henty and exploration interests formerly held by RGC Limited, and the Paddington and Kundana operations formerly held by Pancontinental Mining Limited. During 2000, Goldfields acquired Gild-Edged Mining NL, which held prospective exploration tenements near the Kundana and the Paddington mines in Western Australia. In October 2001 Goldfields acquired Centaur's Mt Pleasant gold assets located north and west of Kalgoorlie, Western Australia. The merger with Delta adds Kanowna Belle and 40% of Granny Smith to the group, and a 21% holding in Zimplats, which has substantial platinum assets in Zimbabwe.

The group has extensive exploration tenement holdings, predominantly in Western Australia. Goldfields six major operations are located in Australia and Papua New Guinea, with Western Australian operations representing approximately 70% of the Group's gold production, for the year ended 30 June 2001. Major operations now comprise 40% of Granny Smith and 100% of Kanowna Belle, Kundana, and Paddington, all in WA, 100% of Henty in Tasmania and 25% of Porgera in Papua New Guinea.

Terry Burgess is the new Managing Director of the new group, which has its registered office and principal place of business in North Sydney.

Geosoft signs agreement with Metech

Geosoft Inc (Toronto, Canada) announced, in January 2002, a cooperative agreement with Metech Pty Ltd (Perth, WA) an Australian software and support services company. To quote from the Geosoft media release:

"The goal of this agreement is to develop a complete solution that helps our clients increase the value and ensure the integrity of their geological, geochemical and geophysical data through better management, quality control, analysis, integration and reporting/presentation. By offering a complete solution for all types of exploration data, we can provide comprehensive and well-supported software solutions eliminating the need for dealing with a multitude of suppliers. The combined software suite represents a significant break from previous generations of software - enabling everyone to exchange data and results easily, both within the exploration and regional office and also via the Internet.

The integration of Metech's acQuire solution with Geosoft's Oasis montaj, the industry standard environment for geoscientists working with spatial data, addresses the major problem experienced by professionals in the exploration and mining industries - storing and accessing quality technical data."

For more information see the Geosoft website at www.geosoft.com or the Metech website at www.metech.com.au.

Grenfell Resources signs Falcon deployment agreement with BHP-Billiton

Grenfell Resources announced in December 2001 that it has entered into an agreement with BHP Billiton to deploy its new Falcon Airborne Gravity system in Australia in the search for major new mineral deposits.

The agreement is for three years with provision for renewal for a further three years, and starts when a new Falcon system is delivered in Australia, around the middle of 2002. Grenfell has undertaken to raise $10 million to fund its participation in this venture.

Under the agreement, Grenfell will have the exclusive right to access 75 per cent of the annual capacity of the new Falcon system, with BHPB retaining 25 per cent for its own projects in Australia and the region.

The Falcon system is the first airborne gravity gradiometer capable of minerals exploration. It is the result of a > 5 year $US30 million technology project on which BHP has 5-year exclusivity on the technology. The first two units, dubbed "Newton" and "Einstein", are deployed in Cessna Grand Caravan aircraft owned and operated by Sander Geophysics, under an exclusive contract with BHP Billiton. BHP Billiton is currently building two additional units. The first, called "Galileo", will also be mounted in Cessna Grand Caravan aircraft to be operated by Fugro Survey Pty Ltd under an exclusive contract to BHP Billiton and will be deployed in Australia. The second will incorporate the latest digital technology that will allow the physical size and weight to be reduced. It will be called "Feynman", completing a quadrella honouring physicists who have changed the world's scientific direction.

Grenfell will negotiate joint ventures with third party mineral title-holders or will take up mineral title in its own right. Grenfell and its third party co-venturers will fund the flying of Falcon surveys, data processing, interpretation and target testing.

In the event of a major discovery, BHPB will have the right to purchase Grenfell's equity for five times Grenfell's project related expenditure, with Grenfell retaining a two per cent royalty over the deposit. If BHPB does not elect to buy back Grenfell's interest, it will retain a two per cent royalty over Grenfell's share of production, or will be entitled to 10 per cent of proceeds of sale where Grenfell elects to sell its interest.

When discoveries are made, Grenfell will hold equity in the resulting mines, or will benefit from BHPB's buy-back and enjoy an ongoing royalty stream in one or more major deposits.

Mr Marcus Randolph, BHPB Minerals Chief Development Officer said "This agreement reflects BHPB's strategy of creating low-cost options by leveraging its distinctive technology capabilities through partnerships with selected exploration companies around the world."

In an associated move, Phil Harman, previously the BHPB executive in charge of Falcon has joined Grenfell as a full-time employee to head up the new project team.

Figures 1 and 2 provided by the Australian Bureau of Statistics

Minerals exploration declines, Petroleum remains steady

Minerals

Figures released in December 2001 by the Australian Bureau of Statistics showed a disturbing trend for the level of mineral exploration during the 3rd quarter of 2001.

The trend estimate for total mineral exploration expenditure in this quarter decreased by 2% from the previous quarter to $165 million. This is 3% lower than the trend estimate of $170 million in the same quarter of 2000 and is the lowest level since 1992. Figure 1, which shows the numbers for the last eight years, tells the story, with a new downward trend in the numbers. The main reduction was in Western Australia, where actual investment levels dropped by 6.8% or $7.6 million to $103 million.

As usual Western Australia dominates the national exploration effort with Queensland being the next largest contributor with $22 million.

The trend estimate for metres drilled also fell in the September quarter to 1272 km. This is a decrease of 103 km from the June quarter and 281 km less than the September quarter in 2000. A worrying statistic is that most of the decrease in exploration investment was in 'Greenfield' or 'all other areas' rather than on production leases. In other words exploration is being focused close to known resources rather than looking for new areas to explore.

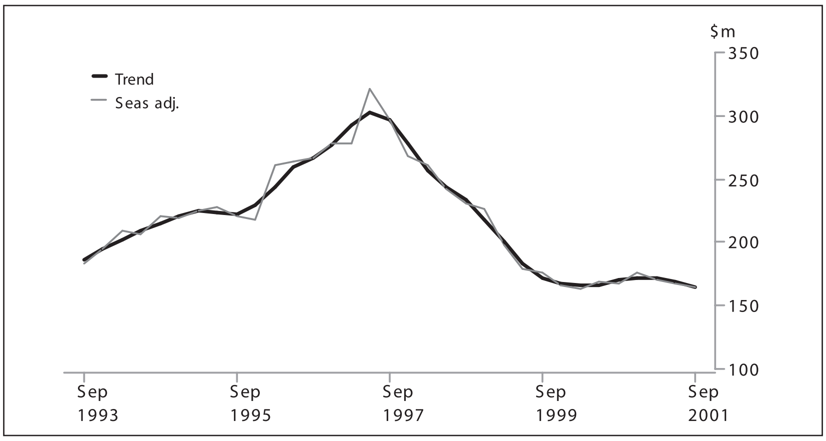
In terms of a commodity focus, gold dominated the scene with a total expenditure of $86 million or about half the exploration invested in all the other commodities except petroleum. Figure 2 shows the importance of gold in the exploration industry.

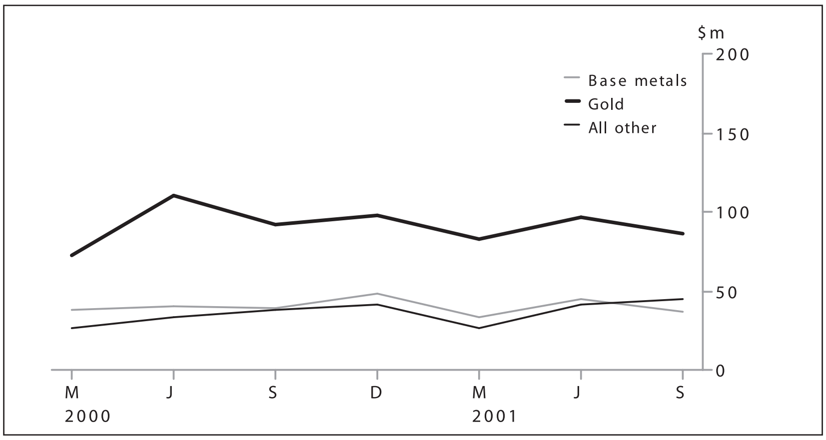
Petroleum

Reported expenditure on petroleum exploration in the September quarter of 2001 was $232 million. This was 13% ($34M) lower than the June quarter for 2001 but 5% ($12M) higher than the September quarter for 2000. The decrease in expenditure was primarily due to the 14% ($31M) decrease in the offshore expenditure, which again dominated the statistics and accounted for nearly 80% of the total investment.

Western Australia was the main contributor with a reported expenditure of $136M for the quarter. This amounts to nearly 60% of the national total.

Figure 3 shows the levels of petroleum exploration from the first quarter of 1998. These indicate a long-term consistency in the figures, unlike the mineral exploration data.





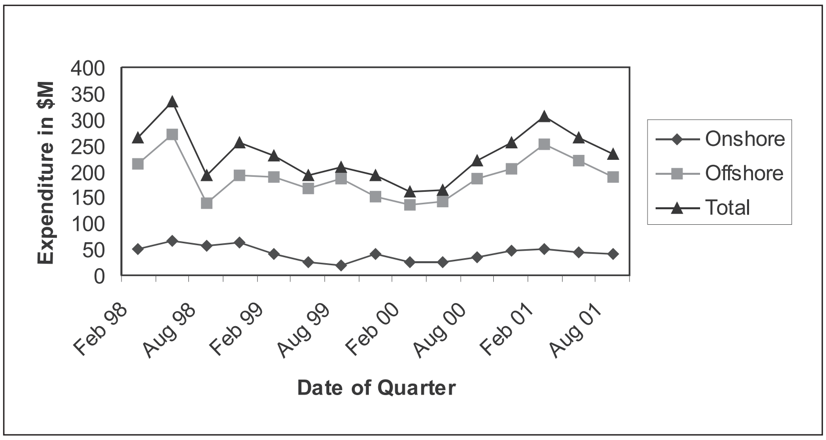


Fig. 1 (Top Left) Mineral exploration expenditure, from September 1993 to September 2001.

Fig. 2 (Middle Left) Mineral exploration by commodity, for the last six quarters.

Fig. 3. (Left) Petroleum exploration expenditure, from the start of 1998.

Numerical Models of Oceans and Oceanic Processes

International Geophysics Series, Vol. 66
by Lakshmi H. Kantha and Carol Anne Clayson

Academic Press
ISBN: 0124340687
940pp 150 x 226mm
Hardback, $A304

Reviewed by Timothy Dean, School of Physics, UNSW@ADFA, Canberra 2600.

The modelling of ocean and oceanic processes has become increasingly important in our understanding of weather and climate. The advent of fast computers has allowed the simulation of oceanic processes on an increasingly thorough level, but to date texts have failed to keep pace. This volume aims to fill the gap, and it does it well, being one of the most comprehensive summaries published to date. Although considered by the authors to contain "elementary" material the 940-page length bears testimony to the relatively in-depth coverage of the issues involved.

Lakshmi Kantha is a professor of Aerospace Engineering Sciences at the University of Colorado. He has 30 years of research experience in industry and academia, and has received several awards for his work with the American military during 'Desert Storm'. Carol Anne Clayson is an assistant professor of earth and atmospheric sciences at Purdue University. In 2001 she received one of only fifty-nine Presidential Early Career Awards for Scientists and Engineers, the highest honour given by the U.S. government.

Chapters 1 and 2 are excellent introductions to ocean dynamics and numerical solutions respectively. Chapters 3-8 cover different models (such as tidal and ice-oceanic processes) and data and data processing. Chapters 9-13 cover more specific models including barotropic, quasi-geostrophic, layered, level, isophycnal, sigma-coordinate and coupled models. Despite dealing with a complex subject the book explains the models well, through the use of simple yet informative examples, although some chapters do include a necessary (though not inconsiderable) amount of mathematical background.

Appendices cover equations of state; wavelet transforms; empirical orthogonal functions and empirical normal modes; and units and constants. There are also biographies of four of the leading workers in the field (Dr. Kirk Bryan, Prof. Allan Robinson, James O'Brien and George Mellor). The volume contains over 1100 references, which occupy 45 pages and include references up to the year 1998. There is a comprehensive 22-page index.

The book should prove to be thorough enough for most readers, even though the authors claim otherwise "The book is written so that a newcomer to the field, provided he or she has the necessary mathematics and physics background and computing skills, can learn the subject with ease and be introduced to some current research topics...". It is rather mathematically intensive however and few chapters have summaries. The small pages size (150x226mm) makes some of the figures hard to read.

On the other hand, the book provides the most specialised and comprehensive coverage currently available and is an excellent starting point for those new to the field. The list

Crustal Heat Flow A Guide to Measurement and Modelling

by G.R. Beardsmore and J.P. Cull

Cambridge University Press, 2001, 324 pages
ISBN 0 521 79703 9
paperback
Price: $80

Reviewed by Ted Lilley

Not knowing this book was in preparation, it was a delightful surprise when a copy arrived on my desk in October 2001. A surprise also because while in many geophysics texts, heat flow is typically given its own chapter, to this reviewer there has been no book quite like this one before. Consistent with the title, the whole book is devoted to heat flow.

Both authors have been closely concerned with heat flow throughout their respective careers, and this volume brings together in a coherent and useful way much of their work.

Heat flow is one of the fundamental quantities in geophysics. Its study has featured prominently in Australian geophysics since the influential role played by J. C. Jaeger half a century ago, following Jaeger's collaboration with Carslaw, which produced the book (by Carslaw and Jaeger) "Conduction of Heat in Solids". The present book has Australian examples and case histories very much to the fore, which is refreshing when many Earth science books come with northern hemisphere examples.

The present book deals with subjects as widely spaced as climate change recorded in thermal profiles in the crust, to fission track thermochronology. There is a useful summary at the end of each chapter.

The book is in three logical parts.

Part 1, on the Thermal State of the Earth, describes, in Chapter 1 (Terrestrial Heat), the present understanding of the Earth's thermal state, and in so doing introduces the units, which will be used throughout the book. SI units are used, perhaps now taken for granted, but at their best in this type of geophysics. The second chapter is the crucial one on Heat Generation (mainly radioactivity, but certain other processes also rate a mention), and the physics is again well introduced.

Part 2 then addresses Measurement Techniques, and the natural elements thereof. Chapter 3 is on Thermal Gradients, and details of measuring this most fundamental quantity on both land and sea. Chapter 4 is then on Thermal Conductivity, the quantity needed for combination with thermal gradient values; wider aspects of the physics of heat conduction in rocks are also discussed. Chapter 5 is on Thermal Maturity, and here there is specialist treatment of the maturation of hydrocarbons in sedimentary basins as measured, for example, by vitrinite reflectance.

Part 3 deals with modelling techniques. Chapter 6, entitled Heat Flow, addresses how actual observed heat flow values are interpreted in terms of geological structures on both local and regional scales. Chapter 7 describes Lithospheric Models in the framework of present plate tectonic theories, in particular returning to the effects expected in boreholes in sedimentary basins (echoing the hydrocarbon exploration theme of the book). Chapter 8 addresses the Numerical Modelling of steady-state heat conduction in three dimensions, as for a known geologic structure in a sedimentary basin.

The book concludes with Chapter 9, entitled Unravelling the Thermal History of Sedimentary Basins. Here the strategy is to use physical data from a basin to deduce its heat-flow history. The passage of time is now introduced, with the simplification pointed out that thermal equilibration in a basin is rapid compared to the lithosphere as a whole. Again there is a return to the theme of the generation of petroleum.

The book thus ranges from detailed technical applications to wide fundamental principles. In so doing, it should please the minds of both practitioners in the subject, and also students who find satisfying the basic physics displayed in this grand piece of apparatus which we call Earth.

In fact the book demonstrates that heat flow can form a worthy basis for a whole introductory geophysics course. Using the present text as a base, a lecturer could steer a route through much of solid-earth geophysics. There are excellent worked examples.

In following such a course, students would find the book presented "benchmark" papers in subjects such as mantle convection, which could then be followed into the literature to find the latest discussions of the subject. Two other examples where these remarks apply are seismic tomography (there have been important developments in Australia since the references given) and the use of electromagnetic methods to determine deep electrical conductivity profiles, and thus thermal state. In this broader view of geophysics, the examples given in the book may be regarded as "sample" papers, which can lead into a wider literature search where that is required.

The book provides ample and interesting connections to relevant history. The authors' humour is revealed also, in such cameos. Amongst the quotations from the great geologists of the 19th century, in their period-piece style, we suddenly (at the start of Chapter 8) come across a most delightful modern one, which could not be more topical or appropriate! (When I model I pretty much blank. You can't think too much or it doesn't work. Paulina Porizkova, actress and model.)

The book is well produced (consistent with the best CUP standards), and the cover attractive. The cover, indeed, emphasises the whole-Earth nature of heat flow. My copy, paper-back, seems well bound and very workable for its 324 pages. The book gives the impression of being free of printing errors (the most I can point out is that the journal of the Hyndman and Everett (1968) paper, the Geophysical Journal of the Royal Astronomical Society, is given as Geophysics Journal.)

Finally, this book is a book of its time. It has a website as an ongoing source of support, in addition to the information and concepts in the text. The website is: http://www.earth.monash.edu.au/heatflow/

For a price of A$80, it is in my view, very good value. There is a great deal which can be learned from this book. With its emphasis on sound physics and quantitative examples, the approach or philosophy is admirable and comes across clearly.