Preview

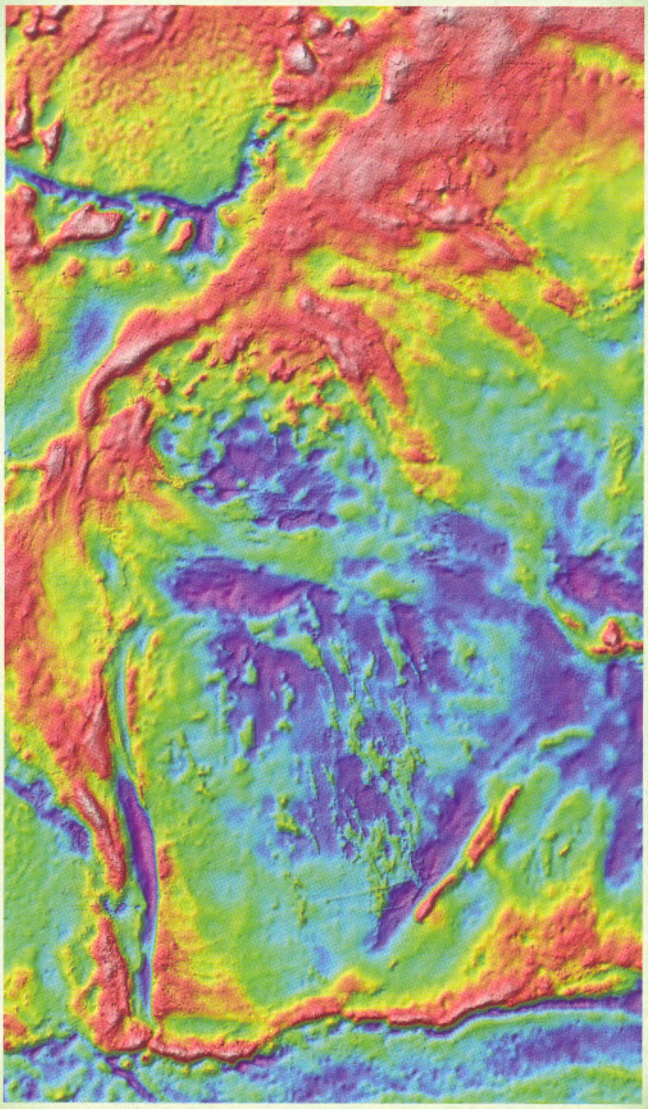
Australian Society of Exploration Geophysicists

ABN 71 000 876 040 ISSN 1443-2471 June 2001 Issue No.92

Geophysical Data Sets Over Continental Australia

Magnetic, Radiometric and Gravity data sets provide vital information for mineral and petroleum explorers as well as researchers studying the geology of the Australian continent...

Page 25



New Gravity Map of Western Australia

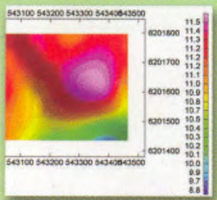
produced by AGSO and the GSWA

Geoscience Information improving online accessibility

Page 13

Development of a short-term model using petrophysical logging at Century Mine, North Queensland

Page 19



Geophysical Response of Porphyry System Mineralisation at the Dam Prospect, Temora, New South Wales

Page 28

Compiled April 2001

Advertisers' Index

2000/2001 Corporate Plus Members

MIM Exploration Pty Ltd
Velseis Pty Ltd

2000/2001 Corporate Members

Anglo Operations - Geophysical Services Dept.
BHP Minerals Discovery Group
Chevron Australia Pty Ltd
Earth Resource Mapping
Encom Technology Pty Ltd
Fugro Airborne Surveys
Geo Instruments Pty Ltd
Geosoft Australia Pty Ltd
Haines Surveys Pty Ltd
Kevron Geophysics Pty Ltd
Normandy Mining Ltd
Origin Energy Resources Ltd
Pasminco Exploration
Petrosys Pty Ltd
PGS Australia Pty Ltd
Office of Minerals and Energy Resources, PIRSA
Quantec Geoscience
Rio Tinto Exploration Pty Ltd
Schlumberger Oilfield Australia Pty Ltd
Scintrex Pty Ltd
Silicon Graphics International
Tesla Geophysics
Veritas DGC
WMC Exploration
Woodside Energy Ltd
Zonge Engineering & Research Organisation

In this issue

Firstly, I would like to offer a warm welcome to our new Federal Executive. Membership of this committee is now spread Australia-wide to meet the needs of our members distributed throughout the continent. In this issue of Preview we have included profiles of three of the FedEx members, and in future issues we will print some more. These officers will lead the Society for the next two years and we should all support them in their quest to build a better ASEG.

The feature articles in this issue are rather a mixed bag. We learn more about the geophysics at Century, look into the future for geoscience data sets and information, and learn about the regolith in the Eastern Goldfields. Tim Dean poses some interesting questions on the different outputs from airborne EM and ground EM over the same piece of ground, and Murray Richardson and Phillip Wynn review the status of the geophysical data sets over the Australian continent.

In recent years both the States/NT and the Commonwealth have invested several million dollars to provide regional geophysical data (gamma-ray, magnetic and gravity) to encourage mineral and petroleum exploration. The results of this investment are starting to be realised. At present nearly half the continent is covered by publicly owned airborne geophysical data sets. This amounts to a total of nearly 16 million line-km of high quality information in State/NT/AGSO databases.

The gravity database is equally impressive, and with the acquisition by AGSO of a new absolute gravity meter, and the development of airborne gravity, this data set is ready to expand with improved quality.

Data access and charges

Although these databases have increased in size and improved in quality, the prices for the products are still bones of contention. The Northern Territory and some other states provide their data sets essentially free of charge, while some others; noticeably NSW and AGSO are obliged to recover some of their acquisition costs through sales of products.
The net effect of the cost recovery regime is that very few geoscientists are able to access the data, and hence the geoscience information paid for mostly by tax payers is not being used as effectively as it should.
The Productivity Commission recently examined this issue and produced its draft report in April this year.
It is a three hundred page plus tome that can be accessed on the web at:
http://www.pc.gov.au/inquiry/costrecovery/index.html

The report has some very important things to say about government information agencies such as AGSO, BoM, ABS, AUSLIG and ABARE and it makes two key recommendations.
These are:

1. Information agencies should carefully define the boundaries of their core and non-core activities determined with reference to:
- The agencies' broad public policy objectives;
- The public good characteristics of the activity; and/or
- Any positive spillovers associated with the activity, and,

2. The core activities of information agencies (which may include some defined level of dissemination) should be wholly budget funded and not subject to cost recovery.

In other words, where outputs are obtained during activities associated with core business, these should not be subject to cost recovery.

Many of our members make use of the information generated by agencies such as AGSO, ABARE, ABS and AUSLIG. Of particular concern are the data provided by AGSO, which are widely used in the mineral and petroleum exploration industries, as research inputs by CSIRO and universities, and as geoscience teaching resources in tertiary institutions.

If the above recommendations are implemented then the availability of the key geophysical data sets provided by AGSO would be greatly reduced in price. Members are invited to send messages of support for the Productivity Commissions recommendations (see the web-site above for contacts).

Science Meets Parliament

FASTS' third, Science meets Parliament day is now scheduled for 22 August this year, so for those who can be in Canberra at that time there will be an opportunity to interact with your local MP and discuss issues relating to science and technology. This is a unique opportunity to make a difference in the S & T environment in Australia.

Brisbane Convention

Before the SmP day however, we have our Geophysical Odyssey. As Henk van Paridon has described, this will take place in Brisbane from 5-8 August this year, and the planning is going well. I hope everyone has completed his or her registration form to attend. I plan to interact with as many potential authors as possible during the coffee breaks, so keep those ideas coming. It looks like being a really good show, and I look forward to seeing you all there.

David Denham

Previous Executive

On behalf of all members of the Society I take this opportunity to thank the outgoing Federal Executive for their efforts over the last twelve months. Brian Spies' leadership as the President has moved the Federal Executive towards reviewing strategies for the future, moving from a reactive committee to one that is looking further ahead. Brian brought a great deal of experience from the SEG in the USA, and this has been of assistance in overcoming some of the problems of "re-inventing the wheel".

I would also like to express sincere thanks to Graham Butt who has put an extraordinary amount of time into the financial running of the Society, and now steps down as Treasurer. He has not only coped with a number of changes in the Secretariat's accounting personnel but has also handled the onset of the GST. The new regulations have required a consolidation of the accounts of the Society, including the State Branch accounts and the conference accounts, every three months rather than every year.

I would also like to acknowledge the diligent efforts of our Honorary Secretary Dave Robson. This role is not easy and Dave has undertaken it over the last two years with great dedication to the task, and has put his hand up for a further 12 months.

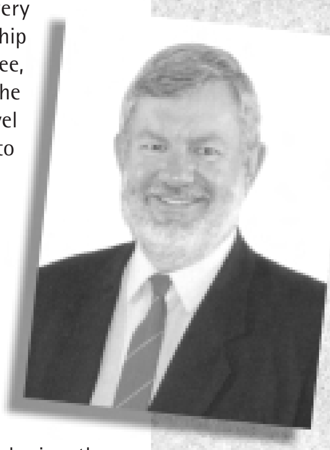
National Executive

As you may be aware from the Council Meeting in Perth or from the reports of previous Presidents, the Federal Executive is moving to become a national body with representation from many States in Australia on the committee. We have progressed this goal through the election of the new Federal Executive with Katherine McKenna from Western Australia, as First Vice President and Suzanne Haydon from Victoria, as Second Vice President.

With the new Executive comes a new Treasurer, Bob White, who has been working with Graham over the last few months, to ensure a smooth transition for this critical position.

Brisbane Conference

From all accounts the Brisbane Conference is hotting up to have a very high quality technical program, and a good size technical exhibition, which, for the first time, will include an area for small consulting companies to display their expertise. We have been very encouraged by the response to the sponsorship program achieved by the Brisbane Committee, with over 20 sponsors assisting in supporting the conference. I urge members to make their travel and hotel bookings for Brisbane soon, and to send in your registration form.



Business Plan

The Federal Executive is developing the next three-year Business Plan which focuses on the financial side of the Society. The plan also covers the goals and directions of the Society for the immediate future. As the demographics of the Society change, with fewer graduates taking on positions in geophysics, the membership aging, the members moving from company employment to consulting the Society needs to evolve to cater for these factors. These will be some of the many issues for discussion at the forthcoming Federal Council Meeting to be held during the Brisbane Conference. An immediate concern is the likelihood of a net deficit for 2002 because the Society will not be holding a major conference and exhibition in that year. The possibility of one or two day workshops in 2002 is under discussion. It has been very encouraging to see the success of the ASEG's involvement this year in the Salinity Seminar in Bendigo, and also the Exploration Strategies Symposium in Sydney.

It is my belief that the ASEG has still a lot of untapped potential and we would like to encourage all fields of geophysics to be represented in the Society. The Federal Executive is also encouraging the Society to continue to extend into the petroleum geophysics arena. Accordingly, it is good to see the strong technical side of the conference program devoted to petroleum.

If there are issues concerning the Society that you would like to raise, please do not hesitate to contact me or another member of the Federal Executive. We would be only too happy to assist wherever possible.

Tim Pippett
President

Print Post Approved – PP3272687 / 0052.

Preview is published six times per year by the Australian Society of Exploration Geophysicists and is provided free to all members and subscribers of the ASEG, which is a non-profit company formed to promote the science of exploration geophysics in Australia. This publication remains the legal property of the copyright owner (ASEG).

Contents

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

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

All contributions should be submitted to the Editor via email at 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 $400 per page for the printing of colour figures. Reprints will not be provided but authors can obtain, on request, a digital file of their article, and are invited to discuss with the publisher, RESolutions Resource and Energy Services, purchase of multiple hard-copy reprints if required.

Deadlines

Preview is published bi-monthly, February, April, June, August, October and December. The deadline for submission of all material to the Editor is the 15th of the month prior to issue date. However, the next issue will be the Conference Edition and the deadline for editorial copy is 29 June 2001.

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. However, the next issue will be the Conference Edition and the deadline for advertising material is 13 July 2001.

New Members

We would like to welcome the following new members to the ASEG. Membership was approved by the Federal Executive at its April and May 2001 meetings.

Name	Affiliation	State
Boris Gurevich	Curtin University	WA
Michael Thomas Moore	NSW Dept. Min. Res.	NSW
Dennis Anthony Myrea	Reeves Wireline	QLD
Timothy O'Sullivan	Theolog	QLD
Jon Pattillo	Oil Search	NSW
Heidi Ann Best	Veritas	WA
Timothy Ray Chapman	Santos	SA
Dennis S Palos	Val d'Or Geofisica	Peru
Paul Simon Webster	Woodside	WA
Thomas Edward Wilson	PPK Env & Infra	WA
D. Greg Hodges	Fugro	Canada
Gregory Francis Patrick Irwin	Magellan Petroleum	QLD
Alan Barry Reid	Reid Geophysics	UK
Edwin David Wilson Belcher	Western Geco	NZ
Cherlotte Kinross White	Western Geco	QLD
Brian Edward Barrett	Adelaide University	SA
Phil Heath	Adelaide University	SA
Tomasz Kivior	NCPGG	SA

Missing Members

Any member who knows the current contacts of the following members please contact the Secretariat (Tel: (07) 3855 8144; Email: secretary@aseg.org.au)

Name	Last Known Address
Hooruddin Al-Andoonisi	Saudi Arabia
Robert Lawrence	SA
Chris Golding	WA
Neil Dunford	Vic
Nicholas Eaton	WA
Ed Neil	SA
Charles Pretorius	South Africa

Published for ASEG by:

Publisher: Brian Wickins
Oilfield Publications Pty Ltd
T/A RESolutions Resource & Energy Services
Tel: (08) 9446 3039
Fax: (08) 9244 3714
Email: brian@oilfield.com.au

Editor: David Denham
7 Landsborough Street, Griffith ACT 2603
Tel: (02) 6295 3014
Email: denham@atrax.net.au

Associate Editors:
Petroleum: Mick Micenko
Email: micenko@bigpond.com

Petrophysics: Don Emerson
Email: systems@lisp.com.au

Minerals: Steve Mudge
Email: vecresearch@bigpond.com

Engineering, Environmental & Groundwater: Geoff Pettifer
Email: g.pettifer@geo-eng.com.au

ASEG Head Office & Secretariat:
Glenn Loughrey
P.O. Box 112, Alderley Qld 4051
Tel: (07) 3855 8144
Fax: (07) 3855 8177
Email: secretary@aseg.org.au
Web site: http://www.aseg.org.au

Federal Executive

President: Timothy Pippett
Tel: (02) 9542 5266
Email: tpippett@ozemail.com.au

1st Vice President: Katherine McKenna
Tel: (08) 9273 6400
Email: kmckenna@fugroairborne.com.au

2nd Vice President: Suzanne Haydon
Tel: (03) 9412 5054
Email: suzanne.haydon@nre.vic.gov.au

Honorary Treasurer: Bob White
Tel: (02) 9450 2237
Email: rwhite@iol.net.au

Honorary Secretary: Dave Robson
Tel: (02) 9901 8342
Email: robsond@minerals.nsw.gov.au

Past President and International Affairs:
Brian Spies
Tel: (02) 9717 3493
Email: spies@dem.csiro.au

Publications Committee: Andrew Mutton
Tel: (07) 3374 1666
Email: andrew.mutton@bigpond.com

Conference Advisory Committee:
Kim Frankcombe
Tel: (08) 9316 2074
Email: kfrankco@ozemail.com.au

Membership Committee: Koya Suto
Tel: (07) 3858 0612
Email:
koya.suto@upstream.originenergy.com.au

Education Committee:
Stewart Greenhalgh
Tel: (08) 8303 4960
Email:
stewart.greenhalgh@adelaide.edu.au

Publicity Committee: Mark Russell
Tel: (08) 9322 8122
Email: info@geosoft.com.au

Internet Committee: David Howard
Tel: (08) 9222 3331
Email: d.howard@dme.wa.gov.au

Web Master: Voya Kissitch
Tel: (07) 3350 1810
Email: kissitch@hotmail.com

ASEG Research Foundation: Phil Harman
Tel: (03) 9609 2678
Email: harman.phillip.pg@bhp.com.au

Committee

Rebecca Denne
Tel: (02) 4358 3944
Email: tully@acay.net.au

Ray Shaw
Tel: (02) 9969 3223
Email: vanibe@bigpond.com

Jim Macnae
Tel: (02) 9850 9291
Email: james.macnae@mq.edu.au

Steve Webster
Tel: (02) 9858 5589
Email: swebster@sneaker.net.au

Graham Butt
Tel: (02) 9957 4117
Email: grahamb@encom.com.au

ASEG Branches

ACT

President: Nick Direen
Tel: (02) 6249 9509
Email: nick.direen@agso.gov.au

Secretary: David Robinson
Tel: (02) 6249 9156
Email: david.robinson@agso.gov.au

New South Wales

President: Steve Webster
Tel: (02) 9858 5589
Email: swebster@sneaker.net.au

Secretary: Michael Moore
Tel: (02) 9901 8398
Email: moorem@minerals.nsw.gov.au

Northern Territory

President: Gary Humphreys
Tel (08) 8999 3618
Email: gary.humphreys@nt.gov.au

Secretary: Dave Johnson
Tel: (08) 8935 0000
Email: david.johnson@expl.riotinto.com.au

Queensland

President: Troy Peters
Tel: (07) 3391 3001
Email: tpeters@velpro.com.au

Secretary: Kathlene Oliver
Tel: 0411 046 104
Email: ksoliver@one.net.au

South Australia

President: Andrew Shearer
Tel: (08) 8463 3045
Email: ashearer@msgate.mesa.sa.gov.au

Secretary: Graham Heinson
Tel: (08) 8303 5377
Email:Graham.Heinson@adelaide.edu.au

Tasmania

President: Michael Roach
Tel: (03) 6226 2474
Email: roach@geo.geol.utas.edu.au

Secretary: James Reid
Tel: (03) 6226 2477
Email: james.reid@utas.edu.au.

Victoria

President: Suzanne Haydon
Phone: (03) 9412 5054
Email: suzanne.haydon@nre.vic.gov.au

Secretary: Vacant.

Western Australia

President: Kevin Dodds
Tel: (08) 9464 5005
Email: k.dodds@per.dpr.csiro.au

Secretary: Guy Holmes,
Tel: (08) 9321 1788
Email: guy@encom.com.au

New Faces on the Federal Executive

At the Society's AGM in April this year, several new office bearers were appointed to the Federal Executive. All have served the ASEG before in one role or another, but we would like to introduce readers to three of the new office bearers and wish them well in the discharge of their very important duties.

Timothy Pippett - President

Having graduated with a B.App.Sc. from Canberra C.A.E. in 1974, Tim was employed by Layton Geophysical International from 1975 to 1981, undertaking geophysical surveys in gravity, magnetics and seismic refraction and gravity recomputation's for the old Bureau of Mineral Resource (now AGSO).

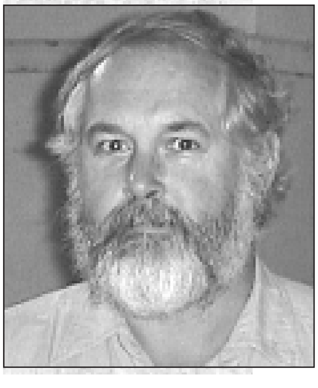
In 1981 Tim joined EG&G Geometrics in Sydney to run the airborne division of the company. His role in the company changed with the change in the company's emphasis away from airborne geophysics and he became the Sales Manager, which included development and integration of systems and training courses on geophysical instruments. The company during this time had a change of owner and the name was changed to Geo Instruments.

1994 brought a moved to ADI Limited-Technology Group (Australian Defence Industries) to run the Sub Surface Imaging Division. In this role Tim used geophysics for the location of environmental targets including unexploded ordnance (UXO) around the world, in particular USA.

In 1997, Tim formed Alpha Geoscience, which was set-up to undertake consulting and contract projects in the environmental, engineering and ordnance fields around the world. These projects include the location of buried UXOs around the world, development of a multi-sensor geophysical package for the coal industry and the use of geophysics for environmental and forensic applications.

Tim has held a number of positions with the ASEG including Business Manager, Co-Chairman of the ASEG Conference in Sydney in 1991, State President of the NSW Branch and has been on the Federal Executive for the last two years.

He is a Member of the ASEG, SEG, EAGE, EEGS, Fellow of the AIG and a Registered Professional Geoscientist in the fields of geophysics and environmental geoscience.



Bob White - Treasurer

Bob White started at Macquarie University in 1967 to study economics but quickly switched to geology and geophysics, realising that the earth sciences people seem to have a more realistic view of what mattered in life.

After some 7 ½ years at University, armed with a BA, MSc and a good appreciation of red wine, he went to work for Cominco Exploration (later to become Aberfoyle) in Adelaide, who promptly sent him off to the wilds of western Tasmania in search of an airborne EM anomaly that was to become the Que River mine.

In 1977 Bob moved back to Sydney to work for Getty Oil in their minerals division. These were interesting times, working for companies with relatively large budgets for exploration, research and lunches. All good things must come to an end and in 1986 Getty was taken over and 23 000 people laid off.

In 1986 Bob, with fellow geophysicist Phil McSharry and others, decided to have a go at what now would be called .COM, i.e. start a hardware and software company (15 years ahead of the pack). Unfortunately the crash of 1987 finished this venture.

In late 1987 Bob got into the contracting and consulting business, in the next 3 years planning and running surveys all over Australia. The largest of the jobs was as survey in Arnhem Land for 2 years. This project involved employing and supervising over 50 people to conduct a large-scale geological, geophysical and geochemical survey in the search for uranium.

For the last 10 years he has been consulting in geophysics and computing for a number of companies in Australia and overseas.

Bob has been on the current Federal Executive for 2 years and this is his second stint as ASEG treasurer, the first was in 1982. His aim is not only to keep the ASEG out of financial difficulty but also to see its assets grow.

Suzanne Haydon - 2nd Vice-President

Suzanne Haydon is a graduate of Melbourne University with Honours in Geophysics. She spent several weeks acquiring gravity data near Casey Base in Antarctica before gaining employment with the Geological Survey of Victoria (GSV). After spending two years roaming Victoria with a gravity meter, she moved on to interpreting magnetic and radiometric data for the GSV's geological mapping program, co-authoring and editing reports and supervising magnetic/radiometric surveys. Suzanne has been actively involved with the ASEG for the past few years, and is currently in her second term as President of the Victorian Branch as well as being recently elected Second Vice-President of the Federal ASEG. In her spare time, Suzanne enjoys outdoor sports including mountain-biking, hiking and skiing.

Events for 2001/2002

2001

August 5-8
Australian Society of Exploration Geophysicists, 15th International Conference and Exhibition, Brisbane, Qld.
Theme: A Geophysical Odyssey
Theme: '2001: A Geophysical Odyssey'
Website: http://www.aseg.org.au
Event Manager: Jacki Mole
Tel: +61 7 3858 5579
Email: aseg2001@im.com.au

September 2-6
7th Environmental & Engineering Geophysical Society, European Section, Birmingham, U.K.
Theme: Better and faster solutions
Email: conference@geolsoc.org.wk
Website: www.geolsoc.org.uk/eegs2001/

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

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

November 25-28
Eastern Australasian Basins Symposium 2001 - New Guinea, East Australia, New Zealand.
Theme: A refocussed energy perspective for the future,
Melbourne Hilton on the Park, Melbourne,
Contact: Miriam Way, EAB Symposium, AusIMM
PO Box 660, Carlton South Vic 3053
Tel: (03) 9662 3166
Fax: (03) 9662 3662
Email: miriamw@ausimm.com.au
Co-ordinated by the Victoria/Tasmania Branch of Petroleum Exploration Society of Australia

November 26-27
New Gen Gold 2001: New Generation Gold Mines Case Histories of Discovery Conference,
Burswood Convention Centre, Perth WA,
Organised by AMF and Keith Yayes & Associates Pty Ltd
Contact: Donna Biddick at the AMF
Tel: (08) 8379 0444,
Email: NewGenGold@amf.com.au
Website: http://www.NewGenGold.com.

December 10-14
AGU 2001 Fall Meeting, San Francisco, Calif., U.S.A.
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: meetings@agu.org
Web Site: www.agu.org/meetings/

2002

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

South Australia Branch - by Andrew Shearer

The start to the year has seen the SA Branch get off to a busy beginning, with a diverse program planned for the remainder of the year. So far two technical meetings have been very well attended, with up to fifty people in attendance at our last meeting.

In April we were given a very professional presentation on the subject of *Interpreting multiple episodes of faulting using 3D visualisation techniques* by Andrew Davids of Origin Energy. Our thanks go to Schlumberger for their sponsorship of the night.

Our most recent talk in May was given by Kathryn Powell, formerly of the South Australian Police and now with the Department of Human Services, SA and titled the *The Detection of Human Skeletal Remains Using Geophysical Instruments*. Kathy's research examines the potential application of geophysical instruments to the detection of clandestine graves and in particular, to the detection of human skeletal remains. Question time was entertaining and beneficial for both presenter and audience alike. Our thanks to Primary Industries and Resources SA (PIRSA) for their sponsorship of the meeting.

It was very encouraging to see large numbers of people staying behind after the meetings to catch up. I feel that this interaction is an important component of our society and suggest that even if the subject mater is not in your field of expertise, attendance is still worthwhile in order to meet fellow members and discover what is happening.

Our June presentation is planned to be a multi speaker presentation led by Chris Henschke of PIRSA dealing with the issues and application of geophysics to dryland salinity in South Australia.

Queensland Branch - by Troy Peters

The branch Christmas dinner was conducted in late December and, from all accounts, the Turkish coffee house proved to be a great venue.

Howard Bassingthwaighte (Schlumberger) displayed to the Branch the finer points of belly dancing, proving the point that this may have been his profession in a former life.

The focus is still primarily on the Brisbane Conference in August, ***2001: A Geophysical Odyssey***. The technical program is in its final stages of compilation, exhibition space is selling fast and support through sponsorship has exceeded expectations. All indications are that this will be a highly successful meeting.

Tasmania Branch - by James Reid

Our second technical meeting for 2001 was held on May 11th, and was well attended. Andrew Fitzpatrick gave a presentation entitled *Scale dependent electrical properties of rocks - new methods*, after which the Branch hosted a lunch at the University Staff Club.

Our next technical meeting will be held at 12:30 pm on Friday 27th July - contact James Reid for details.

ACT Branch - by David Robinson

The ACT Branch AGM was held on the 11th April. The President's and Treasurer's reports were delivered and accepted, followed by the election of the new committee. The new office bearers for the ACT Branch are:

President: Nick Direen
Vice-President: Leonie Jones
Treasurer: Peter Milligan
Secretary: David Robinson

Committee Members:
Tim Mackey
Eva Papp
Ian Hone
Prame Chopra

After the AGM, Terry Crabb (SMS Consulting) gave a presentation titled *An Australian Airborne Gravimeter Development - a review of its history, status at June 2000, & future prospects: a personal perspective of the experience*. The presentation was followed by a tasting of several local wines.

The next gathering will be on the 24th May at 1630 at AGSO. The guest speaker will be Trevor Dhu from AGSO who will talk about *Texture based enhancement of aeromagnetic data using fractal dimension*. According to recent tradition, the meeting will also feature a local wine tasting. Members and guests most welcome!

Western Australia Branch - by Mark Russell

Technical Meetings:
Technical meetings are held on the third Wednesday of each month at the Celtic Club, 48 Ord Street, West Perth (5:30pm drinks and food, 6:00pm meeting commences).
ASEG members admission free; Non-members admission $10.00.

For Information on Upcoming Meetings/Events/Agendas, Please see our website: http://www.aseg.org.au/wa

If your company would like to present a paper and/or sponsor at ASEGWA meetings please contact Kevin Dodds, CSIRO (08 9464 5005) or Guy Holmes, Encom (08 9321 1788) about speakers and sponsorship possibilities

Employment Service
Our Employment Service is available on the ASEGWA web site. This service is available to WA members to facilitate initial contact between employers and those seeking employment. To see who is currently available, or to register yourself, go to the Employment Section of our website: http://www.aseg.org.au/wa/employment_cont.html

Our Website: http://www.aseg.org.au/wa
General Correspondence to:
ASEG-WA Secretary
c/- PO Box 1679
West Perth, WA 6872

President: Kevin Dodds, CSIRO, Tel: 08 9464 5005,
Email: kevin.dodds@per.dpr.csiro.au;
Vice President: Jim Dirstein, Tel: 08 9382 4307,
Email: dirstein@iinet.net.au
Secretary: Guy Holmes, Encom, Tel: 08 9321 1788,
Email: guy@encom.com.au
Treasurer: John Watt, WADME, Tel: 08 9222 3154,
Email: j.watt@dme.wa.gov.au

ASEG 2001 ...The year of the Odyssey

Dr Karl to speak at Conference Dinner

Dr Karl Kruszelnicki, (as seen on TV) the famous author and science commentator will be the guest speaker at the Conference Dinner. Dr Karl is the Julius Sumner Miller Fellow at the University of Sydney, in the Science Foundation of the Physics Department. He is an engaging and lively raconteur and will be a highlight of the Conference.

Fully Refereed Papers Invited

Extended abstracts for all presentations at this year's Conference are currently being processed and will be available on CDROM at the time of the conference. In addition, a number of authors have been selected to submit longer papers for full peer review to be published in Exploration Geophysics later this year. Randall Taylor and Syd Hall will be the guest editors for this process.

Consultants Booths at Exhibition

This year the exhibition has made some space available for 'consultant booths'. These are available to ASEG members who are bona-fide consultants. They provide facilities that are somewhat less than a conventional booth at somewhat less than a conventional booth price. Consultants should contact the secretariat for details on eligibility and services.

To date some 90 exhibition booths have been taken up and are currently being allocated. Bookings will be taken right up to the opening of the Conference but as always sooner is better than later.

Past Presidents never die they just keep rambling on.
Three Past Presidents of the Society will talk at a 2-hour career's seminar to be held on the Sunday before the Conference. This seminar will join together policy makers, managers of exploration companies, practicing geoscientists, career counsellors, geophysical consultants, financial advisors, recruiting agents as well as job seekers, students, new graduates and those who are concerned or interested in career management issues. Attendance to this seminar is free of charge but attendance should be advised at the time of registration.

Student Day

This year the Student Day will be held on Tuesday 7th of August. The format from previous conferences will be followed with students to be addressed in the morning by practising geophysicists followed by a visit to the exhibition

The ASEG 2001 Conference is proudly sponsored by:

Gold Sponsors

Fugro Airborne Surveys
Woodside Energy

Silver Sponsors

BHP
CSIRO
MIM Exploration
Office of Minerals and Energy Resources SA
(formerly PIRSA)
Veritas DGC
WMC

Bronze Sponsors

Anglo American Exploration
Dynamic Satellite Surveys
Geosoft Australia
Green Mountain Geophysics
Origin Energy
New South Wales Department of Mines and Energy
Northern Territory Geological Survey
Queensland Department of Mines and Energy
Quantec Geoscience
Velseis Group

ASEG 15th Geophysical Conference & Exhibition
Brisbane Queensland
5 - 8 August 2001
Tel 61 7 3858 5579
Fax 61 7 3858 5510
Email: aseg2001@aseg.org.au
www.aseg.org.au

ASEG 2001 Provisional Seismic Petroleum Environmental Geophysics Program					
Monday		Tuesday		Wednesday	
Stream A	Stream B	Stream A	Stream B	Stream A	Stream B
		Environmental EM	PSDM and Depth Conversion		Seismic Case Histories
Quantitative Seismic Interpretation	Coal Geophysics	High Resolution Geophysics	AVO	Seismic Anisotropy & Ray Path Analysis	Seismic Acquisition Methodologies
High Resolution Seismic	Seismic Multiple Attenuation	Petroleum Interpretation Technologies	Seismic Modelling of Near Surface Effects	Regional Geophysics	Seismic Tomography
Land Seismic Acquisition	Seismic Processing and Attribute Analysis	Seismic Migration	Data Management and Risk Reduction in Resource Exploration		

ASEG 2001 Provisional Mineral Geophysics Program					
Monday		Tuesday		Wednesday	
Stream A	Stream B	Stream A	Stream B	Stream A	Stream B
		Case History Day – Australia	Downhole Applications	Regional Perspectives	Inversion
Airborne Processing 1	Petrophysics	Case History Day – Australia	Developments in Processing	Electrical Methods	Magnetic Modelling
Innovative Airborne Geophysics	Tomographic Applications	Case History Day – Australia	EM Interpretation	Electromagnetic Interpretation	Exploring Through Cover
Airborne Processing 2	Applications	Case History Day – Australia	Regional Applications		

Workshop schedule at a glance				
	Minerals	Petroleum	Coal	Environment
4 August 5 August	Airborne EM from Start to End. (Part 1:Getting good AEM data) *(J Bishop & J Macnae)* Airborne EM from Start to End. (Part 2:Making the best use of EM data) *(J Bishop & J Macnae)*	AVO and Inversion *(B Russell)* AVO and Inversion *(B Russell)*	Near Surface Seismology *(D Steeples)* Near Surface Seismology *(D Steeples)*	*See* *(Bishop & Macnae)* *& (D Steeples)* *See* *(Bishop & Macnae)* *& (D Steeples)*
5 August	Application of Geophysical Logging to Metalliferous Mining *(Organiser -Fullager)*	Petroleum Geomechanics *(R Hillis)*	Petroleum Geomechanics *(R Hillis)*	
	ASEG 200 Conference 6-8 August			
9 August		Stochastic Modelling for Reservoir Characterisation *(R Dimitrakopoulos)*	Stochastic Modelling for Reservoir Characterisation *(R Dimitrakopoulos)*	
9 August 10 August		Seismic Signal Processing for Interpreters *(Michael Schoenberger)* Seismic Signal Processing for Interpreters *(Michael Schoenberger)*		
A detailed description of the workshops and biographies of the instructors can be found in the registration brochure and also online at the ASEG web site www.aseg.org.au				

Budget 2001, Better than Last Year, but Fails the Modern Economy Test

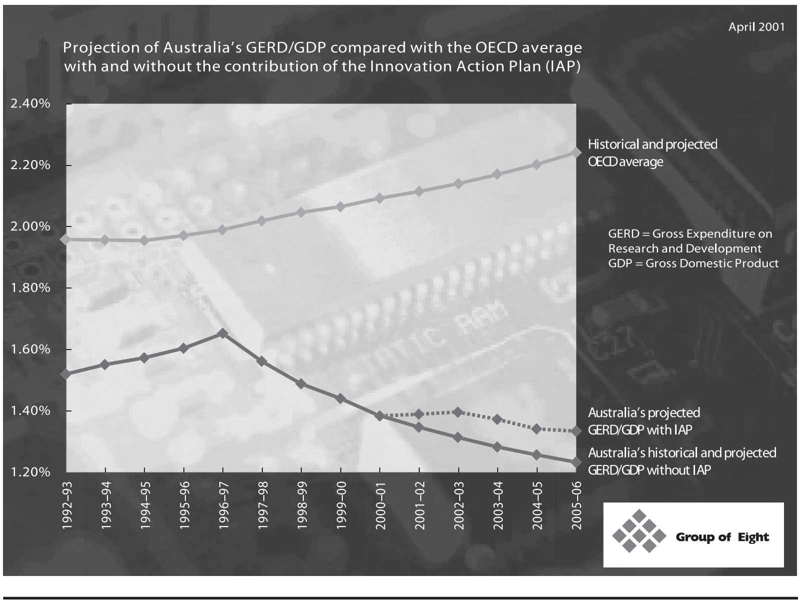
The 2001/2002 Budget delivered a $311 million increase in support for science and innovation to make a total Commonwealth investment of nearly $4.7 billion. This is nearly double the increase of $167 million in the 2000/2001 budget but is equivalent to only about 1/6th of the Royal Dutch Shell's annual profits. It still leaves Australia lagging behind our OECD partners and in terms of percentage increase, it only keeps pace with inflation. The chart below, taken from a presentation by the Group of Eight Australian universities, shows how we have fared over the last few years. In essence we need to invest an extra $13 billion over the next five years to just catch up to the OECD average, and as everyone knows, in this day and age, being average is not really good enough.
The planned Commonwealth investment for 2001/2002 is 0.67 percent of GDP, which is about what it was in 1996/97 but much less than the 0.75 percentage level reached from 1993 to 1996.

The main increases for 2001/2002 are the $159 million to implement the Prime Minister's Innovation Action Plan (see February 2001 Preview), $128 million to medical research funding and, $86 million on the new Lucas Heights replacement research reactor.

It is worthwhile looking at how the main government research agencies fared.

Agency	1999/00	2000/2001	2001/2002
CSIRO	$617M	$611M	$615M
DSTO	$269M	$288M	$284M
ANSTO	$105M	$181M	$222M
Bo Meteorology		$199M	$194M
Antarctic Division	$94M	$103M	$101M
AGSO	$62M	$62M	$63M

Fig.1 Australian Investment in aR & D as a percentage of GDP



As can be seen, apart from the increase for the new reactor at ANSTO these numbers are certainly not spectacular. In fact the Bureau of Meteorology and Antarctic Division both have decreases in budget allocations.

Outside of the Innovation Statement, the government will provide $75 million over ten years to increase environmental flows down the Murray River, and $1.2 million over four years to promote beneficial partnerships between the mining industry and Aboriginal communities. Details of this program will be announced later in the year but at $300 000 per year it is difficult to see how it can make a major impact.
On the whole a very disappointing budget, particularly in the context of the major spending initiatives and tax cuts. There appears to be no real focus on long-term investment to generate wealth for the future, only plans to spend hard earned tax dollars.

AGSO announces New Directions

In a circular to staff in April 2001, the Australian Geological Survey Organisation has outlined the challenges it faces in the next five years. These are to provide geoscience input to the Government's management decisions relating to:

- mineral and energy resources,
- quality of life,
- biological diversity,
- soil and water quality and quantity,
- our marine zone and its resources, and,
- air quality.

According to this Circular, the strategy for the next 5 years, apart from the traditional resource and hazard programs, will include three new output groups - geoscience for:

- urban centres,
- oceans and coasts, and,
- regional and rural areas.

There will also be an integrated information management plan to facilitate access to AGSO data and information. Geoscience data, information, and the knowledge subsequently developed can be applied to a broad range of issues and be useful to many Australians. The plan will be to make this information as widely available as possible.

Eristicus
May 2001

What's the time? The sites included in this month's Web Waves will help you know PRECISELY what the time is in any part of the world. A big thank you to Steve Mudge of W.A. for bringing the following websites to my attention.

Written by:
Natasha Hendrick
natasha@geoph.uq.edu.au

National Institute of Standards and Technology (NIST), USA
www.bldrdoc.gov/timefreq/index.html

The Physics Laboratory of the NIST provides details on the worldwide voice time radio stations and provides direct links to software for setting your computer clock via the Internet.

CNN Time Information
www.cnn.com/WEATHER/worldtime/

Use the CNN world map to work out time zones anywhere in the world, or use the world time converter to compute the local time for a large number of global locations. You'll need to download the free Macromedia Shockwave Player to access the world map.

Official USA Time Clock
www.time.gov

Click your mouse on any location in the USA to find out the local time. There are also a number of interesting links to other time related websites - topics include the history of time keeping, calendars through the ages, mechanisms of clocks and advances in time keeping.

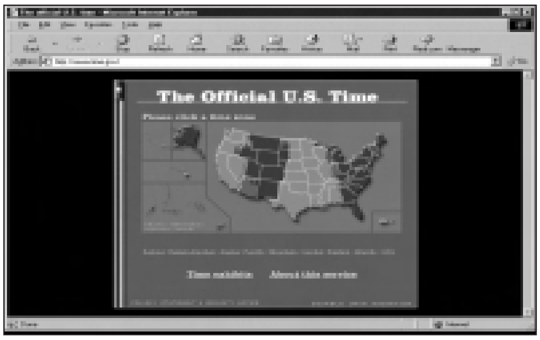
If you have any favourite sites (not necessarily geophysical) that you would like to share with our members please email Natasha (natasha@geoph.uq.edu.au). An ASEG Favourites list will be published in the next edition of Preview.

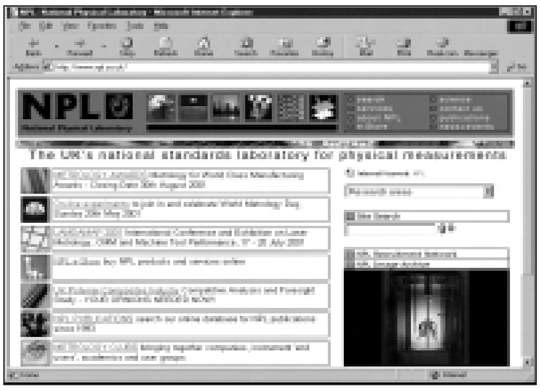
CSIRO Division of Telecommunications and Industrial Physics
www.tip.csiro.au

Check under the National Measurement Laboratory's Standards Development and Maintenance link for time and frequency standard information. You can download time and frequency data, including monthly reports of daily values of UTC (AUS) from Australian laboratory clocks, ABC TV and Radio VNG (Australian standard time radio station).

Greenwich Electronic Time
www.get-time.org.uk

The Greenwich Electronic Time site is a joint initiative of Industry and the U.K. government to facilitate time in the digital age. From this site you can obtain global time updates, download a clock for your computer or add a clock to your website.





National Physical Laboratory (NPL), UK
www.npl.co.uk

Check out the Beginners' Guide to Atomic Time Keeping (www.npl.co.uk/npl/publications/atomic/).

Or visit the Time and Frequency Homepage (www.npl.co.uk/npl/ctm/) to find out more about time scales and the definition of time. Further time information can be found in the listed publications or related www links.

Geoscience Information – Improving Online Accessibility

Jonathon Root and
Tim Mackey, Australian
Geological Survey Organisation
johnathon.root@agso.gov.au
tim.mackey@agso.gov.au

The volume of geoscience data available on the Internet is growing rapidly. Users can now access dozens of GIS layers, real-time feed from geophysical observatories, online GIS systems, databases and catalogues of open file data, agency products, and more. AGRF calculators are available and users can do simple image processing of geophysical and satellite imagery, all in addition, of course, to the agency descriptions and static project activity pages which were the staple of early websites. Much of the data are available free, or for purchase through online eCommerce systems.

An example of the direction of online information delivery can be seen in the recent upgrade to the national geoscience datasets pages on AGSO's website. The online GIS tool has been enhanced to provide zoom-to functions, session saving, raster imagery, configurable menus and a host of new data layers, including translucent polygon layers for improved overlaying. Data layers are linked to a metadata database, providing up-to-date information on data quality, and the majority of layers can be downloaded as either Arcview shapefiles or Mapinfo tab files. Most of the data files are free; others are available for online purchase.

The integration of applications and data delivery systems demonstrated in the national geoscience datasets site is taken one step further with the online catalogue of petroleum information (Figure 1). In this system up-to-date databases of holdings in the AGSO petroleum data repository are linked to mapping tools and online ordering to allow users to locate and order petroleum survey information, core and cuttings, and destructive analysis reports.

Web delivery systems are becoming increasingly complex, with a number of programs, server daemons, databases, and scripts interacting to produce a particular application in the users browser. Figure 2 shows a typical example of geoscience data delivery systems based around AGSO's current environment. This ability to integrate disparate systems into a single, simple user interface is a great strength of the web browser environment. Now that most major data suppliers have implemented web interfaces to their main data holdings, the next stage is likely to be applying these integration technologies to data and information sources on distributed servers, and from different providers.

AGSO is currently constructing two national web portals addressing the themes 'government geoscience' and 'disaster information'. These sites are being built in cooperation with other agencies at State and Commonwealth level, and aim to improve user access to the emerging wealth of online geoscience information. Avoiding service duplication while improving access is an important consideration. Figure 3 shows the relationship between various initiatives with each building to provide a comprehensive national information infrastructure.

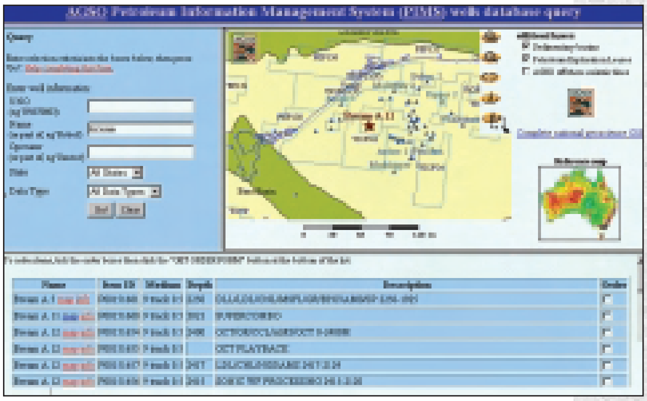


Fig. 1. User interface to AGSO's petroleum data repository database.

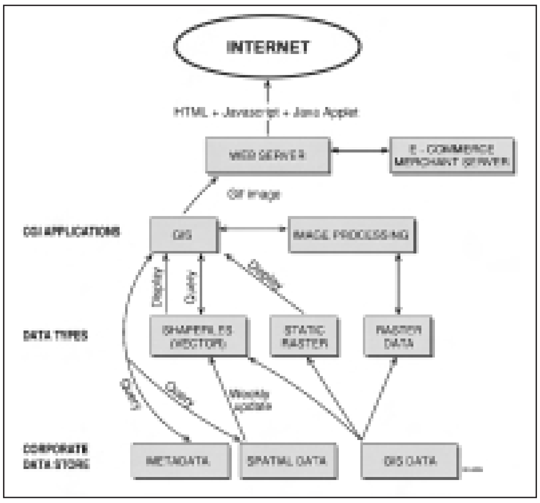


Fig. 2. Schematic representation of part of AGSO's data delivery system.

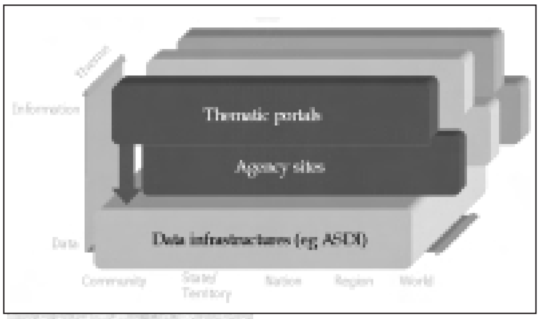


Fig. 3. Relationship between various components of the emerging information infrastructure. ASDI is the Australian Spatial Data Infrastructure (see URL below).

Sites will utilise common portal technologies, such as search engines targeted to trawl specific servers, user customisation options, and collections of URLs linking similar content. In addition, because of the spatial nature of much geoscience information, distributed web mapping systems are being developed, along the lines of those tested as part of the CSDC clearinghouse trial (see web link below).

Distributed web mapping systems allow map layers from online GIS systems on different servers to be overlain on the fly, provided that servers adhere to a common request protocol (in this case the OpenGIS Consortium's web mapping specification). At present AGSO and CSIRO are both serving considerable amounts of GIS data using Internet map servers that comply with the OpenGIS protocol.

Despite (or perhaps because of) the recent collapse of the 'dot-com boom', use of the Internet to deliver improved client service has accelerated rapidly in the last six months. This trend is likely to continue into the near future. Managing access to the high volume, complex data types used in the geosciences will require strong collaboration between providers, if we are not to place an onerous burden on clients in discovering, acquiring, integrating and managing data themselves. Internet technologies aim to reduce costs in these areas, and portals such as the government geoscience portal, if implemented correctly, should do just that.

Relevant URLs:

- www.agso.gov.au/map - Online web mapping and image processing at AGSO
- www.agso.gov.au/databases - AGSO databases
- www.agso.gov.au/databases/catalog/agsocat.html - AGSO products database (tip for searching: less is more!)
- www.agso.gov.au/geoscience/national - national datasets homepage
- www.agso.gov.au/geoscience/national/download.html - download page for national datasets
- www.agso.gov.au/geophysics/geomag - real time geomagnetic data, AGRF calculator
- www.agso.gov.au/databases/npd/ - AGSO petroleum data repository
- www.agcrc.csiro.au:80/4dgm/gixwebmap/ - CSIRO geoscience web mapping system
- www.agso.gov.au/front/links.html - links to state agencies
- www.auslig.gov.au/robo/index.html - CSDC clearinghouse trial
- www.opengis.org - OpenGIS Consortium
- www.auslig.gov.au/asdi - ASDI

Geophysics in the Surveys

Northern Territory Geological Survey

2001 Magnetic Map of the Northern Territory

NTGS has released the 2001 digital Magnetic Map of the Northern Territory. This product, which was produced by Roger Clifton, is available as a 100 m grid in ERS (ER Mapper) format, and takes two forms:

1. NTGS data only, which comprises data from 150-500 m spaced NTGS surveys, and,
2. NTGS plus AGSO data, which comprises all available semi-regional government data across the NT (150-500 m spaced NTGS and AGSO surveys, plus AGSO wide spaced reconnaissance data).

Both products are provided in AGD66, and AMG53 by default.

The digital grid of the Magnetic Map of the Northern Territory can be obtained by email from: geoscience.products@nt.gov.au
Option 2 will only be provided if the AGSO reconnaissance magnetic data for the Northern Territory has already been purchased from AGSO.

New airborne geophysical surveys

The NTGS has recently let contracts for the acquisition and processing of almost 500 000 line-km of airborne magnetic and radiometrics. The program comprises 3 separate surveys (see Fig. 1). These are:

1. Barkly: to be flown by Tesla Airborne Geoscience (400 m line spacing N-S, 91 000 line-km) over the Wallhallow, Calvert Hills, Brunette Downs, Mount Drummond, Alroy, Ranken and Avon Downs 1:250 000 Sheet areas.
2. Eromanga: to be flown by Kevron Geophysics (400 m line spacing N-S, 141 000 line-km) over the Sandover River, Tobermory, Hay River, Illogwa Creek, Hale River, Rodinga and Finke 1:250 000 Sheet areas.
3. Waterloo: to be flown by Kevron Geophysics (400 m line spacing N-S, 53 000 line-km) over the Waterloo and Auvergne 1:250 000 Sheet areas.

A substantial portion of the Barkly and Waterloo survey areas is covered by existing private sector data of acceptable standard and specifications, totalling approximately 210 000 line-km. These data will be reprocessed and merged in with new flying in these areas.

The surveys are scheduled to start by early-mid June.

Compressed located magnetic, radiometric and elevation images from each survey will be posted on the NTGS Image Web Server:
http://www.dme.nt.gov.au/ntgs/geophysics/air_map/air_geo_map.html
approximately every 3-4 weeks, to enable early access the emerging geological picture.

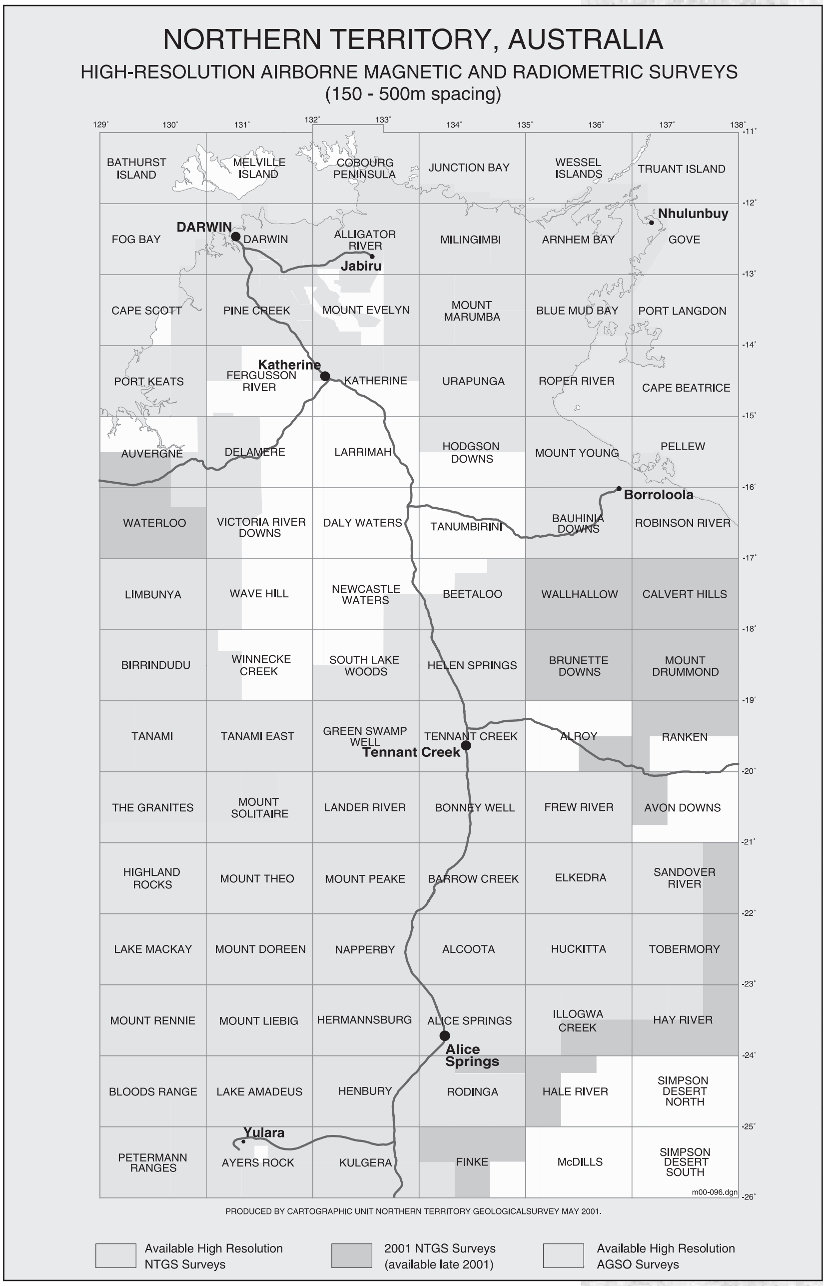


Fig. 1. Coverage of high-resolution airborne magnetic and radiometric surveys over the Northern Territory and locations of surveys

Geological Survey of Victoria

Publication of Palaeozoic Geology of Victoria

The Tasman Fold Belt System in Victoria is the culmination of a decade of geological work by the Geological Survey of Victoria that has, for the first time, been supported by high quality airborne geophysical data. It describes the evolution of Victoria through time, from the Neoproterozoic through to the Permian, and covers the development of the Victorian part of the Lachlan Fold Belt as part of the Tasman Fold Belt System. The different styles, timing and controls on mineralisation that developed in Victoria during this period are described, and links to similar styles of

Continued On Page 16

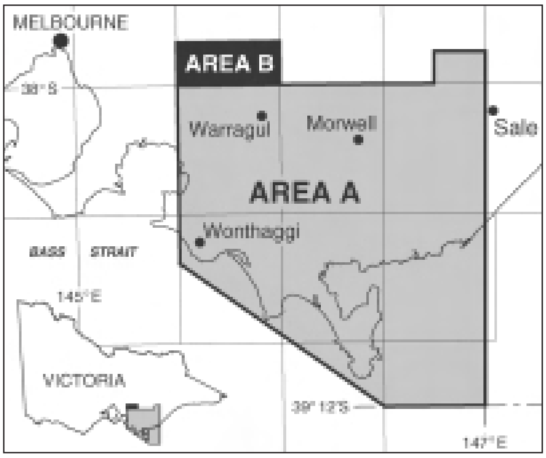


Fig. 1. Victoria 2001 magnetic and radiometric airborne surveys. Area A: Western Gippsland Basin; Area B (Coloured black): Healesville South.

Continued From Page 15

mineralisation in both Tasmania and New South Wales are made.

Three new maps are now available:

- Surface geology map,
- Pre-Permian geology map that shows the interpreted geology of Victoria, with the Permian and younger units stripped off, and,
- Mineralisation map of metallic and major industrial minerals.

The Pre-Permian geology map was compiled from the surface geology map and interpretation of the extensive new magnetic, radiometric and gravity data, along with seismic profiles where available. We have made considerable effort to reconcile the mapped geology with the geophysical data sets, to produce a map that is both geologically and geophysically reasonable. The Pre-Permian geology map background magnetic image and the subsidiary images elsewhere on the map face help support the new interpretation presented for the covered areas. The background image also gives extra information that could not be adequately presented on the map, such as sedimentary or contact metamorphic changes in the magnetic properties of rock packages, dyke swarms, and thick basalt cover. The volume is available from the Minerals and Petroleum Business Centre for $110. Tel: 03 9412 5020.

Airborne surveys

Two airborne surveys have been conducted under the Victorian Initiative for Minerals and Petroleum (VIMP) for 2001 (Figure 1). The larger of the surveys covers the Warragul-Sale area over the western Gippsland Basin and has been contracted to Tesla Geophysics. It has been flown with a 250 m line spacing and 80 m height and is about 68 200 line-km.

A small helicopter survey of about 5800 line-km has been flown by Geo Instruments around the Warburton area. This survey now completes the magnetic and radiometric coverage of the Warburton 1:250 000 Sheet area.

Processing for these surveys is in progress and the data will be released in November 2001 during the Mining 2001 Convention.

The VIMP program and joint projects with the Australian Geological Survey Organisation (AGSO) and a few large industry surveys has enabled the collection of industry standard magnetic and radiometric data covering 95% of the State.

Gravity surveys

Gravity surveys are being done in the eastern Victorian highlands by Geological Survey of Victoria (GSV) staff and contractors. The GSV is continuing to collect data on geological-project specific map areas, and in some instances infilling gaps that were inaccessible at the time of previous contract work. Tesla Geophysics is doing surveys for GSV under contract.

The program is expected to deliver results for seven 1:100 000 sheet areas by July 2001.

2001 Acreage Release

In April 2001, the Commonwealth of Australia and the State of Victoria Joint Authority released four offshore areas adjacent to Victoria. Three of these blocks, V01-1, V01-2 and V01-3, are in the Otway Basin and one V01-04 in the Gippsland Basin. At the same time, Natural Resources & Environment (NRE) will be releasing three onshore Otway Basin areas designated VIC/O-01(1), VIC/O-01(2) and VIC/O-01(3) (Figure 2).

Minerals & Petroleum Victoria (MPV) has prepared three reports on the hydrocarbon prospectivity and potential of the 2001 released areas.

For further information on gazetted blocks, conditions and criteria for selection and submission of applications, can be seen on: -Commonwealth (ISR) web-site: http://www.isr.gov.au/resources/petr_exploration/index.html or the State of Victoria (NRE) web-site http://www nre.vic.gov.au /minpet/pet/pet.htm. The contact officer is: Maher Megallaa on 03-94125081 or maher.megallaa@nre.vic.gov.au

Reprocessed Otway Basin seismic

MPV has reprocessed 220 km of onshore Otway Basin seismic data under VIMP The data are generally of good standard, but in certain areas, which are affected by near-surface basalt extrusives, the signal-to-noise ratio is low to moderate. The objectives were to optimise processing parameters for fault delineation, improve the imaging of the deeper section, and to recommend on ways to optimise acquisition parameters. Robertson Research Australia did the reprocessing.

Eleven seismic lines with original processing quality ranging from poor to good were selected. The lines are located in the Portland Trough Area (four lines), the Warrnambool Area (one line), the Port Campbell Area (three lines) and the Geelong / Anglesea Area (three lines).

The results show that by carefully selecting processing parameters with the emphasis on maintaining resolution, the quality of the processed seismic section can be substantially improved. Generally more significant improvement was seen on reprocessed lower fold lines, where heavy pre-stack noise attenuation and wider gap deconvolution techniques were previously used. Traverses were also selected along the extension of regional offshore dip-lines in order to assist in providing regional cross-sections. For further information contact Maher Megallaa on 03-94125081 or maher.megallaa@nre.vic.gov.au.

Fig. 2. Otway and Gippsland Basin acreage release areas.

Queensland

Isa-Georgetown Geophysical Surveys

Isa-Georgetown Airborne Geophysical Survey

The Minerals and Petroleum Division of the Department of Natural Resources and Mines has completed a regional airborne geophysical survey in north Queensland. Covering 30 300 square km, the Isa-Georgetown Airborne Geophysical Survey fills the gap between the Department's recently completed Hodgkinson-Georgetown Airborne Geophysical Survey and industry surveyed areas in the Mount Isa region.

The Isa-Georgetown Airborne Geophysical Survey is designed to attract mineral exploration to the relatively unexplored region between areas of proven mineralisation in the Georgetown region and the world class North West Queensland Mineral Province. The area to be covered by the Isa-Georgetown geophysical surveys (airborne and gravity) is largely under sedimentary cover.

The survey commenced on 27 September 2000 was completed on 20 November 2000. 120 800 line km of magnetic and radiometric data were collected. The survey incorporates parts of the Croydon, Georgetown, Millungera, and Gilberton. 1:250 000 Sheet areas.

The northern part of the survey area, where cover is thinner, was flown with 200 m line spacing, while the southern part was flown with 400 m line spacing. Located and gridded data from this survey were released in April 2001.

Isa-Georgetown Gravity Survey

A 4 km x 4 km ground gravity survey commenced in May 2001 in the same general area as the Isa-Georgetown Airborne Geophysical Survey. Approximately 5 250 gravity survey points are planned over the Croydon, Georgetown, Millungera, Gilberton, and Julia Creek 1:250 000 Sheet areas.

Data from the Isa-Georgetown gravity survey will be released early in the second half of 2001.

Contact: David Searle
Department: Department of Natural Resources and Mines
Telephone: (07) 3237 1445

AGSO

Northeast Lord Howe Rise Geophysical and Geological Survey planned for late 2001

The survey, to be carried out on the National Facility R.V. Franklin from 30 October to 22 November, will be a joint AGSO and James Cook University activity, led by AGSO's Neville Exon and JCU's Jerry Dickens.

Recent geophysical investigations indicate that much of the Fairway Basin (eastern Lord Howe Rise) in the Tasman Sea contains sediment diapirs, gas hydrate and probably free gas (PESA Journal 26, 1978). Water depths are largely 1500-2500 m. The RV Franklin will be used to:

- continue seismic mapping of basin sequences, sediment diapirs and bottom simulating reflectors (BSR, suggesting gas hydrate layers) within the Australian and New Caledonian/French seabed jurisdictions;
- core to help determine the origin and composition of gas on the Lord Howe Rise, especially in any identified seafloor structures above sediment diapirs;
- ground-truth seismic data by sampling older outcropping sequences; and
- core to establish the composition, character and climate history of shallow sediment of Holocene and Pleistocene age.

The seismic system, provided by AGSO, will use two GI airguns, and a Stealtharray seismic cable 600 m long with 24 channels, recorded digitally. It is hoped to record about 1700 km of data with a penetration of up to 3 seconds.

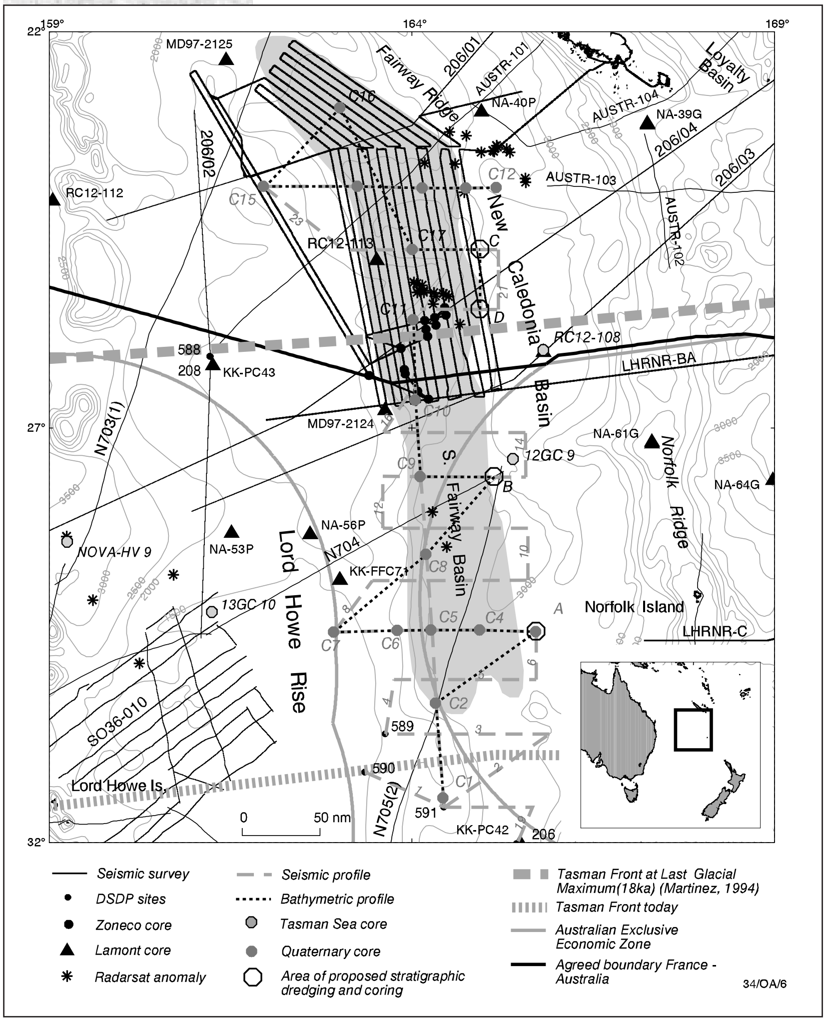


Fig. 1. Map of the eastern Lord Howe Rise and Fairway Basin showing previous work in the region and work proposed here. Note the absence of cores and seismic lines in the South Fairway Basin within Australian jurisdiction. Indeed, this part of the basin is inferred from satellite observations.

Development of a Short-term Model Using Petrophysical Logging at Century Mine, North Queensland.

Paul Basford[1]
Ian Kelso[2]
Terry Briggs[3]
Pasminco Exploration - Australia
[1]basfordp@pasminco.com.au
[2]kelsoi@pasminco.com.au
[3]briggst@pasminco.com.au

Mathew Clifford[1]
Rodney Anderson[2]
Peter Fullagar[3]
[1,2]Pasminco Century Mine - Australia
[3]Fullagar Geophysics
[1]cliffordm@pasminco.com.au
[2]andersor@pasminco.com.au
[3]p.fullagar@mailbox.uq.edu.au

Abstract

Pasminco Century Mine has developed a geophysical logging system to provide new data for ore mining/grade control and the generation of Short Term Models for mine planning. Previous work indicated the applicability of petrophysical logging for lithology prediction, however, the automation of the method was not considered reliable enough for the development of a mining model.

A test survey was undertaken using two diamond drilled control holes and eight percussion holes. All holes were logged with natural gamma, magnetic susceptibility and density. Calibration of the LogTrans auto-interpretation software using only natural gamma and magnetic susceptibility indicated that both lithology and stratigraphy could be predicted. Development of a capability to enforce stratigraphic order within LogTrans increased the reliability and accuracy of interpretations.

After the completion of a feasibility program, Century Mine has invested in a dedicated logging vehicle to log blast holes as well as for use in in-fill drilling programs. Future refinement of the system may lead to the development of GPS controlled excavators for mining ore.

Introduction

The use of borehole logging for grade control is developing across the industry (Fullagar and Fallon, 2001). At Pasminco Century Mine the grade is relatively consistent within discrete strata and the more important factor is determining the location within the mineralised sequence. Several different approaches have been tested for the development of a cost-effect and quick short-term mining model. The current use of in-fill diamond drilling is expensive and the practice of chip logging of the blast holes is labour intensive, slow and unreliable. Both measurement-while-drilling systems and borehole logging were considered as an alternative method.

Borehole logging is not new at Century, with Fullagar et al. (1996), Charbucinski et al. (1997) and Mutton (1997) all demonstrating uses of various logs and interpretation styles for the delineation of mineralisation. Both Fullagar and Mutton et al's work focussed on using borehole logs to predict lithology and mineralisation, with the aim of developing a reliable system for the replacement of diamond drilling with percussion drilling and geophysical logging for cost savings.

Mutton (1997) demonstrated that the lithology could be predicted from natural gamma and magnetic susceptibility by using a known log as at template and matching the curve characteristics of the unknown logs. Although this proved to be moderately successful (50 holes were logged), the technique is labour intensive and requires manual input into the mining model.

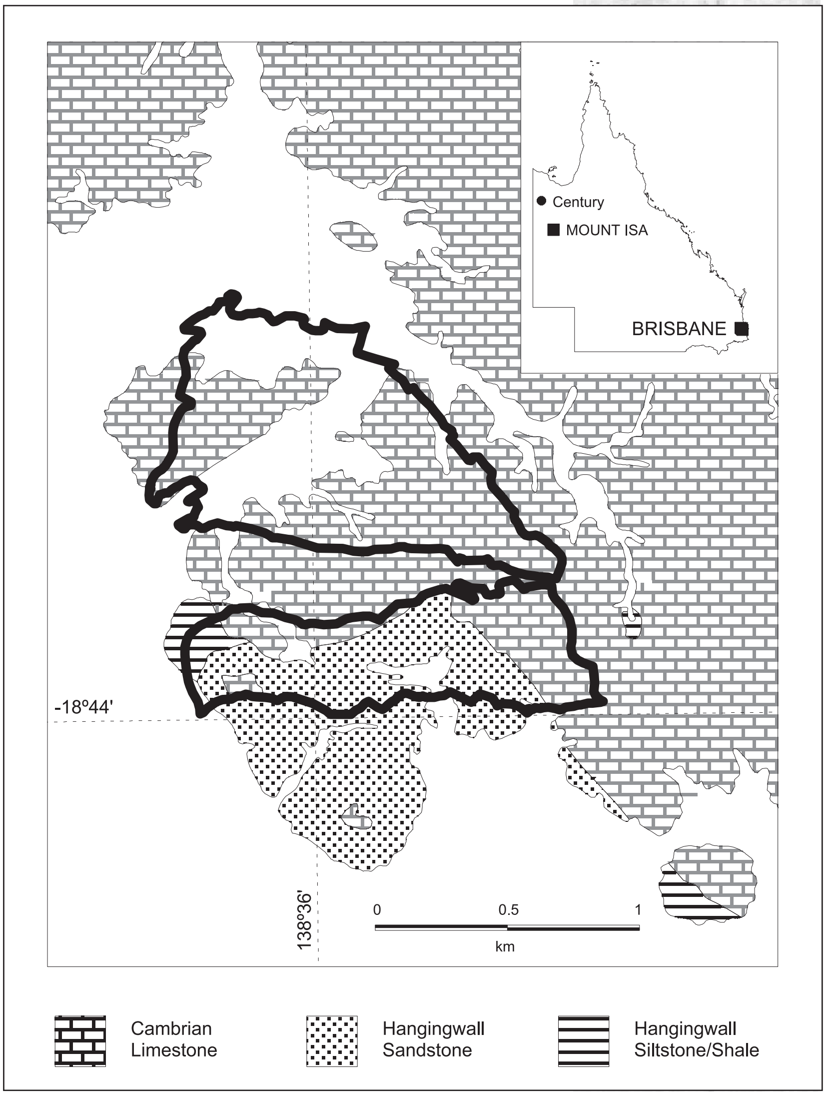
Fullagar et al. (1996) proposed an automated interpretation scheme based on multi-variate analysis. The LogTrans software, developed as part of the AMIRA P436 project, requires the calculation of statistical data, based on a training data set. Results from this work were found to be encouraging, using the three geophysical tools of natural gamma, magnetic susceptibility and density.

Measurement-while-drilling systems (MWD) are relatively new and untested in Australia. The current systems tend to rely on specific drilling techniques and require intensive calibration. The geological sequence at Century of alternating siltstone and shale units were found to be very similar in most of the MWD parameters.

A series of tests were undertaken using borehole logging (natural gamma and magnetic susceptibility) with the

Continued On Page 16

Fig. 1. Location map of Century deposit and mineralisation outline. Areas not defined by stratigraphy represent Cainozoic cover.



Century Stratigraphy

	Sequence	Unit	Lithology	Description	% Zn	%Pb
Waste	Cambrian Limestone	CLS	limestone	Bedded Limestone		
	Carbonate Breccia CBX	CBX	limestone	Limestone Breccia		
	Hangingwall Sandstone	HWS	sandstone	Quartz Sandstone		
	Hangingwall Sandstone	HWB	sst/sh	Sandstone interbedded shale		
	Hangingwall Siltstone	HWD	siltstone/shale	Interbedded siltstone and thin shale		
	siltstone	145	siltstone/shale	Interbedded siltstone and thin mineralised shale		
Upper Zone - Marginal	Shale Band 1	140	shale	Thinly bedded with sphalerite and pyrite in thin bands.	5.3	0.9
	siltstone	155	siltstone	Thinly interbedded siltstone and shale. Can contain some mineralised shales.	1.6	0.4
	Shale Band 2	160	shale	Thinly bedded with sphalerite and pyrite in thin bands.	11.0	3.7
	siltstone	165	siltstone	Thick beds, strongly sideritic, similar to Unit 320	1.9	0.4
Upper Ore Zone	Shale Band 3	170	shale	Sphalerite rich Shale, minor pyrite	13.6	4.7
	siltstone	175	siltstone		2.0	2.2
	Shale Band 4	180	shale	Galena rich shale, similar to Unit 200.	9.4	7.6
	siltstone	185	siltstone	Usually thin bedded and coffee colored.	2.5	4.1
	Shale Band 5	190	shale	Sphalerite rich Shale	11.8	7.7
	siltstone	195	siltstone	Difficult to distinguish	3.2	2.3
	Unit 200	200	shale	Thick massive shale, sphalerite rich with galena-rich veins and boudinaged.	10.5	5.2
Interburden	Unit 310	310	siltstone/shale	Thin bedded shale/siltstone. Sphalerite decreases from top to bottom.	6.6	0.8
	Unit 320	320	siltstone	Thick bedded barren sideritic siltstone	1.1	0.2
Lower Ore Zone	Unit 410	410	shale	Thick bedded shale, sphalerite rich	18.2	2.1
	Unit 420	420	mudstone	Carbonaceous mudstone band - sideritic	0.9	0.2
	Unit 430	430	shale	Thick bedded shale, sphalerite rich	21.1	1.1
	Unit 440	440	siltstone	Thin band sideritic siltstone, similar to Unit 320	2.3	0.2
	Unit 450	450	shale	Zn rich top grading down into a pyritic base	12.1	0.5
Waste	Footwall Shale UFW	UFW	shale/siltstone			

Fig. 2. Mineralised sequence stratigraphy.

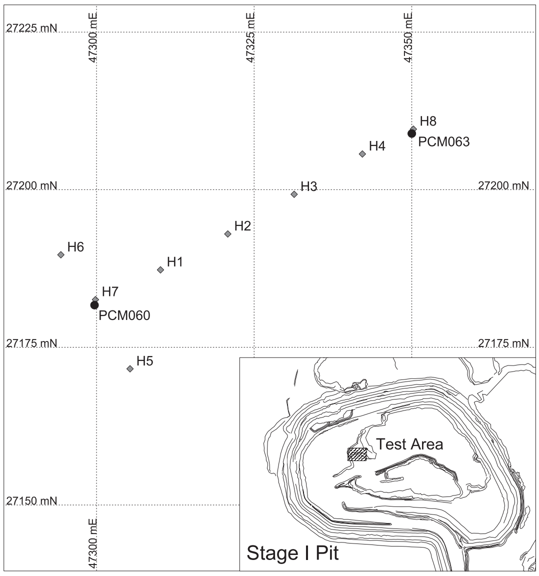


Fig. 3. Geophysical logging test; location of diamond and percussion holes. Test Area defined by box within pit design insert.

Continued From Page 15

LogTrans software (Fullagar et al., 1999) to develop an automated interpretation of ore and waste. After several trials and further development of LogTrans' NewStrat option, to impose stratigraphic order on the interpretation, it was determined that lithology and stratigraphy could be predicted automatically with high reliability. Only minor adjustments are required for each hole prior to uploading into the mine database for the development of a short-term mine model.

Geology and Mineralisation

The Century Zn-Pb-Ag deposit is located approximately 250 km NNW of Mount Isa, Queensland (Figure 1). The deposit was found in 1990 and contains a mineable high-grade resource of approximately 105.1 Mt grading 12.10% Zn, 1.69% Pb and 46 g/t Ag (Broadbent and Waltho, 1998).

Dolomitic siltstones and carbonaceous shales of the Lawn Hill Formation host the stratiform mineralisation. The mineralised sequence is approximately 40m thick and confined within four subdivisions. Each subdivision may be further divided based on lithology.

The primary mineralisation is sphalerite, with minor galena and pyrite, within black carbonaceous shales. The shale units dominate unit 2 and 4 but also occur within unit 1. Less mineralised sideritic siltstone and carbonaceous sideritic mudstone separate the mineralised shale units, with some defined as characteristic marker horizons throughout the mineralised sequence. Across the deposit there is a relatively uniform thickness of these different units (Broadbent et al. 1998). Figure 2 shows the typical stratigraphic sequence at Century, from the hanging wall, through the mineralised sequence and the footwall geology.

From the resource drilling and sampling it has been concluded that the grade continuity within stages of mining is good. The lateral continuity of stratigraphic units is more of a problem, as there is a significant amount of structural displacement. The degree of fault displacement varies, along with the orientation of the movement.

Borehole Logging Trial

Despite the fact that a number of the diamond holes had been previously surveyed with petrophysical logs during resource definition drilling, it was decided to start from scratch at the testing phase of geophysical logging. This was primarily because trials were to be undertaken using large diameter blast hole drilling rigs, not the smaller diameter exploration diamond drillholes.

A test survey was completed around two diamond holes, PCM060 and PCM063, drilled through the entire mineralised sequence within the stage 1 pit. A percussion hole simulating a blast hole was drilled next to each diamond hole, within 0.6 m of the collar location. Four percussion holes were drilled between the two diamond holes along the strike of stratigraphy, and a further two holes were drilled on either side of PCM060 (Figure 3), across the strike.

Geophysical logging was carried out down each of the blast holes as well as the two diamond holes. Natural gamma, magnetic susceptibility and density data were collected down each hole. The choice of tools was based on the earlier results of both Fullagar et al. (1996) and Mutton (1997). All data were collected in raw counts per second, as calibrated data were not of concern. The aim of the project was to determine the signatures of individual lithological and stratigraphic units, not the absolute values of their physical properties.

Specific signatures (amplitude and shape) in the logs became apparent at the initial stage of testing. The magnetic susceptibility data appear to have the greatest character, reflecting the siderite alteration within the siltstone. Gamma logs display a locally elevated response in the mineralised zone within the shale units, due to an increased content of clay minerals.

A hand interpretation of the data inferred a fault located between holes H3 and H4, which had not previously been detected from resource drilling. The apparent dip and plunge interpreted from the geophysical data were later shown to match those mapped in the ore faces and pit floor.

Characteristic signatures have been defined, some of which are highlighted in Figure 4. One of these is the large magnetic susceptibility response associated with unit 320. Unit 320 is an interburden unit that separates the upper and lower mineralization. The contacts of units 200 to 310 and 320 to 410 are considered to be highly important to reduce the amount of dilution and increase ore recovery.

Two other marker horizons with high magnetic susceptibility responses are units 165 and 440. Both have significant amounts of siderite within the siltstone and both units 165 and 440 are considered to be an equivalent of unit 320. These three units also have low ?-ray responses.

The carbonaceous mudstone, unit 420, is also characterised as a major marker horizon due to the large natural ?-ray response associated with it. Unit 420 is unlike most of the waste units insofar as it lacks siderite alteration and so it is not magnetic.

From Figure 4 it can be observed that the mineralised units 200, 410, 430 and 450 all have similar low magnetic responses. This is due to the dominant lithology of the units being the same (carbonaceous shale) and therefore distinguishing between them is quite difficult. The maker horizons delineated by the geophysical data (e.g. units 420 and 440) help defines stratigraphic position.

Normal blast hole logging is undertaken on holes drilled to a total depth of around 10 m. As each individual mineralised shale unit is no thicker than 5 m, it is always expected that at least two other units will be observed in each log. This will assist in the interpretation, especially aiding location within the stratigraphy.

Auto-intepretation

An automated interpretation system (computer based) was required to enable rapid interpretation of a blast hole pattern. At the time of testing, the blast patterns employed at Century mine were on average 75 m by 50 m, with holes spaced 6 m by 7 m apart and drilled to a nominal depth of 10 m. The average blast pattern contains over 100 holes, which need to be logged, interpreted and the interpretations loaded into the drill hole database prior to blasting.

Drilling of an individual blast pattern takes on average four shifts (48 continuous hours) and there is usually only one shift (12 hours) from the completion of drilling to priming and blasting. Logging and interpretation work is only undertaken during day shifts, leaving approximately two shifts (24 hours) for the work to be completed.

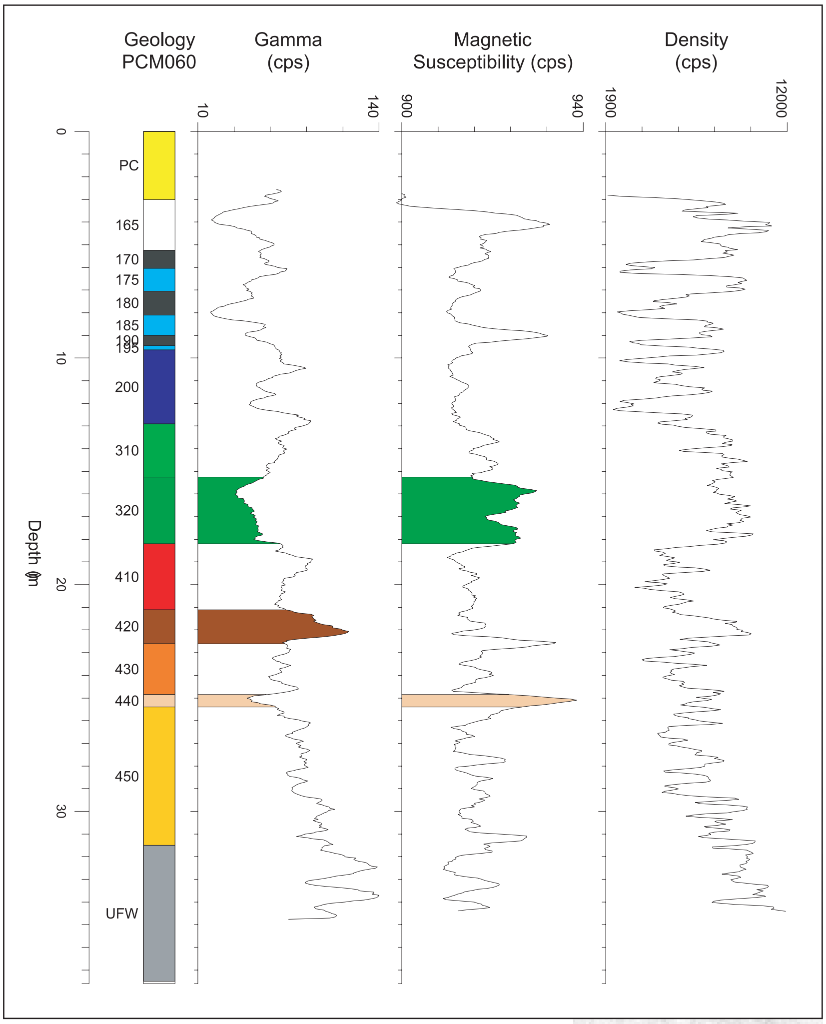


Fig. 4. Geophysical log down H1 mapped against geology from PCM060. Several marker horizons have been highlighted including units 165, 320, 420 and 440. Note that density is raw and therefore inverted (smaller number equates to higher density).

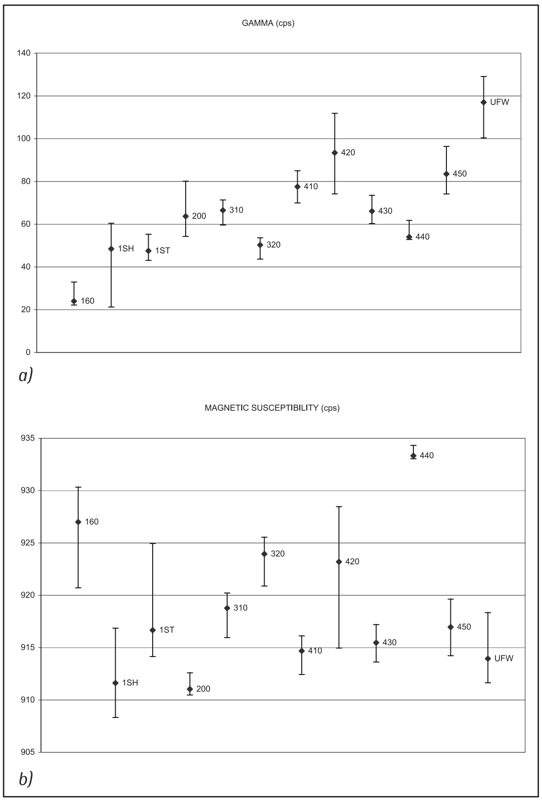
The LogTrans software developed from AMIRA P436 (Fullagar et al., 1999) was tested to determine if the hand interpretations could be duplicated using multi-variate analysis. Previous work on the data at Century indicated that this was possible, however that analysis utilised three petrophysical logs. The initial attempts with LogTrans were restricted to natural gamma and magnetic susceptibility, despite the fact that density (gamma-gamma) data was collected.

The reason for leaving out the density data is that the gamma-gamma tool contains a radioactive source.

The use of a radioactive source creates a number of additional problems for geophysical logging. It was the intention at Century Mine for all geologists and field technicians to be able to operate the system if required. If a radioactive source tool were used, the number of operators available for logging would be greatly reduced. There are also significant safety considerations when using a radioactive source tool. These include proper storage of the source and recovery of the source if it is lost down a hole. Although in theory this is simpler for an open cut

Continued On Page 18

Fig. 5. Statistical variation of the stratigraphic units, showing range and median value a) Natural ?-ray response plotted for each unit, b) Magnetic susceptibility plotted for each unit



Continued From Page 17

mine compared to an underground mine, the loss of a tool can cause lost production time and significantly alter the mining schedule. These issues can be simply avoided if no such tool is used.

The initial training of the LogTrans software was based on only two holes, H1 and H8, drilled next to diamond holes PCM60 and PCM63 respectively (Figure 3). The statistical analysis indicated a modest variation in both gamma and magnetic susceptibility between units (Figure 5).

Although the parameter ranges for the stratigraphic units overlap, there is a distinct separation between 'ore' and 'waste' units. When an overlap exists in specific units of ore and waste in one parameter, a significant gap exists to allow discrimination in the other parameter.

Combining parameters can also be undertaken to assist in classifying units, as shown in Fallon and Fullagar (1997). In the initial trials at Century, a variation of magnetic susceptibility over gamma ('MOG') was used to assist in confining the stratigraphic interpretation, by providing a third variable.

Auto-interpretation of the remaining six percussion holes was considered to be encouraging.

Stratigraphic Ordering

As the Century mineralised sequence is relatively flat lying, a strict stratigraphic ordering applies. LogTrans contains a utility called NEWSTRAT that develops an acceptable stratigraphical interpretation based on the initial auto-interpretation and a minimum significant thickness assigned by the operator. Layer thickness is used by NEWSTRAT as one indicator of interpretational reliability.

Gaps in the stratigraphy are allowed and do occur at Century.

Initially the NEWSTRAT function was not working well for the Century ore sequence and several improvements were required. The main problem occurred when thin units of 'real' stratigraphy were lost as the interpretation thickened the units above and below (Figure 6).

An improvement to the stratigraphic ordering algorithm was the inclusion of a maximum thickness for each unit. When the maximum thickness is exceeded, the NEWSTRAT software alerts the user. Although the software cannot change its 'best guess', it displays the 'over thick' unit in two segments. The operator then needs to reinterpret the 'over thick' area. This was often found to be occurring in the lower zone mineralisation, where units 410, 430 and 450 have similar petrophysical values.

The development of a preferential marker horizon was also included within NEWSTRAT. This is especially useful for thinner units that are interpreted correctly but not used in the initial NEWSTRAT interpretation due to their small thickness. The operator nominates units within the stratigraphy that are to be retained in the initial phase of stratigraphic ordering, even if they are thin. A good example of how this works was found in the lower zone mineralisation, where thin units 420 and 440 were often ignored in the initial stratigraphic ordering until defined as markers. If they are found to be in the appropriate position, they are often retained in the final NEWSTRAT interpretation (Figure 6).

The introduction of the maximum thickness for individual units and preferential marker definition improved the reliability of NEWSTRAT interpretations.

Feasability Study

A feasibility study was undertaken in ore production blast patterns from January to June 2000. A winch, data logging system and two probes were rented during this period. The natural ?-ray and magnetic susceptibility parameters were used for the feasibility study. A combination of these two parameters, MOG, was used in the initial trials, but later dropped.

As the magnetic susceptibility and ?-ray tools were separate, each hole logged was entered twice. To maximise the data coverage every second hole was logged (as a minimum) for the blast hole logging feasibility study. Time restrictions on the availability of the holes, prior to being primed for blasting, also impacted on the decision to log every second hole.

Data were collected and an initial interpretation was undertaken using the LogTrans software, with all units available for selection. Due to both dipping geology and structural offsets, a large range of stratigraphic units can be expected in a single blast pattern. Holes were then grouped according to their likely geological position and then re-interpreted using only the limited stratigraphic units expected. This resulted in more reliable matches and

enabled better use of the NEWSTRAT stratigraphic utility. All interpretations were then checked and altered if necessary (usually minor variations on the contact positions) prior to inclusion into the mine database.
After the first few blast patterns were interpreted, and the models had been verified from mining and face mapping, the statistical database was rebuilt using the interpreted data. Only minor changes in the original statistics were apparent, indicating that although the training data set had been under sampled, there is limited petrophysical variation across the deposit (Stage 1 pit area). The new statistical database did however provide a higher reliability in the first pass interpretations.

Part of the feasibility study included the use of the logging system in an in-fill resource-drilling program. A proposed in-fill diamond-drilling program was converted to percussion drilling and geophysical logging.

The initial program of in-fill drilling was based on a 25 m by 25 m grid. The results correlated well with diamond holes proximal to the areas drilled as well as face mapping in benches. The data have been integrated with the face mapping to assist in the development of both the stratigraphic and structural model of the mine.

Short Term Model

The feasibility program was considered to be successful. The system used during the feasibility program was however labour intensive, with best performances achieved when two people were operating the system. A single operator system was required to allow full implementation of the geophysical logging of blast holes for the development of a short-term mine model. Scintrex-Auslog had previously built such systems. A single combined magnetic susceptibility and natural gamma tool would also be required to allow full logging of all holes in the blast patterns. The two sensors on the tool would also need to be placed as close as possible to allow as much coverage as possible from the short blast holes.

A dedicated logging vehicle with the single tool was delivered to Century Mine on 30 November 2000 (Figure 7). The magnetic susceptibility and natural gamma sensors are located 40 cm apart.

When the system arrived on site, the first blast patterns logged were interpreted manually. This was due to a change in the blast hole diameter drilled compared to the feasibility study. These interpretations were then used as a training data set for the development of the statistical database.

To monitor the reliability of the probe a dedicated calibration hole was drilled through the entire ore sequence within the area of the Stage 7 pit. This hole is logged every second week and allows the operators to detect probe problems, monitor the performance of the sensors (aging) and ensures that data collected down each blast hole will compare to its neighbour.

Currently every hole drilled in every blast pattern within ore is logged. The current blast hole spacing is 5 m by 6 m. Each hole is drilled to a nominal depth of 10 m. The data are compared to face mapping and continue to show good correlation. Ore mining at Century is currently undertaken on 8 m benches, with an additional 2 m drilled due to the coning effect of blasting. The combination of the extra 2m logged and face mapping provides additional information to the operator to restrict the available stratigraphy for the auto interpretation when blast patterns commence on the benches below those previously logged.

Accuracy of the models has increased significantly since the initial trial program. With the addition of extra software to speed up data conversion and organization for LogTrans, interpretation time has been reduced from a day

Continued On Page 20

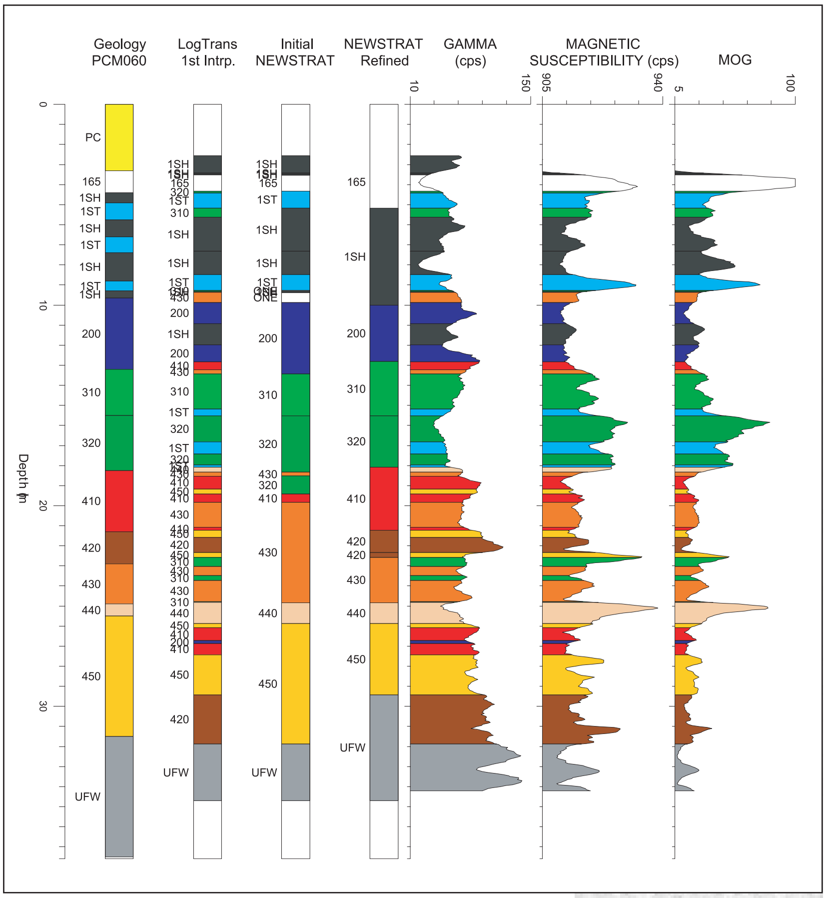


Fig. 6. (Top) Initial LogTrans auto interpretation of geophysical data and after NEWSTRAT stratigraphic correction

Fig. 7. (Above) Century Mine logging vehicle at the calibration hole. Geology in background contains Hangingwall siltstones on the left, split by Pandora's fault with the following sequence on the right; Limestone (brown), Hangingwall sandstones (light grey) and Hangingwall siltstones (dark grey).

Continued From Page 19

to approximately a few hours. The future plan is to test the reliability of the short-term model for the application of GPS controlled diggers.

Conclusions

The implementation of petrophysical blast hole logging with natural ?-ray and magnetic susceptibility tools has resulted in the rapid development of a short-term mine model that exceeds the resource model in accuracy and useability. The use of an auto interpretation scheme makes the logging viable, as manual interpretation (including digitising) could not be undertaken in time to impact on the mining process.

Definition of the exact location of the different units can influence the mining schedule as well as increase ore recovery and decrease dilution. More accurate calculation of bulk tonnes of ore and waste per bench is another benefit of the model. The logging also aids in interpreting the stratigraphic sequence below the planned benches, which can impact on future bench design as the pit is developed.

Future research to be undertaken at Century will be to investigate the applicability of the geophysical derived model for GPS-controlled mining.

Acknowledgements

The support from the staff at Century Mine was invaluable to achieve the work undertaken to date. Support from Neil Hughes was greatly appreciated during the project. We would also like to acknowledge the work of Andrew Mutton. Acknowledgement also goes to Scintrex-Auslog. This paper is published with the kind permission of Pasminco Australia Limited.

References

Broadbent, G. C., Myers, R. E., and Wright, J. V., 1998, Geology and origin of shale-hosted Zn-Pb-Ag mineralisation at the Century Deposit, Northwest Queensland, Australia: Economic Geology, 93, 1264-1294.

Broadbent, G. C., and Waltho, A. E., 1998, Century zinc-lead-silver deposit: Berkman, D. A., and Mackenzie, D. H., Eds., Geology of Australian and Papua New Guinean Mineral Deposits, 729-736.

Charbucinski, J., Borsaru, M., and Gladwin, M., 1997, Ultra-low radiation intensity spectrometric probe for ore body delineation and grade control of Pb-Zn ore: Gubins, A. G., Ed., Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration, 631-638.

Fallon, G. N., and Fullagar, P. K., 1997, Optimising the drilling budget with geophysical logging, Proceedings of 3rd International Mine Geology Conference, Launceston, Austral. Inst. Min. Metallurg., Publ. 6/97, 167-174.

Fullagar, P. K., Fallon, G. N., Hatherly, P. J., and Emerson, D. W., 1996, Implementation of geophysics at metalliferous mines - Final report AMIRA Project P436: Cooperative Research Centre for Mining Technology and Equipment Report MM1-96/11.

Fullagar, P. K., Zhou, B., and Fallon, G. N., 1999, Automated intepretation of geophysical borehole logs for orebody delineation and grade estimation: Mineral Resources Engineering, 8, 269-284.

Fullagar, P. K., and Fallon, G. N., 2001. Geophysical Grade Estimation in Mines: Preview, 90, 30-32.

Mutton, A. J., 1997, The application of geophysics during evaluation of the Century zinc deposit: Gubins, A. G., Ed., Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration, 599-614.

Geophysical Data Sets Over Continental Australia

Murray Richardson
Murray.Richardson@agso.gov.au
Phillip Wynne
Phill.Wynne@agso.gov.au

Australian Geological Survey Organisation, Canberra ACT.

Introduction

Magnetic, Radiometric and Gravity data sets provide vital information for mineral and petroleum explorers as well as researchers studying the geology of the Australian continent. In recent years the Commonwealth, and State and Territory governments have invested millions of dollars into acquiring new geophysical data sets and making these available to encourage exploration activities.

This contribution shows the current situation over the Australian continent, as provided by the AGSO databases in May 2001.

Airborne data sets

The figures above show the line spacing of data coverage over Australia for magnetic and gamma-ray spectrometric data as of May 2001.

Magnetic Data Coverage

The line spacing of aeromagnetic data over onshore Australia can be summarised in the following table:

Line Spacing (m)	Percentage Coverage (%)
<= 500	42.6
1 500 - 1 600	36.9
3 000 - 3 200	12.8
> 3 200	7.5

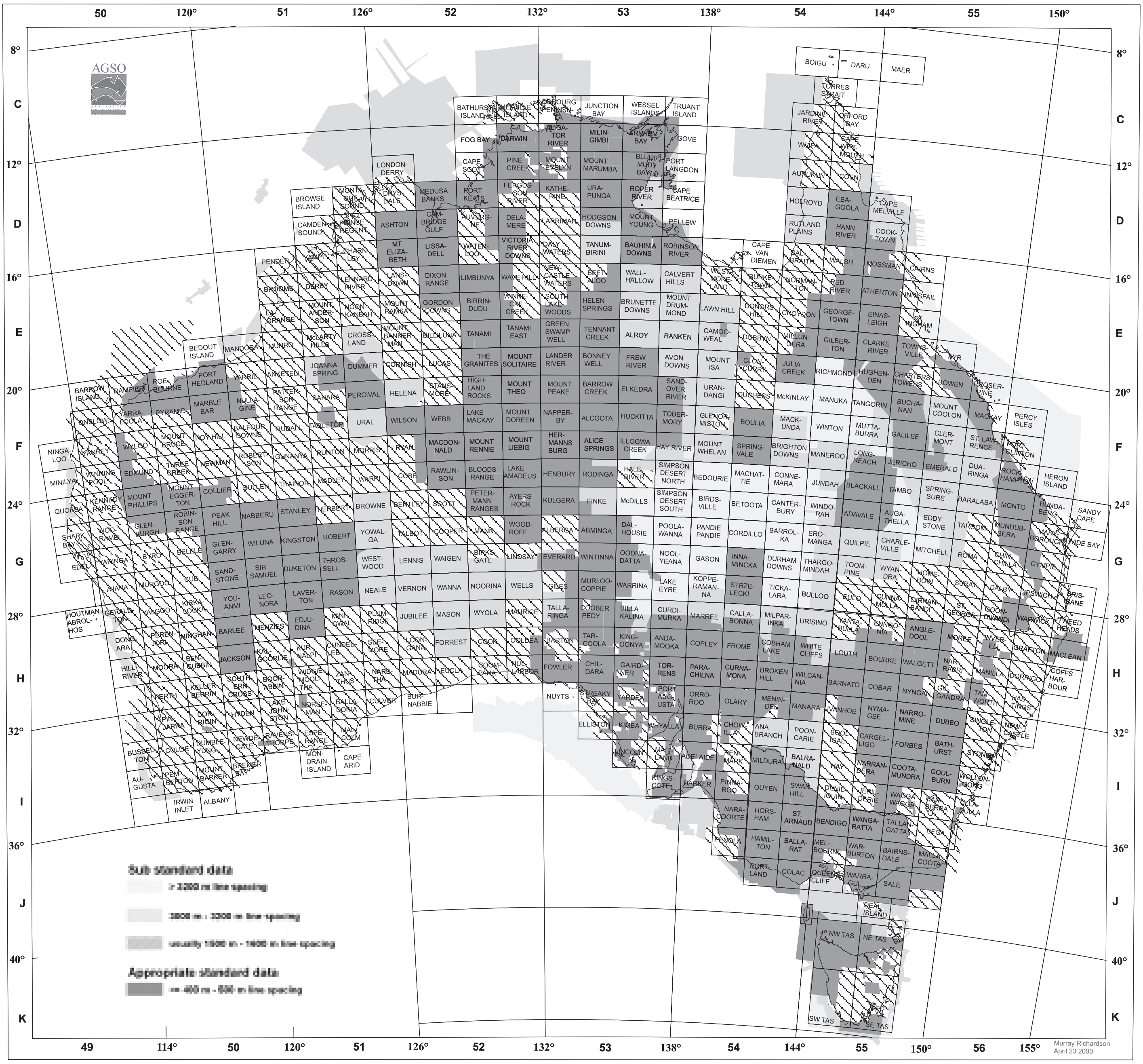


Fig. 1. Airborne Magnetic Coverage of Australia - Line Spacing. Map Scale 1:25 000 000.

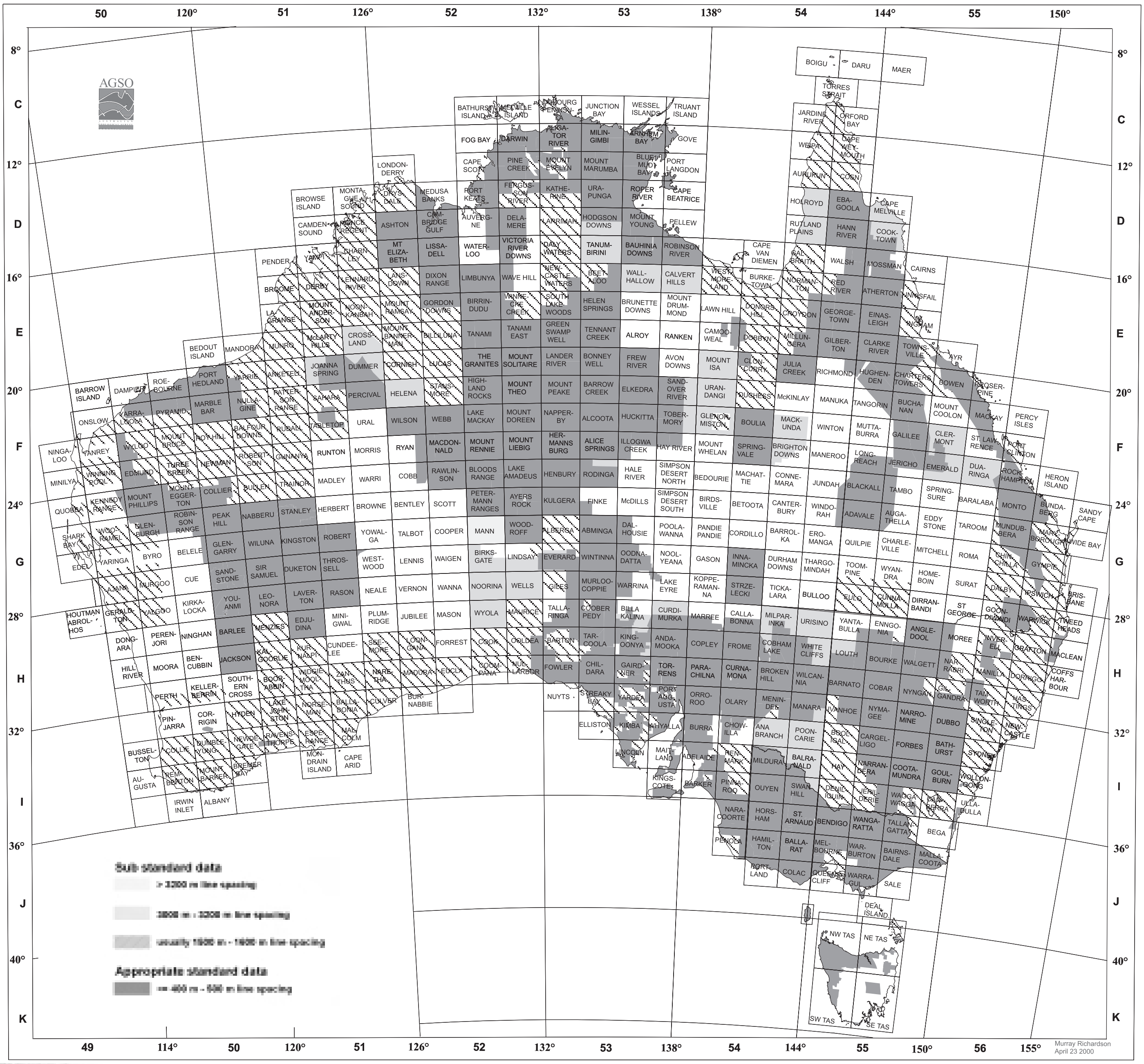


Fig. 2. Airborne Gamma-Ray Coverage of Australia - Line Spacing.
Map Scale 1:25 000 000

Gamma-Ray Spectrometric Data Coverage

The line spacing of gamma-ray data over onshore Australia can be summarised in the following table:

Line Spacing (m)	Percentage Coverage (%)
<= 500	42.6
1 500 - 1 600	31.6
3 000 - 3 200	6.4
No coverage	19.3

Since 1997 the coverage of digital airborne geophysical data acquired along flight lines spaced at 500 m or less has gone from less than 25% to approximately 42% of onshore Australia, mainly due to initiatives by State and NT governments.

At the end of 2000, the National Airborne Geophysical Database contained approximately 17 million km of airborne geophysical data from over 850 surveys flown by the States/Northern Territory and Commonwealth Governments. Nearly 11 million km have been acquired at a line spacing of 500 m or less; approximately 4.5 million km at a line spacing of 1 500-1 600 m; and the remaining 1.5 million km flown at spacings greater than 1 600 m.

Note: The numbers in the above tables are only approximate as not all surveys correspond to standard map sheet boundaries.

Figure 3 shows the rate of acquisition over the last fifty years. Notice the huge rate of investment in the early 1990s.

Product Availability

Most data from the National Airborne Geophysical Database are available at low cost from AGSO. Data owned solely by the State governments are available from the relevant State department.

Digital Data

The point-located digital magnetic and gamma-ray data for surveys with flight-line spacing of 1 500 m or more are available in units of 1:250 000 Sheet areas. For surveys with flight lines of 500 m or less, they are available in units of 7.5´ x 7.5´ for 1:25 000 Sheet areas.

The gridded magnetic data for surveys with flight-line spacing of 1 500 m or more are include in compilations of 1:1 000 000 Sheet areas, released as part of the Magnetic Map of Australia grid. For surveys of 500 m or less, magnetic and gamma-ray data are available in units of 1:100 000 Sheet areas.

Digital elevation data are available in units of 1:250 000 Sheet areas.

Further information regarding the National Airborne Geophysical Database can be obtained from Murray Richardson Geophysical Acquisition & Databases, Tel: (02) 6249 9229.

The map above indicates the gross spacing between stations and their relative reliability, but does not show individual surveys. The areas are broken into roughly 1:100 000 mapsheet size and both density and reliability are based on the predominant attribute.

For further information about the database contact: Mr Phillip Wynne, Tel: (02) 6249 9463. The map is available at a scale of 1:10 000 000 for $10.80.

A new gravity map of Western Australia is featured on the front cover of this issue. The second edition of the Gravity Map of Australia was released in late 1997.

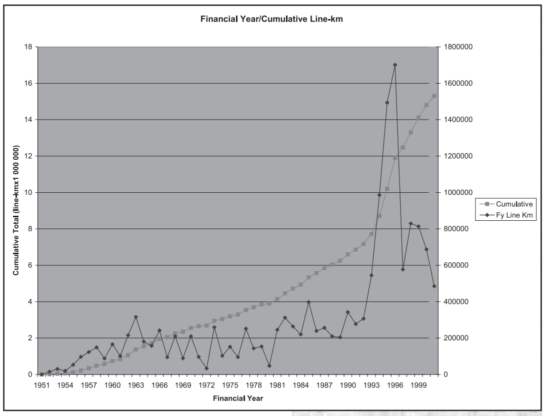


Fig. 3. Accumulation of data from State/Northern Territory and Commonwealth Government airborne geophysical surveys into the National Airborne Geophysical Database from 1951 to the present.

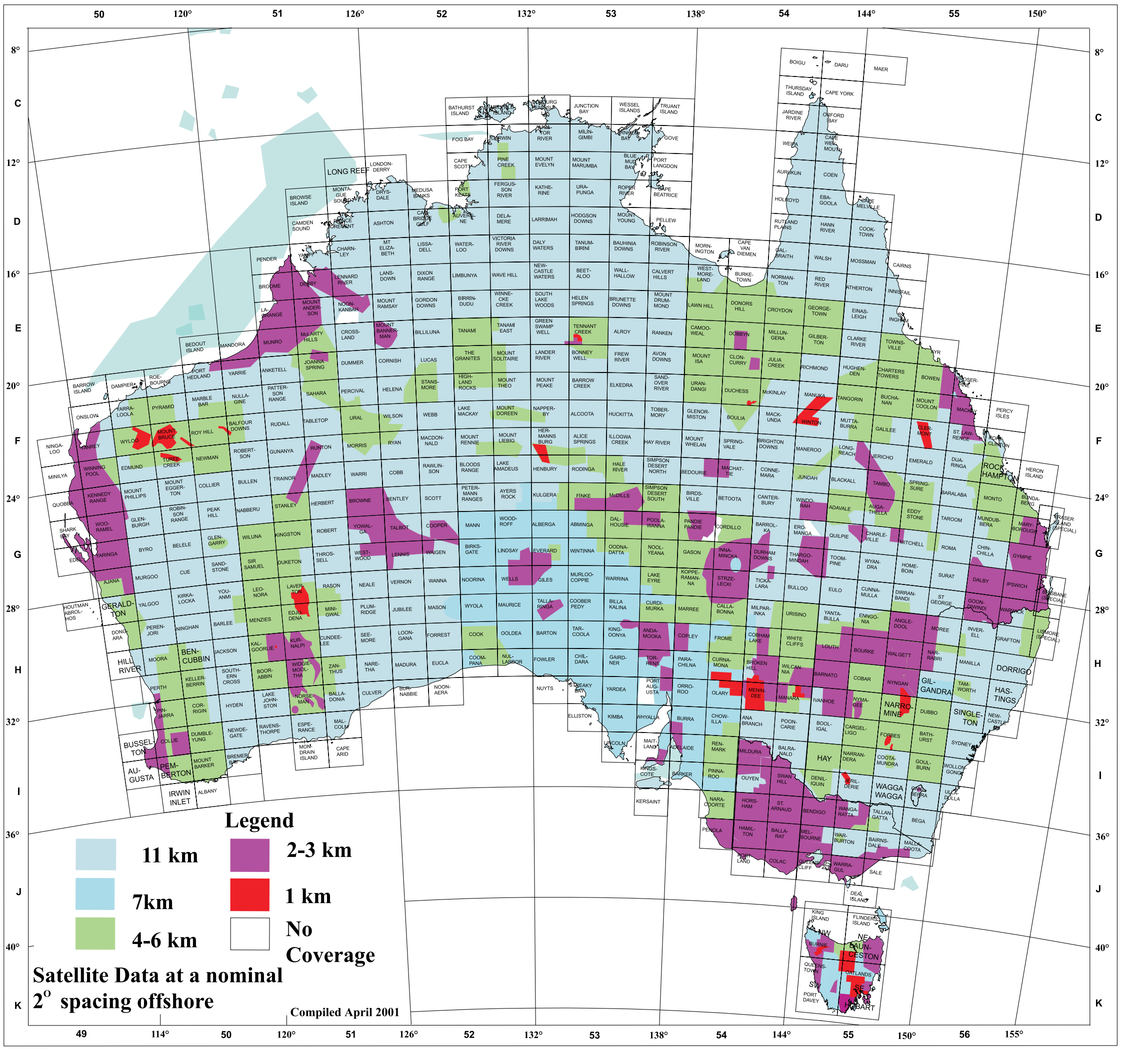


Fig. 4. The gravity coverage of onshore Australia

T. J. Dean
Doctoral Fellow
Physics Department
University College
Australian Defence
Force Academy
Canberra ACT 2600

Ph: (02) 6268 8795
Fax: (02) 6268 8786
tjd@ph.adfa.edu.au

Geophysical Response of Porphyry System Mineralisation at the Dam Prospect, Temora, New South Wales

Abstract

Recent advances in airborne Time Domain Electromagnetics (TDEM) have led to suggestions that ground based methods may be obsolete. The results of a study conducted at the Dam Prospect (located near Temora in New South Wales), using both ground and airborne EM methods, showed that although airborne TDEM can be successful in locating deposits, ground based methods are still needed to fully establish their extent and position.

Introduction

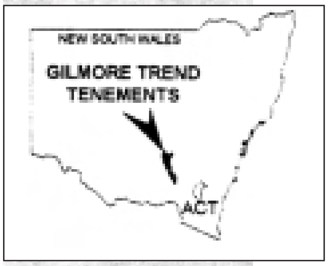


Fig. 1. Location of the Dam Prospect within the Gilmore Trend Tenements. (Adapted from Shywolup, 1997).

The advent of recent advances in airborne TDEM has lead to speculation that ground based methods may soon be obsolete. To test this theory the Dam Prospect was chosen as a test area to compare airborne and ground TDEM results. The Prospect is located within the 'Gilmore Trend Tenements' near Temora in New South Wales (Figure 1). The area has been heavily studied over the last 20 years leading to an in-depth understanding of its Geology and Geophysical signatures. During 1999, an airborne TDEM survey was flown over the area by World Geoscience using the new TEMPEST system. This work was followed up with a ground survey by members of CRC-AMET and students from Curtin University, using magnetic, downhole and frequency and time-domain electromagnetic methods. These results were then compared with the results of the TEMPEST survey enabling the importance of ground TDEM surveys in this area to be evaluated.

Geology

The structural geology of the Dam Prospect (Figure 2) is dominated by the 'Footwall Fault', a post-mineralisation fault that has been interpreted by Shywolup (1997) as a high angle reverse fault (east side up) with a minimum (but likely larger) displacement of 200 m and a dip of 20° to the east. This fault separates the porphyritic to granular felsic rocks to the east from the younger unmineralised sedimentary rocks to the west. The porphyritic to granular felsic igneous rocks (thought to be volcanics or sub-volcanic intrusives) predominate to the east of the fault and are host to the mineralisation (Shywolup 1997). The mineralisation itself is thought to have been a result of advanced argillic alteration, which overprinted the original porphyry zone alteration (Shywolup, 1997).

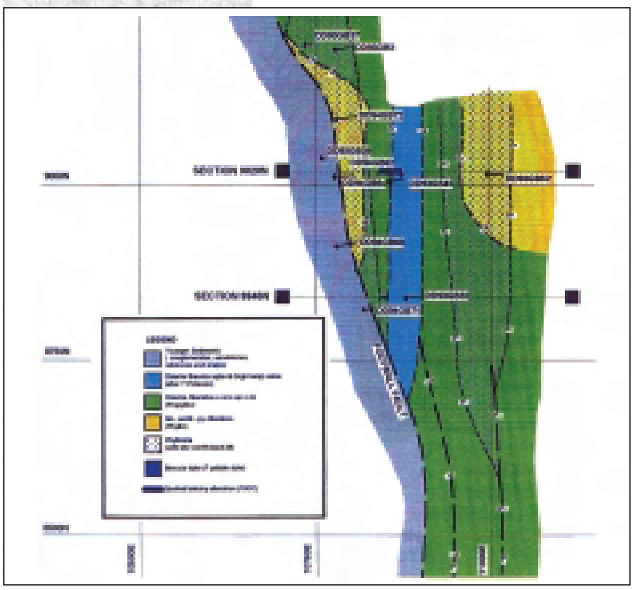


Fig. 2. Local Geology of the Dam Prospect. (Point 10705E, 9770N corresponds to 542504E, 6202112N (WGS84) with an 8° rotation east of north). (Adapted from Shywolup, 1997).

Previous Geophysics

As shown in Table 1 extensive geophysical exploration has been conducted for more than 20 years at the Dam Prospect. Techniques including magnetic and radiometric surveys, induced polarisation surveys, various downhole logging techniques, electromagnetic surveys and a refraction survey have been trialed with mixed success.

Year	Description
1977-79	Airborne Magnetic and Radiometric
1979	Two E.I.P dipole-dipole traverses
1979	Magnetic Induced Polarisation (MIP)
1984	Low-level aeromagnetic and radiometric
1984	Dipole-dipole IP
1984	CSAMT and SIROTEM
1984	Downhole radiometrics
1985	Multi-spectral scan
1986	Downhole IP
1986	Re-interpretation of aeromagnetic data
1987	INPUT (induced pulse transient airborne EM)
1987	Multi-spectral scan
1987	Downhole IP
1988	Seismic refraction
1989	UTEM
1991	Dipole-Dipole Induced Polarisation
1992	Aeromagnetic and radiometric
1993	Dipole-Dipole IP
1995	Gravity
1996-97	Ground Magnetometer
1999	TEMPEST

Table 1. History of geophysical exploration conducted on the Dam Prospect (Dean, 1999).

Airborne magnetic surveys conducted over the prospect failed to identify it as a region of interest due to its low magnetic intensity (Fitton, 1994; Jones, 1986). The 1992 ground survey identified two linear features that were interpreted as basic dykes (Shywolup, 1997).

EIP and MIP surveys located suspected palaeo-channels filled with up to 45 m of very conductive, flat-lying, lacustrine clay (Baglin, 1979). Further dipole-dipole EIP lines delimited a resistive polarisable zone, which coincided with disseminated to massive sulphides present in drill holes (Fitton, 1994). The 1991 gradient-array I.P. survey identified several zones of interest at depths ranging from 25 to over 400 m (Howland-Rose, 1991).

The INPUT survey over the Prospect located a region of high conductivity thought to be due to propylitically altered intermediate volcanics. The UTEM survey was considerably more successful with results agreeing with the known geology but not with assumed geology and previous IP surveys (Fitton, 1994).

The TEMPEST system (developed by the Australian Mineral Exploration Technologies CRC) is the latest airborne electromagnetic survey system to be employed by World Geoscience Corporation (now Fugro). During 1999 a survey was flown over an extensive area surrounding the Dam Prospect for the Bureau of Rural Sciences, Department of Agriculture, Forestry and Fisheries Australia; Australian Geological Survey Organisation, Department of Industry, Science and Resources; and the CRC for Landscape Evolution and Mineral Exploration. The results of this survey are discussed below.

The NSW Department of Minerals and Energy conducted an experimental refraction Survey line across the Dam Prospect in 1988. The area with the greatest depth to the base of the overburden was found coincide with the location of the footwall fault and its associated mineralisation (Palmer, 1988).

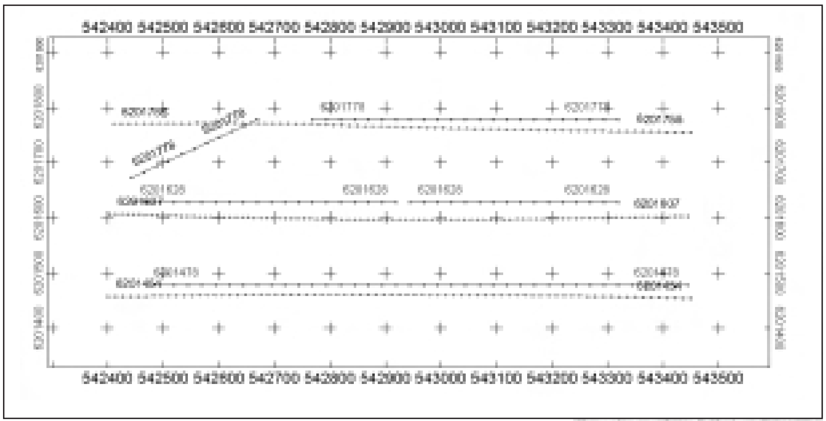


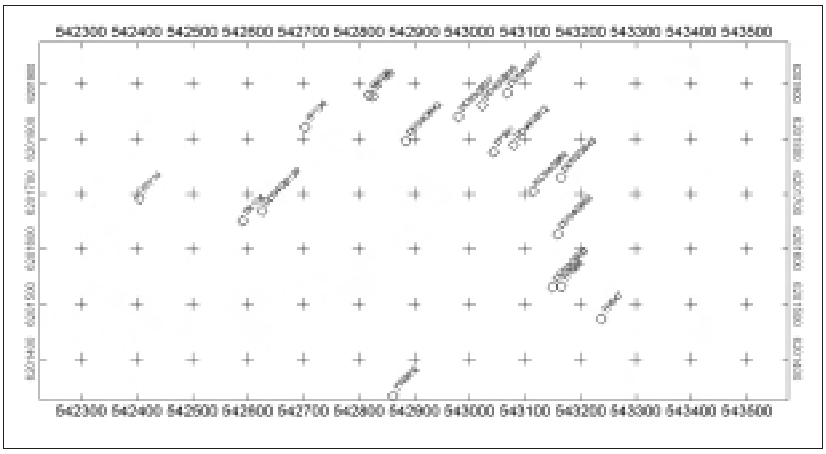
Fig. 3. Location of the TEMPEST survey lines (dotted) and the ground geophysical lines (continuous lines). Line 1 runs approximately south-west/north-east while the horizontal lines are numbered from the top down. (All coordinates in WGS84).

Recent Geophysical Surveys

More work was conducted in 1999 by students from Curtin University and members of CRC-AMET to improve understanding of the geophysical signatures of the Dam Prospect and to provide further results to compare with the recently completed TEMPEST survey. This program included magnetic, EM31 and EM47 lines conducted roughly coincident with those flown by TEMPEST and downhole EM39, g-ray and magnetic logging.

Ground Based Geophysics

The survey lines are shown in Figure 3. Magnetic data were acquired across all lines including one another 150 m to the south (not shown on the diagram). EM31 data were



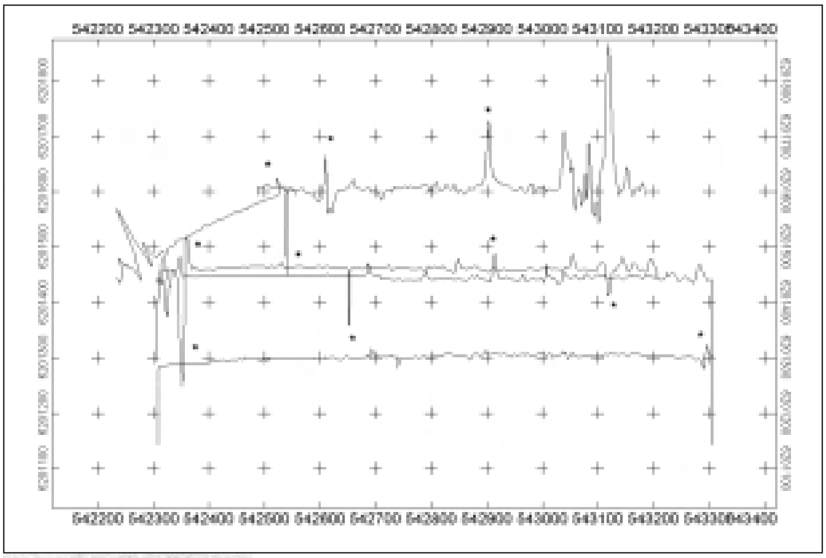


Fig. 4. (Top) Location of the drillholes for which downhole data were acquired. (All coordinates in WGS84).

Fig. 5. (Above) Unfiltered stacked magnetic profiles. Base: 58000nT, scale 20nT/1mm. (denotes an anomaly due to a fence).*

acquired across all lines, including one 150 m to the south except 6201628. EM47 data were acquired along all lines. The station spacing for EM47 and EM31 was 25 m (coincident stations) while the magnetic survey had a station spacing of 2 m. Magnetic data were acquired using a Geometrics 856 proton precession magnetometer with a sensitivity of ~1 nT.

The Geonics EM31 is a frequency domain EM instrument operating at 9.8 kHz with an effective depth of penetration of 6 m (Geonics, 1995). Data were collected with the instrument in the vertical dipole configuration both parallel and perpendicular to the survey lines with the instrument placed on the ground.

The Geonics EM47 is a TDEM instrument that uses a coincident transmitting and receiving loop (Geonics, 1992). Data were collected with a 50 m loop side giving a loop area of 2500 m2. High (25 Hz), very high (62.5 Hz) and ultra-high (237.5 Hz) frequencies were used to give a complete depth sounding.

Downhole Geophysics

Data were acquired using the EM39 induction meter data from 19 drill holes as shown in Figure 4. Magnetic and g-ray data were also acquired for 6 holes. Data were acquired both up and down the hole with a sample rate of 0.1 m.

Petrophysical Property Measurements

Core samples were collected at various depths from two holes known to intersect the mineralisation. The resistivity, density and magnetic susceptibility of these samples were measured using the techniques detailed in Serway (1990) and Emerson (1969).

Results

Magnetics

No major magnetic anomalies were identified on the prospect (Figure 5). The most prominent minor anomaly is at the eastern end of line 2 while other anomalies are present at the eastern ends of lines 1 and 4.

EM31

Gridded EM31 results are shown as Figure 6. The major feature evident on these plots is the gradual decrease in conductivity from west to east with a minimum (20 mS/m) along a roughly north/south line centred on 542500E. The conductivity then sharply increases and stays at high values (~150 mS/m) until gradually decreasing at the far eastern extent of the survey area.

EM47

The EM47 data were generally noise-free at the ultra-high frequency but noise increases with the lower frequencies. Data were analysed using TEMIX XL (Interpex, 1996) to form a layered earth model based on 3 layers. The results of this analysis are presented in Figure 7.

Petrophysical Properties

Specific gravity values were found to range from 2.15 to 2.74 and showed a strong correlation to the source depth (r = -0.577, p = 0.1). Magnetic susceptibility measurements were less than 120 SI-5 with values generally in the range of 10-30 SI-5.
The condition of the samples made resistivity measurements too unreliable and hence it was not possible to consider them in this study.

Downhole Geophysics

The ?-ray logs all showed values of less than 250 cps with a typical range of 50-120 cps (Values varying by less than 100 cps over 50-80 m). All the magnetic logs show typical values of less than 5 SI-4.

Typical conductivity values obtained from the induction logs range from 20-1000 mS/m for the overburden and 10-200 mS/m for other rock units.

Discussion

The geophysical signatures of the mineralisation present at the Dam Prospect are characterised by:
- A lack of magnetic expression; based on ground, airborne, downhole and petrophysical measurements,
- No useful density contrasts; from petrophysical measurements, and

- A limit in the use of downhole induction (EM39) and g-ray logs to map the extent of the overburden.

The limit on the use of these methods makes the relative success of EM even more important in delineating the extent of the mineralised zone and the position of the fault.

Comparisons of the data sets (Figure 6) indicate that the first channels of TEMPEST data do not show the Fault's surface conductivity expression as seen on the EM31 and EM47 results. This expression is also evident from the top 6 m of the conductivity logs with a high correlation between increased conductivity and proximity to the Fault. There is also good agreement between EM31 and EM47 results but not TEMPEST results.

TEMPEST layered earth models (Figure 7), although processed differently from the EM47 results, show little correlation with the EM47 model (Figure 7) and the EM31 results (Figure 6). The position of the footwall fault (east side up) can clearly be seen as the area with the lowest depth on the EM47 results. The increase in depth to the west also corresponds well with previous findings. Comparisons between layered earth results and induction logs indicate that TEMPEST failed to show conductivity contrasts of up to 700 mS/m at depths of 50-70 m.

When equivalent time windows for both TDEM systems were examined the EM47 results were found to have greater consistency and a better ability to map the known Geology. The results obtained from EM47 also corresponded more accurately with previous EM surveys. The effective recording times for both TDEM systems were found to be equivalent, implying that the effective depth of penetration was also the same.

The cause of the differences between TEMPEST and the other systems cannot really be identified from this study. There does however appear to be some difficulty in identifying the exact ground position of anomalies identified from the TEMPEST data.

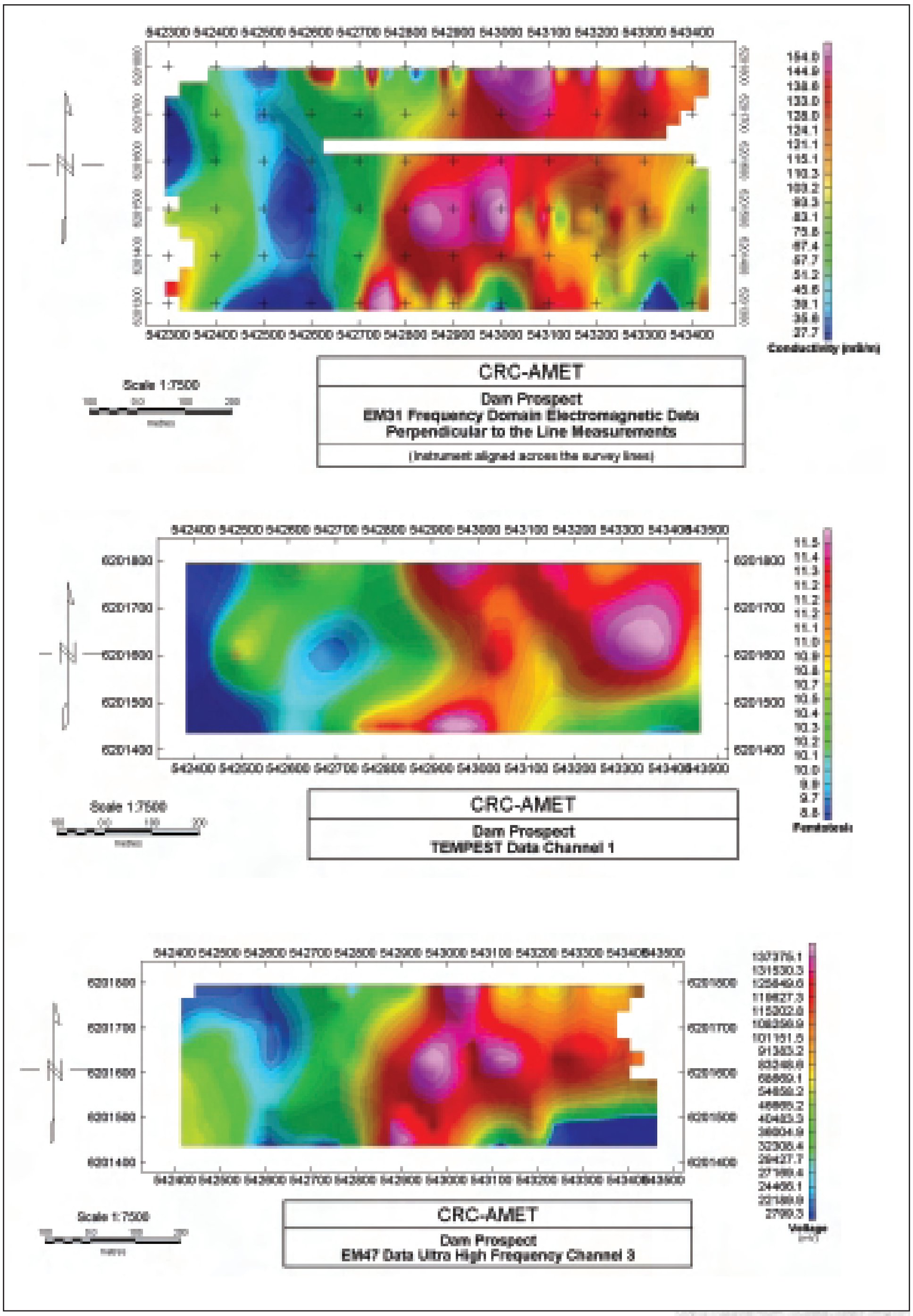


Fig. 6. (Right) Plots of the EM31 results, TEMPEST time channel 1 and EM47 channel 3 results respectively. The footwall fault runs approximately north/south along 543000/543100E, east-side up with a dip of 20° to the east.

Conclusion

The TEMPEST survey at the Dam Prospect did locate an area of high conductivity associated with the fault and mineralisation, however further ground work was required to locate it accurately.

Although it has been claimed that the recent development of new airborne electromagnetic technologies may render ground methods obsolete, evidence suggests that their use may only be applicable to large deposits with high conductivity contrasts.

Acknowledgements

Vernon Wilson (Supervisor) and Paul Wilkes (both from the Department of Exploration Geophysics, Curtin University); CRC-AMET; Ben Bartlett and Tenille Scott for assistance with fieldwork.

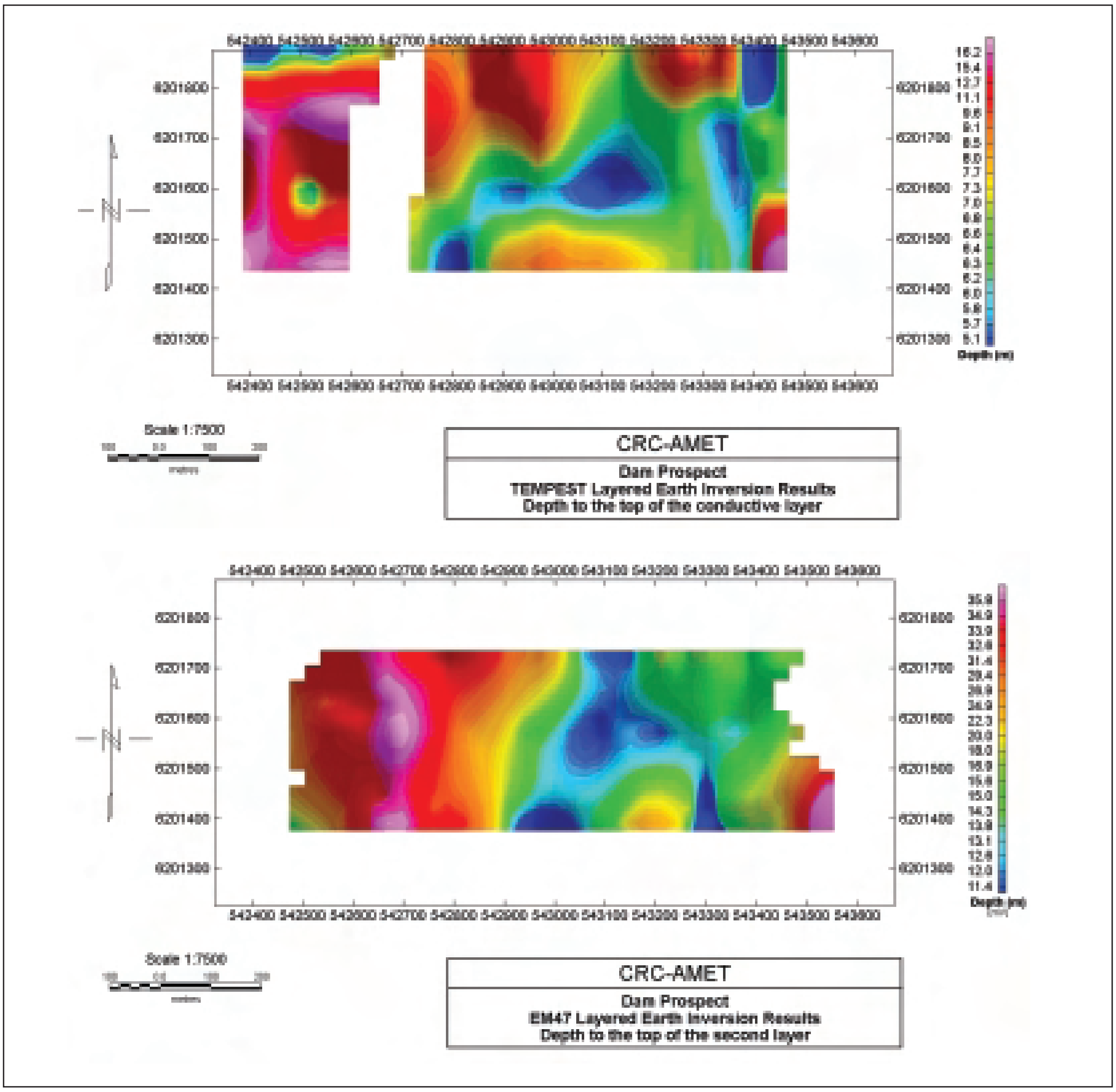


Fig. 7. TEMPEST and EM47 Layered Earth Results. Depth to the top of the conductive layer. The footwall fault runs approximately north/south along 543000/543100E, east-side up with a dip of 20° to the east.

References

Allibone, A., 1989, Outlying alteration systems in the vicinity of the Temora Au-Ag mine: Petrography and implications for exploration: unpub.

Baglin, G. R., 1979, Exploration Licence 971 Temora, New South Wales Final Report summary of exploration activity period: 18th April, 1977 to 16th July, 1979: (unpub.) by Samedan Oil Corporation.

Dean, T.J., 1999, Geophysical Signatures of the Dam Prospect, Temora, New South Wales: Hons thesis, Curtin Univ. of Technology.

Emerson, D. W., 1969, Laboratory electrical resistivity measurements of rocks: Proc. Aust. Inst. Min. Met., 230, 51-62.

Fitton, S., 1994, Temora Geophysics: A literature review: Report 1994/21 (unpub.) by Gold Mines of Australia (NSW) Pty. Ltd.

Geonics, 1992, Protem 47 Operating Manual: Geonics Ltd.

Geonics, 1995, EM31-Mk2 Operating Manual: Geonics Ltd.

Howland-Rose, A. W., 1991, A report on gradient array electrical induced polarization survey over the Temora Gold Mine area Gidginbung, New South Wales: Report 189 (unpub.) by Paragon Gold Pty. Ltd.

Interpex, 1996, TEMIX XL V4 users manual: Interpex Limited.

Jones, R. K., 1986, A review of geophysical data in E.L.s 2196 and 2059 near Temora N.S.W.: R.K. Jones & assoc. P/L (inpub.).

Palmer, D., 1988, An Experimental Seismic Refraction Survey at the Temora Gold Mine: Report GS 1988/300 (unpub.) for Paragon Gold Pty Ltd.

Serway, R. A., 1990, Physics for Scientists and Engineeers 3rd ed.: Saunders College Publishing.

Shywolup, W., 1997, Cyprus Gold Australia Corporation, Annual Exploration Report EL 2059 - Reefton & ML 1167: Report 925 (unpub.) by Cyprus Gold Australia Corporation.

Further Physical Property Data from the Archaean Regolith, Western Australia

Don W Emerson
Systems Exploration (NSW) Pty Ltd
systems@lisp.com.au

James Macnae
CD 3D Pty Ltd
james.macnae@dem.csiro.au

Abstract

At Lawlers, generally low resistivity heterogeneous regolith materials, developed by weathering over the Archaean Yilgarn Craton (WA), comprise highly porous, textured, mineral aggregates of quartz, clays, iron oxides and various silicates as residuals or alteration products, in a brackish groundwater environment. Saprolite occurs at depth; this salient unit is not a clay, but an extremely weathered clayey rock type with a retained fabric, which behaves physically as a clayey sand. The dominant mafic and ultramafic saprolite clay is smectite, while that for metasedimentary and felsic saprolite is kaolinite. The saprolite, with its high porosity and concomitant low resistivity, density and velocity, is a distinct geophysical unit as it presents high physical property contrasts to the underlying bedrock. However, the properties of saprolite cannot by themselves be interpreted to identify parent lithologies because, owing to porewater salinity and clay mineralogy variation, overlaps in the values of physical properties do occur for metasedimentary, felsic, mafic and ultramafic saprolites and also with overlying palaeochannel clays. Above the saprolite, ferruginous (goethitic and hematitic) regolith materials, including laterites, have lower porosities and higher densities, resistivities and velocities than saprolite. Magnetisations, carried by both induced (through and susceptibility) and remanent components, vary considerably but the upper horizons (colluvium and lateritic residuum) are more magnetic on account of shallow maghemite occurrences. These give way to goethite and iron deficient saprolite zones and hence much lower magnetisations at depth. Overall the regolith processes of surface and mid-level ferruginisation, silicification and deep argillisation are reflected well in the physical properties.

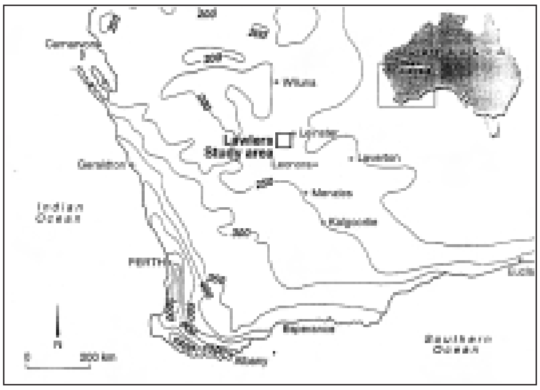


Fig. 1. (Left) Locality map showing the Lawlers regolith study area in Western Australia and rainfall contours (mm/yr).

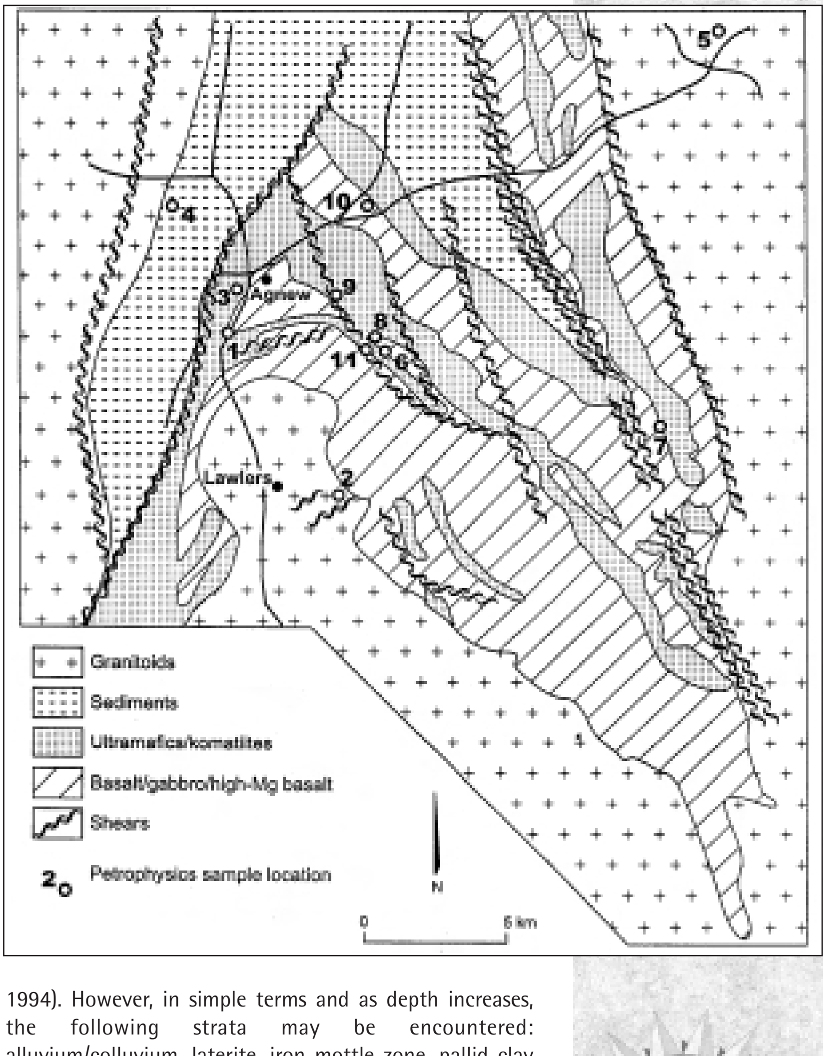


Fig. 2. (Below) Typical geological crossection of the Lawlers regolith (vertically exaggerated).

Introduction

Extensive weathering is encountered on about one third of the Earth's land surface, where bedrock is variably weathered in the 10 to 100 + m range. This occurs mainly in middle to low latitudes. Palaeoclimate patterns since the Proterozoic have produced deep weathering and concomitant regolith development, with abundant near surface ferruginous materials, over many parts of the Yilgarn Craton in Western Australia (Hall and Kneeshaw, 1990) where zones of extreme weathering can extend to well over 100m. Regolith (Gr. ρηγος - rug, blanket; Gr. λιθος - stone) refers generally to the mantle of unconsolidated and weakly consolidated materials, of any origin, which overlies coherent bedrock and commonly, and perhaps incorrectly, in geophysics it is termed the overburden (which refers, strictly, only to unconsolidated material). Frequently the term laterite (L. *later* - brick) is applied to the weathered profile, but laterite is a confusing term that more or less refers to ferruginous indurated near surface material, which later processes may bury, and which occurs as a crust or fragmented debris. There is no universally agreed regolith terminology (Butt and Anand, 1994). However, in simple terms and as depth increases, the following strata may be encountered: alluvium/colluvium, laterite, iron-mottle zone, pallid-clay zone, saprolite, and saprock. This article discusses some physical properties of the regolith from the Lawlers study area (Figure 1) for which a simplified geological section is given in Figure 2.

The upper part of the profile is enriched in, and the lower part deficient in, iron. The distribution of the iron is a

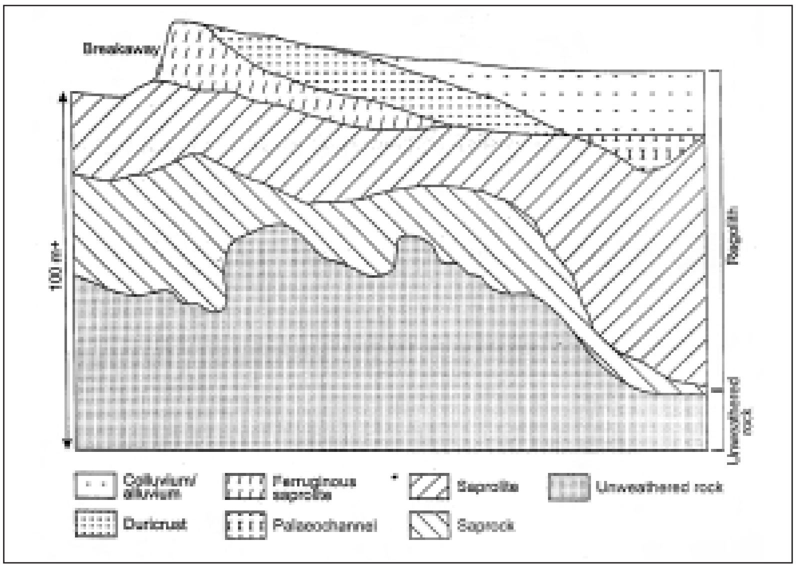
Zones	material	dry bulk density DBD g/cm3	apparent porosity PA %	galv. elec resistivity 1kHz ro Wm (saturated ρ_w=5Ωm)	ultrasonic Pwave velocity 500kHz Vp m/s	magnetic volume suscept k SIx10-5	frequency effect mag k % FE	Koen Ratio Qn J_{NRM}/J_{IND}
	surface ferrug. zones							
1	**hardpanised colluvium**	2.27	23.2	63	2148	1055	3.6	13.6
	lateritic residuum	2.86	18.2	315	3358	4774	10.8	11.9
	palaeochannel sediments							
	clay (smectitic)			3		14		
2	**clayey grit (Permian)**	1.90	28.2	12		5		0.4
	silic. grit, Ss, (Permian)	2.25	15.0	72	3299	3		
	mid level ferrug. zones							
	ferrug. saprolite	2.18	29.1	72	2838	56	3.7	12.0
3	**mottled zone**	2.03	24.7	33	2420	36	1.1	0.3
	"iron"segregation (goethite)	2.96	17.6	1263	3940	105	1.5	3.4
	deeper weathered zones							
	saprolite	1.71	37.8	8	2008	94	<0.1	1.2
4	sil. zones in u'mafic saprol.							
	quartz	2.63	2.0	4902	6295	-1		
	opaline silica	2.29	7.6	1544	4731	-1		
5	**saprock**	2.67	7.7	141	4591	603	<0.1	0.1
	basement							
6	**slightly weathered/ altered bedrock**	2.92	1.6	5954	5731	206	<0.1	0.3

Table 1. ***Average Values - Lawlers Petrophysics Data*** *arithmetic means cited, see crossplots (Emerson et al, 2000) for data spread*

contentious matter - one school of thought favours vertical processes, the other (Ollier, 1994) invokes lateral migration. Be that as it may, the regolith with its distinctive zones is a very significant feature of applied geology and geophysics in Western Australia, where its morphology is being investigated by intensive exploration drilling, but its physical properties are not well known. In electrical and electromagnetic investigations, the saprolite (Gr. σαπρος - rotten) is a key rock type - soft, clayey, thoroughly decomposed, relict textured bedrock formed *in situ* by chemical processes.

The regolith contains pathfinder elements in rock units that exploration geochemists seek to map, it hosts economic deposits of lateritic and saprolitic gold and sedimentary uranium, some of it can be used for engineering works, it can contain groundwater supplies, useful, even if saline, for mining purposes, it is the site of some environmental degradation in the form of dry land salinity, and it seriously hinders geophysical exploration for bedrock targets by masking deeper-sourced responses. Emerson et al. (1993) investigated and documented the properties of the weathered zone materials around the Koongarra uranium deposit, but not from a regolith viewpoint. With an increasing airborne electromagnetic, aeromagnetic and other geophysical effort directed at the regolith itself (Street and Anderson, 1993), there is a need for regolith physical property information.

Although there are many physical property values of unconsolidated material cited in geoscience and engineering publications and compilations, few studies have focused on the regolith, but some have investigated the effects of clay on soil conductivities. In engineering classifications (Bieniawski, 1989) regolith materials can only be regarded as low to very low strength. In McDonald et al. (1990) a tabulated generalised summary is given of strength, density and velocity of dry earth and rock masses in the regolith and bedrock zones. Welby (1984) studied the hydrogeology of North Carolina saprolites with porosities of 40 to 50% and specific yields of 15 to 30%. These acted as reservoirs holding and releasing infiltrated waters to wells tapping fractures in the crystalline bedrock. Walker et al. (1973), in a field study of tropical soil conductivities, noted a correlation of conductivity with smectite clay content. Soils with high smectite content were observed with conductivities of about 150mS (resistivity ~ 7 Ωm) while kaolinite rich soils had distinctly lower conductivities of about 50mS (20 Ωm). Smith-Rose (1934) measured



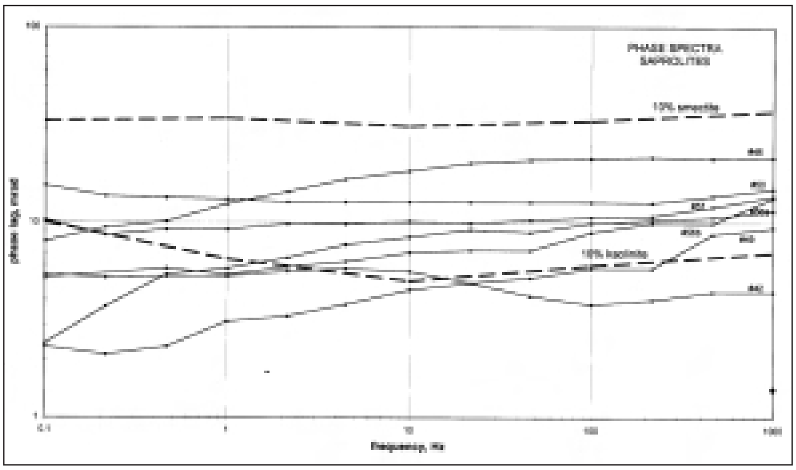


Fig. 3. (Above Left) Archaean bedrock geology and the eleven sampling locations for the 104 samples studied for mesoscale physical properties in the laboratory.

Fig. 4. (Left) Phase lag spectra from 0.1 to 1000 Hz for Lawlers saprolites which show low magnitude effects; Kelly's (1994) data for dispersed kaolinite and smectite are also shown.

resistivity changes from about 11 to 33 Ωm as moisture content diminished from about 35 to 15 percent in clays of unspecified types. The effects of clay on the resistivities of soils and sands were considered theoretically by Elliott and Thomas (1986) who constructed characteristic curves, which demonstrated the effects of variations in clay content, porosity and water salinity. Such an approach is useful if prior knowledge of several independent variables is available.

Palacky and Kadekaru (1979) used ground resistivity and airborne and ground electromagnetic measurements in a study of the electrical properties of the weathered layer in Brazilian tropical to temperate regions. They asserted that EM measurements were affected by weathering which was controlled by climate, lithology and geomorphology. They observed that patterns in apparent resistivity maps followed lithological features and noted that airborne EM might be useful for geological mapping in weathered terrain that was difficult to access. Interpreted weathered layer resistivities were of the order of tens of Ωm. Palacky (1986, 1987) summarised weathering processes and discussed their relevance to geophysical investigations. He presented interpreted *in situ* resistivity data from many areas to demonstrate inferred resistivities as low as 5 Ωm in mafic saprolites. His averaged values for mafic, ultramafic, metamorphic, and felsic saprolites were 15, 23, 46 and 100 Ωm respectively.

It is the purpose of this article to comment on some of the key physical features identified in a mesoscale laboratory petrophysical study of regolith materials from Lawlers (Emerson, et al., 2000) in an endeavour to understand better the regolith's various roles as a target, a screen, and a noise source. This article addresses galvanic electrical, magnetic, and environmental data not covered in the previous publication.

Previous Work

The extraordinarily porous nature of the Lawlers weathered Archaean regolith materials has been documented by Emerson et al. (2000). Here, in a brackish groundwater (water resistivity $\rho_w \approx 5$ Ωm, 25°C) regime, and in a currently arid environment, five weathered zones, with porosities ranging up to nearly 50%, overlie slightly weathered basement rock occurring at about 80 m depth. These zones and their average mesoscale physical properties, based on laboratory measurements of 104 samples from 11 sites (Figure 3), are summarised in Table 1.

Galvanic Electrical Properties of Saprolite

The resistivity values cited in Table 1 are for the fully saturated state. For desiccated, near surface materials, resistivities may be estimated approximately by using the Sw-2 factor where Sw is the fractional porewater saturation (Emerson and Yang, 1997).

The regolith may contain quite conductive sections. Saprolites are variable mixes of clays, quartz, feldspar, mica and other minerals. In felsic saprolites kaolinite predominates and smectite is subordinate; in mafic saprolites smectite is dominant over kaolinite. The saprolite zone (4, Table 1, Figure 2), which is usually saturated, can be quite thick (tens of metres), but is mechanically weak

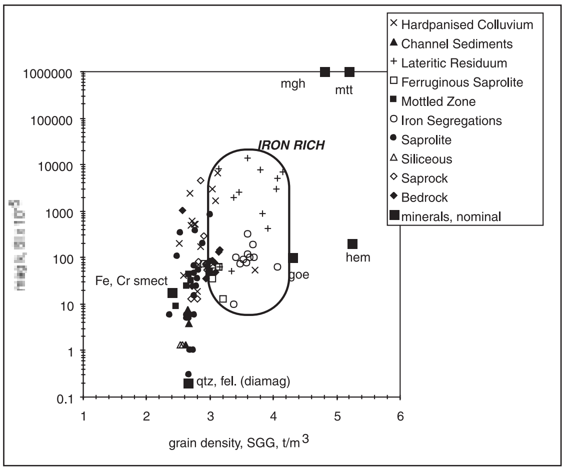


Fig. 5. (Left) Crossplot of magnetic volume susceptibility against grain density for the Lawlers regolith components; reference minerals are also shown.

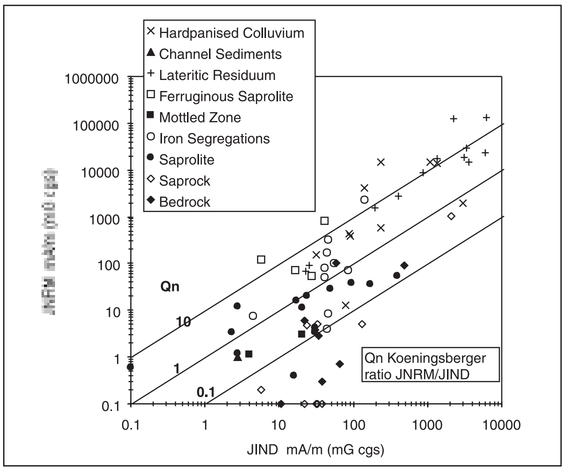


Fig. 6. (Below Left) Crossplot of raw remanent magnetisation against induced magnetisation for the Lawlers regolith components, some of which manifest high Koenigsberger ratios.

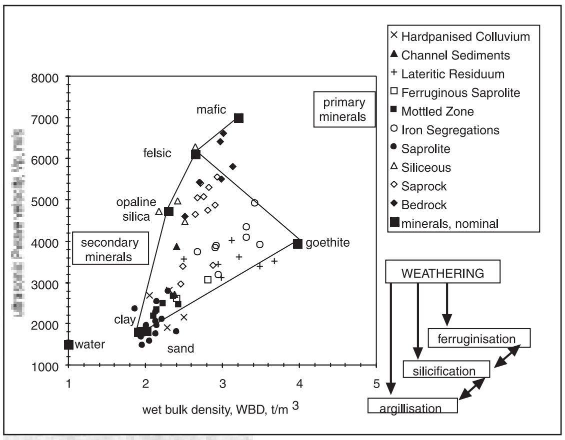


Fig. 7. (Above) Crossplot of ultrasonic compressional wave velocity against density for water saturated Lawlers regolith components; reference minerals are also shown.

and behaves acoustically more as a suspension than a solid. It has a low resistivity at Lawlers, averaging 8 Ωm for 25 samples. In the metasedimentary-felsic-mafic-ultramafic saprolite categories, resistivities averaged 9, 8, 6 and 7 Ωm respectively. However, it is not a straightforward procedure to differentiate saprolite lithologies on the basis of resistivities owing to the number of independent variables involved (porosity, porosity structure, salinity, conductive solids), and also owing to the usually subtle inter-saprolite contrasts that may exist, in the Lawlers area at least.

In the highly saline areas of the Western Australian Archaean, south of Kalgoorlie, brine saturated saprolites attain very low resistivities: 0.4 Ωm for mafics and 0.5 Ωm for felsics. This order of magnitude drop is a consequence of the extreme salinities in this region, where groundwater conductivities can be of the order of 20 S/m.

Palaeochannels are common in the weathered WA Archaean. These sinuous, incised features can be quite smectitic and are often the most conductive feature in the profile, as is the case at Lawlers where the clayey channel sections have a resistivity of 3 Ωm. In the hypersaline areas south of Kalgoorlie the resistivity of these materials may be an order of magnitude lower.

In assessing the more conductive features in a weathered area, saprolites may be distinguished from palaeochannels by their quite different inferred or interpreted source geometries.

The induced polarisation responses of saprolites are not well reported. Measurements on the Lawlers samples are shown as phase spectra in Figure 4. Low frequency (0.1 Hz) phase lags vary from 2 to 25 mrad. Kaolinitic saprolites have lower responses than the smectitic saprolites. For comparison Kelly's (1994) laboratory data for 10% clay mixes in small glass spheres are shown; the saturant was 9.5 Ωm water. The upper dashed curve is for a 10% smectite mix with 13.5 Ωm resistivity, 38.5% porosity, and 7.89 meq/100 g cation exchange capacity. The lower dashed curve is for a 10% kaolinite mix with 22.4 Ωm resistivity, 34.7% porosity, and 2.58 cec. The phase responses of the Lawlers saprolite are ascribed to membrane effects of smectite/kaolinite distributions in a sandy matrix, and to physical pore wall - pore water interactions having low phase magnitudes.

Magnetic Properties of the Regolith

The Lawlers data in Table 1 show a surficial high magnetic susceptibility maghaemite/hematite laterite zone, underlain by low suscepibility channel sediments, then moderate susceptibility goethitic ferruginous saprolite and saprolite proper (which, if of ultramafic origin, can contain extensive diamagnetic quartz zones).

The data are readily appreciated in the format of Figure 5 where the Lawlers magnetic susceptibilities and grain densities are crossplotted together with the relevant reference minerals: maghaemite, magnetite, goethite, hematite, Fe/Cr smectite. Quartz and feldspar are diamagnetic negative susceptibility minerals, (~ -1×10^{-5} SI), but for convenience have been plotted as shown. Mineralogical studies show that maghaemite and hematite (and perhaps a little magnetite) tend to dominate in the upper part of the regolith, while the lower part is usually goethite-rich. This is reflected in Figure 5 especially in the denser, iron rich samples.

Remanent magnetisations are plotted against the product of susceptibility and ambient magnetic field (i.e. induced magnetisation) in Figure 6. The remanence values are raw (AF demagnetisation not applied). The Koenigsberger ratios range from around unity to over 10 for the ferruginous materials and clearly indicate the importance of considering remanence in magnetic investigations of the regolith, especially in near surface sections where induction and remanence can combine to produce considerable magnetic responses.

Frequency effects in magnetic susceptibility are also cited in Table 1. These are significant for the ferruginous materials where the low frequency susceptibility (460 Hz) exceeds the high frequency 4600 Hz) value. These magnetic viscosity effects are particularly noticeable in ferrimagnetic minerals with very fine grainsizes close to the superparamagnetic/stable single domain boundary, ~0.05 µm. An 11% effect, as seen in the Lawlers laterite, is considered quite large (Thompson and Oldfield, 1986). These ultrafine particles of maghaemite (oxidised, cation deficient magnetite) can be generated by bushfires, bacteria and chemical processes in soils (D Clark, pers. comm.).

Physical Characterisation of the Regolith Environment

An appreciation of the regolith in physical terms can be gained from a compressional wave velocity-density crossplot as displayed in Figure 7 for samples in the water saturated state. Here the Lawlers regolith components can be seen in the perspective of their constituent material properties. Although porosity exerts some control on the position of the plotted points, and the Lawlers rocks do not have a constant porosity (but their porosities generally are high), the velocity-density space depiction is still a useful and valid way of viewing the materials.

The reference materials in Figure 7 are mafic (e.g. amphibole), felsic (e.g. quartz, feldspar) opaline silica, water, clay, sand, and goethite. In bulk terms, goethite (a little studied mineral in physical terms) is the dominant iron oxide. The regolith materials cluster at or trend towards their main components. The weathering process changes the primary felsic and mafic mineral assemblage to secondary mineral assemblages and this is reflected in velocity-density space.

Conclusions

Archaean regolith components in Western Australia that have been subject to intensive study in the fields of geological, geochemistry and mineralogy can also be appreciated in physical terms. Surficial and mid-level ferruginous zones, deep saprolite, and incised palaeochannel lithologies have recognisable characteristics in density, magnetic, acoustic and electrical properties, that are best seen as crossplots of pairs of properties. Merging and overlaps of properties do occur from lithology to lithology as a consequence of variable degrees of weathering, but, broadly, the main regolith units have distinctive physical properties that should be useful in borehole, surface and airborne geophysical work.

Acknowledgements

This study was undertaken for the Cooperative Research Centre for Australian Mineral Exploration Technologies (CRCAMET) supported by the Australian Mineral Industries Research Association (AMIRA) Project P407 - CRCAMET Geophysical Methods Program which had access to the Lawlers area opencut pits, grid drilling and geological data. The authors gratefully acknowledge the research sponsors: BHP Minerals International, Acacia Resources Ltd, CRA Exploration Pty Ltd, North Ltd, MIM Exploration Pty Ltd, Pasminco Exploration Ltd, World Geoscience Corporation Ltd. The Co-operative Research Centre for Australian Mineral Exploration Technologies kindly made facilities available and staff members, particularly CSIRO personnel R Anand, T Munday and A Green, and L Worrall contributed to discussions on geology, geophysics and petrophysics of the Lawlers region. D Sattel's field help and advice were invaluable. Y Yang assisted with data and measurements. A Vartesi of CSIRO Division of Exploration Mining drafted Figures 1 to 3. Gratitude is expressed to S Franks and R Astridge for assistance in measurements and manuscript preparation.

References

Bieniawski, Z. T., 1989, Engineering Rock Mass Classifications: John Wiley and Sons, Inc.

Butt, C. R. M., and Anand, R. R., 1994, Terminology of deeply weathered regoliths, Abstract Volume, Australian Regolith Conference'94: Austral. Geol. Surv. Org., Record 1994/56, 11-12.

Elliott, P. J., and Thomas, L. T., 1986, Interpretation of lithology from the formation resistivity of unconsolidated argillaceous/arenaceous sediments: Explor. Geophys., **17**, 75-79.

Emerson, D. W., Mills, K. J., Miyakawa, K., Hallett, M. S., and Cao L. Q., 1993, The petrophysics, geophysics and structure of the Koongarra site, Northern Territory: Explor. Geophys., **24**, 1-71.

Emerson, D. W., and Yang, Y. P., 1997, Effects of water salinity and saturation on the electrical resistivity of clays: Preview, **68**, 19-24.

Emerson, D. W., Macnae, J. and Sattel, D., 2000, Physical properties of the regolith in the Lawlers area, Western Australia: Explor. Geophys., **31**, 229-235.

Hall, G. C., and Kneeshaw, M, 1990, Yandicoogina-Marillana pisolitic iron deposits, in Geology of the Mineral Deposits of Australia and Papua New Guinea (ed. F. E. Hughes), Austral. Inst. Min. Metall., 1581-1586.

Kelly, B. F., 1994, Electrical Properties of Sediments and the Geophysical Detection of Ground Water Contamination: PhD thesis unpubl., Dept of Water Engineering, School of Civil Engineering, University of NSW, Nov. 1994.

McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J., and Hopkins, M. S., 1990, Australian Soil and Land Survey Field Handbook: Intaka Press.

Ollier, C., 1994, Exploration concepts in laterite terrains: Austral. Inst. Min. Metall., Bull., **3**, 22-27.

Palacky, G. J., 1986, Geological background to resistivity mapping, in Airborne Resistivity Mapping (ed. G. J. Palacky): Geol. Surv. Can., Paper 86-22, 19-27.

Palacky, G. J., 1987, Resistivity characteristics of geological targets, Electromagnetic Methods in Applied Geophysics - Theory (ed. M.N. Nabighian), Vol. 1, Ch.3, 72-82. Soc. Explor. Geophys., Tulsa.

Palacky, G. J., and Kadekaru, K., 1979, Effect of tropical weathering on electrical and electromagnetic measurements: Geophysics, **44**, 69-88.

Smith-Rose, R. L., 1934, Electrical Measurements on Soil with Alternating Currents: Proc. IEEE., **75**, 221-237.

Street, G. J., and Anderson, A., 1993, Airborne magnetic surveys of the regolith: Explor. Geophys., **24**, 795-800.

Thompson, R., and Oldfield, F., 1986, Environmental Magnetism: Allen & Unwin.

Walker, J. W., Hulse, W. H. and Eckart, D.W., 1973, Observations of the electrical conductivity of the tropical soils of Western Puerto Rico: Bull. Geol. Soc. Amer., **84**, 1743-1752.

Welby, C. W., 1984, Ground-water yields and inventory for land-use planning in crystalline rock areas of Wake County, North Carolina: Water Res. Bull., **20**, 875-82.

The Conductivities of Komatiitic Nickel Ores at Kambalda W.A.

D W Emerson
Systems Exploration (NSW) Pty Ltd, systems@lisp.com.au

P K Williams,
Resolute Ltd (formerly of WMC Resources Ltd)
and
S Luitjens
WMC Resources Ltd

When this article was published in the June Preview Fig. 7 was omitted. We now publish the correct version

Fig. 1. Location map showing Kambalda in Western Australia, and also Leinster (discussed in previous Preview paper: Emerson et al., 1999).

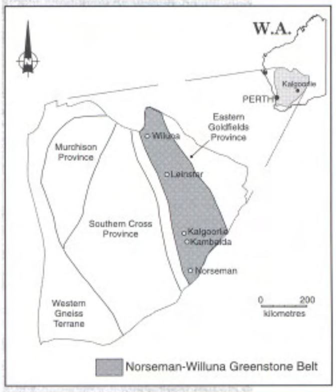


Table 1. Preliminary data for Kambalda nickel ores - mineralised ultramafics - mean values from 19 mine and drill sites.

ore type	conductivity kS/m	density t/m^3
massive (n=29)	30.6	4.46
matrix (n=17)	2.11	3.51

Introduction

The famous komatiite-associated Kambalda nickel sulphide deposits of WMC Resources Ltd lies to the north and south of Kambalda, 60 km south of Kalgoorlie, WA, in the central part of the Norseman-Wiluna Greenstone Belt (Figure 1). Here, fine to medium grained pyrrhotite-pentlandite-pyrite-magnetite ores occur as thin ribbon-like bodies (a few metres thick) at the base of a high Mg ultramafic lava pile. The ores occur as massive, matrix (connected sulphides) and disseminated types, and constitute a pre-mining resource of 67 Mt at 2.9% Ni. These deposits have been discussed by Cowden and Roberts (1990) and Stone and Masterman (1998).

This article describes the results of a mineralogically and chemically controlled, mesoscale laboratory study of the conductivities of blocks and cores of ores from eleven mines: Blair, Carnilya Hill, Foster, Hunt, Mariners, Miitel, Mt. Edwards, Otter-Juan, Schmitz, Victor, and Wannaway. Thirteen massive ores and four matrix ores were studied in the light of XRF, XRD, optical mineralogy and SEM-EDS data provided by WMC Resources.

The primary texture of Kambalda sulphides varies from the finely banded massive ores to the truly disseminated ores where the individual sulphide grains are not in contact at all. The massive sulphide ores are classified as those having more than 80% sulphide, and they can have up to 20% nickel, which equates to about 60% pentlandite. The disseminated ores contain between 1-2% Ni, and have less than 40% total sulphides. The sulphide texture can be regarded as granular, except in restricted areas where a structural overprint may result in a linear fabric and the reshaping of the sulphide minerals. The matrix ores grade about 4%-5% Ni, and contain between 40%-80% total sulphides.

Previous Work

The results of a 1995 preliminary laboratory study of Kambalda ore conductivities are given in Table 1. The conductivities shown are averages of the maximum-recorded mesoscale values. The conductivities, measured DC galvanically (Emerson, 1969) and electromagnetically (Yang and Emerson, 1997), were found to be sensitive to the orientation of the ore banding i.e. the conductivities can be quite texture dependent with anisotropies of about 2:1.

In contrast to the excellently conducting sulphide continuum of the dense massive ores, the sparsely networked matrix ores had a fair to good conductivity ranging from 50 S/m to 7000 S/m.

Disseminated ores had an average density of about 3 t/m^3 and were usually resistive (hundreds of ohm m) with occasional restricted zones of fair conductivity (few S/m) in favourably textured horizons.

The massive ores manifested a considerable conductivity range: 2.9 kS/m to 135 kS/m. Massive ore conductivities seemed to decrease somewhat as tenor increased from low (~8% Ni) to high (~18% Ni). With a mean conductivity of 30.6 kS/m (std dev, 22.1), the Kambalda massive ores appeared to be less conductive than those at Leinster, 400 km further north on a similar greenstone belt, where good quality, medium to coarse grained, pyrite/magnetite-poor, massive ores have an average conductivity over twice that cited in Table 1 (as reported by Emerson et al., 1999). This disparity was intriguing and it was decided to investigate possible reasons (beyond those of texture) for conductivity variations.

Current Work

Conductivities were measured at mesoscale on cored or shaped sulphides from which material was taken for the chemical and mineralogical determinations. Conductivities cited are the maximum values (parallel to foliation or favourable texture) whether determined by inductive or galvanic (DC) means. Magnetic susceptibilities were measured at low frequency (<1 kHz) in an induction coil; the values cited are averages. Dry bulk densities were also determined and, as porosities are very low, these approximate the composite grain densities. Table 2

Table 2
Data Summary Selected Kambalda Sulphides

#	major chemistry (wt %) % Ni	% Fe	% S	% SiO_2	% Mg0	Al_2O_3	CaO	Cu %	ore mineralogy (wt %) pn	po	py	cpy	mtt	density DBD t/m^3	cond. σ_{max} S/m	suscept mag k SIx10^{-5}
massive sulphides																
n= 13																
mean	**12.29**	**43.9**	**34.2**	4.3	1.7	0.4	1.1	0.48	**35.8**	**41.8**	**10.9**	1.4	0.9	**4.57**	**54016**	**13894**
s. dev	*3.37*	*6.6*	*3.7*	*5.0*	*2.4*	*0.7*	*1.0*	*0.79*	*9.9*	*19.6*	*9.9*	*2.3*	*1.5*	*0.17*	*39615*	*9461*
matrix sulphides																
n = 4																
mean	**4.78**	**20.3**	**12.5**	25.6	19.3	1.8	1.7	0.19	**14.0**	**17.2**	**2.2**	0.6	2.8	**3.39**	**258**	**10523**
s. dev	*2.61*	*2.4*	*3.0*	*4.4*	*3.1*	*0.3*	*1.6*	*0.09*	*7.6*	*1.6*	*1.2*	*0.2*	*1.4*	*0.19*	*197*	*5122*

summarises the measured data and Figures 2 to 7 display the data in crossplotted perspective.

The fine to medium grained (0.1 mm - 0.5 mm) remobilised sulphides comprised: pentlandite, monoclinic (mainly) and hexagonal pyrrhotite, pyrite, and minor chalcopyrite. Also present were magnetite and chromite (difficult to distinguish in XRD) and gangue minerals including forsterite, talc, serpentine, magnesite, dolomite, calcite, siderite, amphiboles, chlorites, andradite, plagioclase, and quartz.

The stratified ore samples studied were from the basal chill zone of an Archaean volcano-sedimentary sequence that exhibited variation in constituents and properties. The petrophysical data presented here should be regarded as a mesoscale physical snapshot of a suite of materials that is considered to be a reasonable and useful representation of a selected range of ores, but it is by no means a definitive picture of the physical characteristics of Kambalda mineralisation.

Discussion

The mean conductivity value for massive sulphide ore (Table 2) is 54.0 kS/m, which is an average of a considerable spread of data, 4.27 kS/m to 131.8 kS/m. The densities show a tighter grouping. The most conductive massive sulphide with 53% monoclinic pyrrhotite, came from Foster mine, 131.8 kS/m; the least, with 1% pyrrhotite and 40% pyrite, was from Schmitz, 4.27 kS/m. The most pentlandite-rich sample, 55% pentlandite (18.8% Ni), from Victor, with 36% monoclinic pyrrhotite and 8% pyrite, gave a maximum conductivity of 19.9 kS/m. It is interesting to explore the likely controls on such variations. These can be inferred from the crossplots.

Magnetic susceptibility plotted against density in Figure 2 shows three groupings: the matrix ores (with an average of 2.8% mtt and 17% mon po), the massive ores (0.9% mtt, 42% mon po, av.), and two hexagonal pyrrhotite bearing ores from Wannaway (71% hex po and 45% hex po/34% troilite [FeS]).

Conductivity against density in Figure 3 shows a clear trend for those samples containing monoclinic pyrrhotite (as the dominant sulphide). Two hexagonal pyrrhotite-bearing samples and three others, containing significant amounts of the cubic sulphides pentlandite and pyrite, lie off this trend and have diminished conductivities.

Conductivity against % Fe in Figure 4 shows four groupings: the relatively low conductivity matrix ores, the high conductivity monoclinic pyrrhotite ores, the lower conductivity cubic mineral set, and the hexagonal pyrrhotite set.

High concentrations of pervasive, anhedral monoclinic pyrrhotite produce excellent conductivities. When conductivity is plotted against pyrrhotite (and the quite minor chalcopyrite content) a very clear trend emerges for all the massive ores except for two Wannaway hexagonal pyrrhotites which are in high concentration but clearly with conductivity below that of monoclinic pyrrhotite (Figure 5). Ward's (1970) data on synthetic pyrrhotites suggested that hexagonal pyrrhotite's conductivity could be an order of magnitude less than that of the monoclinic variety.

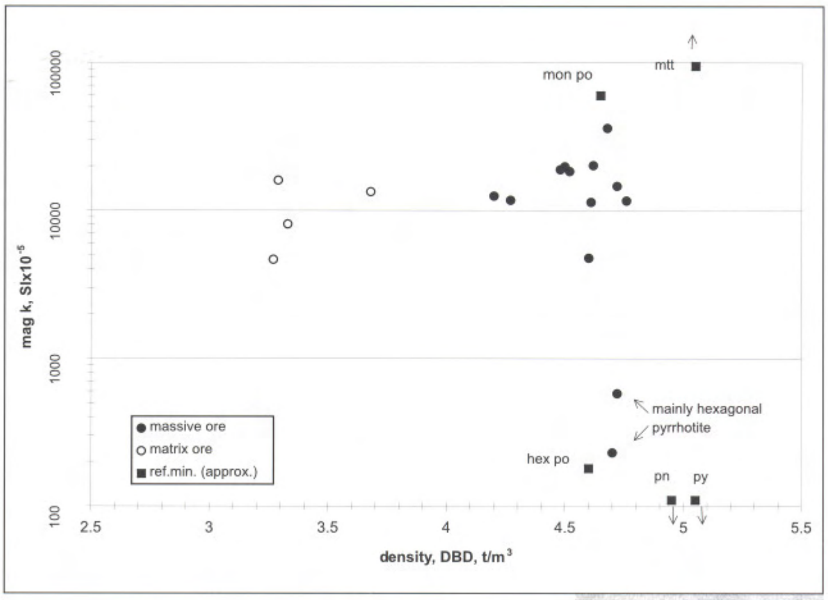


Fig. 2. Magnetic volume susceptibility plotted against dry bulk density depicts the intermediate susceptibilities of the studied Kambalda nickel ores with respect to the approximate values of reference Fe sulphide and oxide minerals (shown); lower density diamagnetic and paramagnetic gangue minerals are not shown. The influence of monoclinic pyrrhotite is clear in several of the massive ores.

Conductivity of nickel-bearing pentlandite-rich pyrrhotite is seen to diminish as nickel content increases, in Figure 6. This effect is noted too in Figure 7, where conductivity diminishes as metallic cubics (pentlandite, pyrite, magnetite) increase. Despite high crystalline conductivities, the aggregate conductivity of cubic metallics may not be high owing to grain contact impedances and current scattering effects. It is the significant presence of pyrite and spinels (magnetite, and usually minor chromite) that reduces the overall Kambalda conductivities below these of

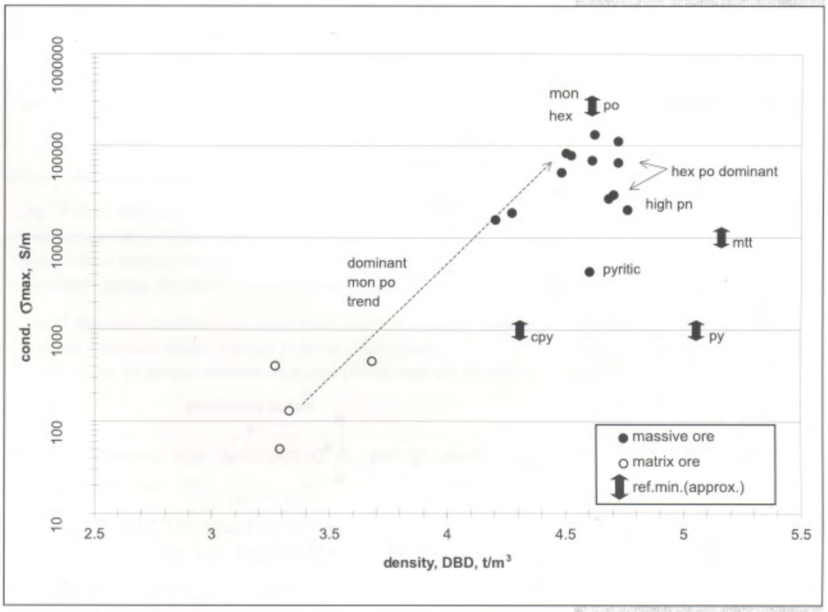
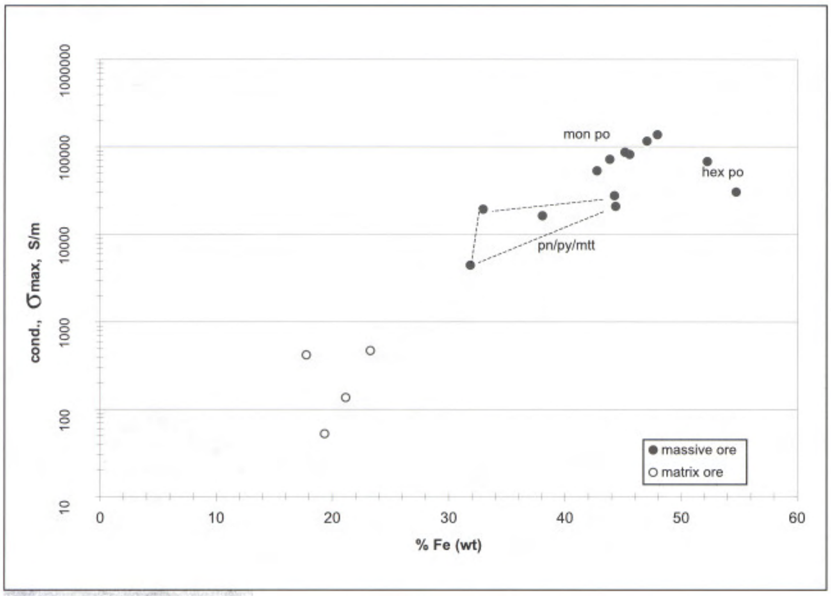
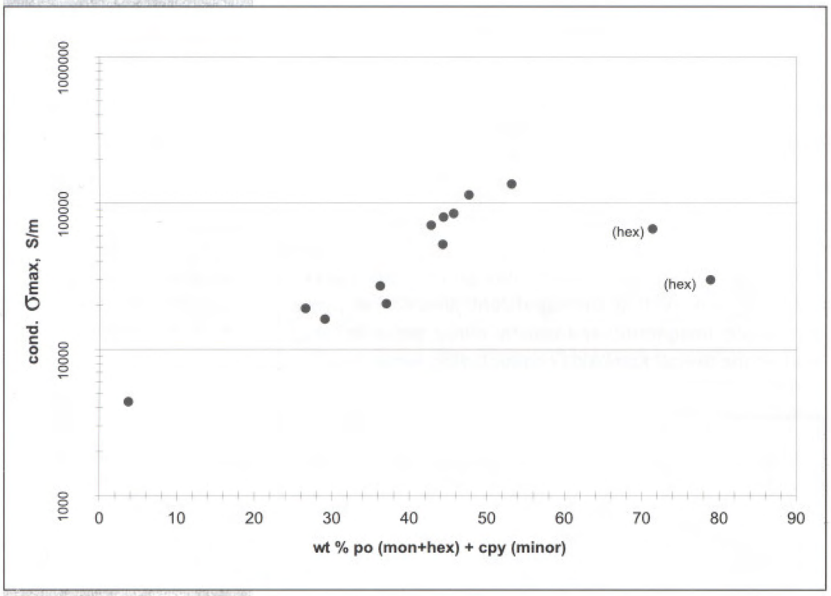
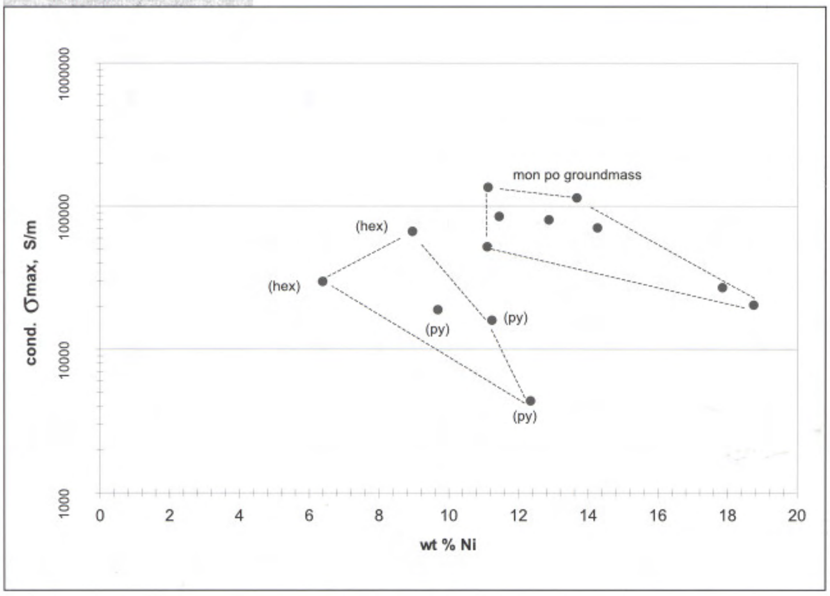


Fig. 3. Maximum ore conductivity plotted against density shows a trend towards the pyrrhotite field for most of the samples. Heavily pyritic and pentlanditic ores and those with hexagonal pyrrhotite (and troilite FeS) show off-trend diminished conductivities. The approximate crystalline conductivities of the main sulphide and metallic oxide minerals are shown. The trend line is visual.







Leinster. Shuey (1975) has documented the conductivities of metallic lustre minerals and discussed such textural effects, generally.

As well as looking at conductivity from the viewpoint of conductors present, it is also instructive to consider the insulators, i.e. the silicates and carbonates present as sediment or country rock impurities caught up in the seafloor environment of the ancient ore forming process. These are represented chemically in Figure 8, where conductivity can be seen to decrease broadly as gangue content increases.

Conductivity of Hexagonal Pyrrhotite

On the basis of the two samples tested, the conductivity of hexagonal pyrrhotite appears to be distinctly less than that of monoclinic pyrrhotite which, in substantial concentration at Kambalda attains values well in excess of 100 kS/m and could be regarded as having a nominal aggregate conductivity of around 200 kS/m (in a pure Kambalda-textured form). A maximum conductivity value of about 100 kS/m would seem to be indicated for undiluted hexagonal pyrrhotite aggregates at Kambalda. Hexagonal pyrrhotite does not occur in pyritic environments.

Conductivity of Pentlandite

Harvey (1928) tested one sample of pentlandite crystal with a microprobe and obtained a conductivity similar to that of several pyrrhotites. However, crystalline and grain-aggregate conductivities can differ considerably owing to texture, especially in cubic minerals such as pyrite and magnetite (Emerson and Yang, 1994). This effect was noted in the present study where miniprobe galvanic tests on clusters of Kambalda pentlandite grains indicated that their aggregate conductivities were up to an order of magnitude less than the monoclinic pyrrhotite groundmass i.e. around 20 kS/m, in aggregate (i.e. for pn).

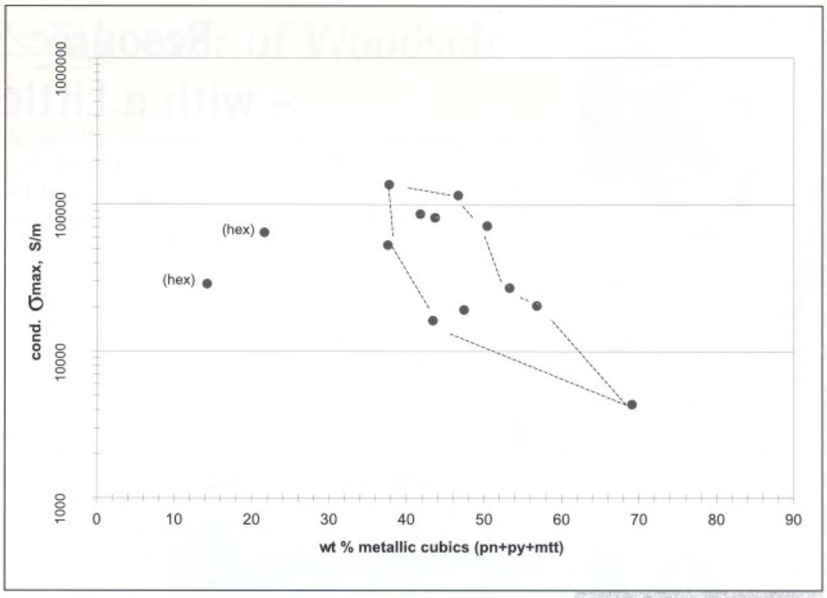
Fig. 4. (Top) Maximum ore conductivity plotted against iron content shows a broad trend of increasing σ with increasing Fe. Above the 40% Fe level, monoclinic pyrrhotite-rich massive samples have the highest conductivities (as a group); massive ores with significant amounts of cubic metallics (mainly pentlandite with pyrite and/or magnetite) and hexagonal pyrrhotite have lower conductivities. Gangue minerals exert a deleterious effect on conductivity below 40% Fe, for both massive and matrix ores.

Fig. 5. (Middle) Maximum conductivity plotted against percent pyrrhotite (and quite minor chalcopyrite) shows, for massive ores, a clear trend of conductivity increasing with the amount of monoclinic pyrrhotite. The two off-trend points are for hexagonal pyrrhotite-rich samples of which one, with lower conductivity, has 45% hex po and 34% troilite (FeS).

Fig. 6. (Bottom) Maximum conductivity plotted against percent nickel shows two groupings for massive ores: a higher conductivity monoclinic pyrrhotite group and a lower conductivity hexagonal pyrrhotite and pyritic group. Both groups have trends that suggest diminishing conductivity as nickel content increases.

The electrical conductivities of the Kambalda massive nickel sulphide ores are dominated by pyrrhotite, which in its usual monoclinic aggregate form probably has an undiluted conductivity of around 200 kS/m. In the rarer hexagonal form pyrrhotite's conductivity is probably around 100 kS/m. In massive concentrations this pyrrhotite forms a superb electrical continuum, as would be expected in a low mobility metal (Shuey, 1975) with platy grains and well sutured grain boundaries. However, the addition of the cubic minerals pentlandite, pyrite and magnetite impairs the continuum and diminishes conductivity significantly in massive, low gangue, high-density nickel sulphide ores, and in some cases by over an order of magnitude. Nevertheless, in absolute terms, excellent conductivities are the norm for these ores as shown by the mean value in Table 2, 54.0 kS/m, which is around half the value of the mean maximum value of the Leinster massive sulphides reported by Emerson et al., (1999).

The occurrence of a large volume of silicate gangue and the disruption of the pyrrhotite continuum completely changes the electrical character of the nickel ores. Conductivity is maintained by a sparse network pyrrhotite but at greatly reduced levels, ~260 S/m for the four ores (average density 3.4 t/m³) in this study and ~2100 S/m for the 17 ores (average density 3.5 t/m³) in a previous study. For the matrix ores good conductivities may be expected, usually.



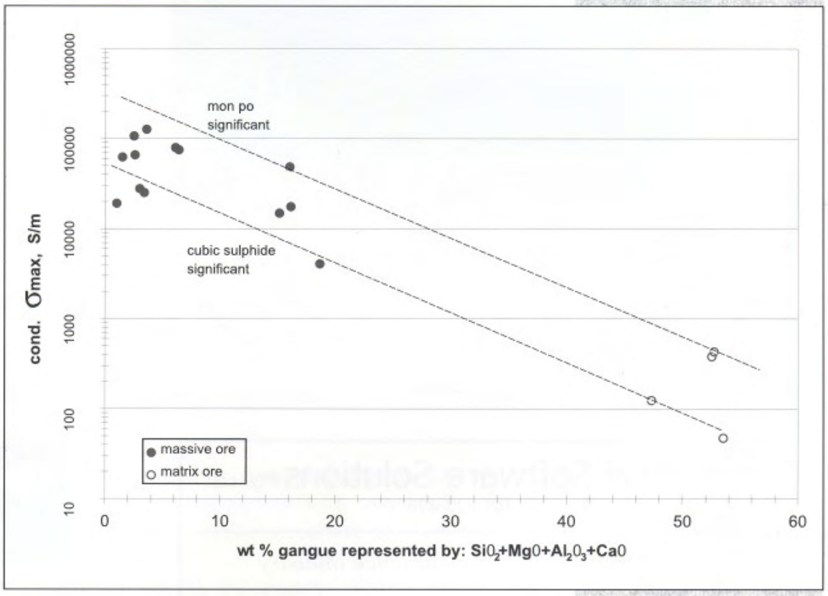


Fig. 7. (Top) Maximum conductivity plotted against metallic cubic mineral content (i.e. pentlandite, pyrite, magnetite), for massive ores, shows a broad decrease in conductivity, for the monoclinic pyrrhotite group, as cubic mineral content increases.

Fig. 8. (Bottom) Maximum ore conductivity plotted against gangue mineral chemistry shows a broad trend of diminishing conductivity as gangue content increases (trend lines are visual).

Acknowledgements

Thanks are due to Mrs S Franks for her assistance in producing this article's text and Figures. The WMC Resources Ltd Laboratory at Kalgoorlie provided the analytical data. This article is published with the permission of WMC Resources Ltd.

References

Cowden, A., and Roberts, D. E., 1990, Komatiite hosted nickel sulphide deposits, Kambalda, in: Geology of the Mineral Deposits of Australia and Papua New Guinea (ed. F. E. Hughes), AusIMM, 567-581.

Emerson, D. W., 1969, Laboratory electrical resistivity measurements of rocks: Proc. AusIMM, **230**, 51-62.

Emerson, D. W., Martin, K., and Williams, P. K., 1999, Electrical, Magnetic and Mass Properties of the Nickeliferous Komatiite Sequence Near Leinster, Western Australia: ASEG Preview, **81**, 13-22.

Emerson, D. W., Turner, G. S., and Williams, P. K., 1998, P Wave Velocities of Ores in Komatiitic Nickel Sulphide Deposits: ASEG Preview, **74**, 28-33.

Emerson, D. W., and Yang, Y. P., 1994, Electrical Properties of Magnetite Rich Rocks and Ores, Final Report (unpubl.) AMIRA Project P416.

Harvey, R. D., 1928, Electrical conductivity and polished mineral surfaces: Econ. Geol., **23**, 778-803.

Shuey, R. T., 1975, Semiconducting Ore Minerals: Elsevier Science Publ. Co., Inc.

Stone, W. E., and Masterman, E. E., 1998, Kambalda nickel deposits, in: Geology of Australian and Papua New Guinean Mineral Deposits (eds. Berkman, D. A., and Mackenzie, D. H.), AusIMM, 347-356.

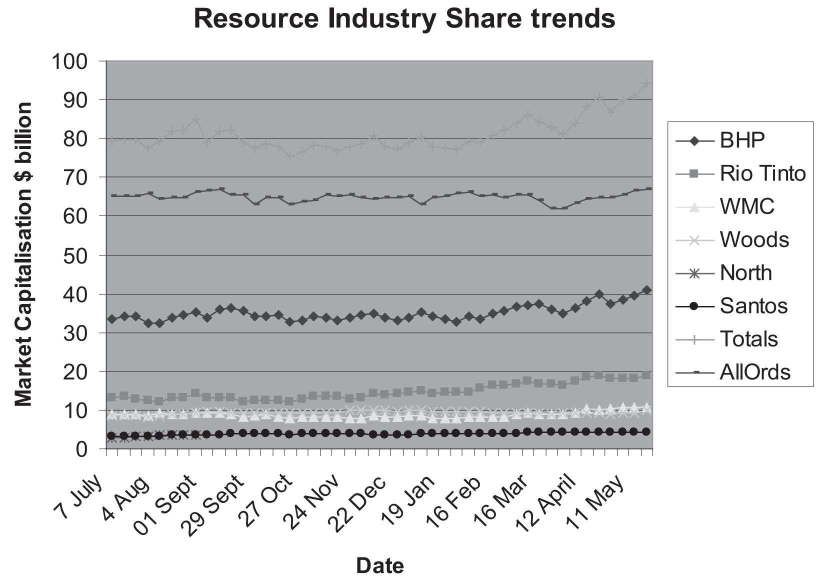
Ward, J. C., 1970, The structure and properties of some iron sulphides: Rev. Pure and Appl. Chem., **20**, 175-206.

Yang, Y. P., and Emerson, D. W., 1997, Electromagnetic conductivities of rock cores: Theory and analog results: Geophysics, **62**(6), 1779-1793.

Resource Stocks Surge - with a Little Help from Gold

Fig. 1. The 'Totals' represent the total market capitalisation of the 13 top resource companies listed on the ASX. Only the top 6 companies are plotted individually. 'All Ords' represents the (All Ords index)/50.

The first half of 2001 has so far been a good period for investors in resource industry shares. From mid-January until mid-May, while the All Ordinaries index rose a mere 2.6 per cent from 3254 to 3340, the market capitalisation of the top 13 resource companies on the ASX rose a massive 21.4 per cent from $77.7 billion to $94.3 billion. The chart below indicates the sharp upturns so far this year.



While the value of petroleum stocks changed very little, the mineral-focused companies mostly performed well. The movements of the top five are shown below in terms of increases in market capitalisation.

1. BHP, from $33.5 to $40.9 billion (+22 per cent)
2. Rio Tinto, from $14.5 to $19.0 billion (+31 per cent)
3. WMC, from $7.9 to $10.6 billion (+34 per cent)
4. MIM from $1.6 to $2.4 billion (+48 per cent) and,
5. Normandy from $1.7 to 2.1 billion (+23 per cent)

Only Pasminco performed poorly with a fall of 23 per cent from $0.70 billion to $0.54 billion.

The wealth of the resource companies continues to be concentrated in fewer and fewer companies. We now have a situation where the top three mineral resource companies dominate the market by holding approximately three quarters of the total capitalisation in the resource sector.

One of the main contributing factors to these increases has been the gradual increase in the price of gold from about US260/oz at the start of the year to US$288/oz on 19 May. This provided a major boost to companies with gold interests.

We will have to watch the exploration figures for the June quarter to see if the surging share market kick-starts exploration activity.

Government Rejects Shell's Takeover of Woodside

In April the Federal Government rejected Royal Dutch/Shell Group's proposed takeover of Woodside Petroleum Ltd, because it considered that foreign ownership of Woodside would be contrary to the national interest.

The decision was a surprise to investors, who had generally expected the government to approve the deal with few conditions. Woodside shares initially fell nearly 10 per cent but have since bounced back to be more than 7 per cent higher than they were just before the Treasurer's announcement. Likewise the $A which fell as a result of the decision is now at an all-time high for the year. So much for the doom and gloom forecasters who said our reputation would suffer in the global market place if the takeover did not proceed.

If the $10 billion take over had gone ahead, Shell would have become the operator and marketeer of the huge North-West Shelf gas reserves, which has six joint partners (including Shell).

However, although the Shell Australia chairman, Peter Duncan, was disappointed at the decision, it is difficult to feel too sorry for the Royal Dutch/Shell Group. During the first quarter of 2001, it reported a 23 per cent increase in profits to US$3.86 billion and a rise of 6 per cent in sales to a massive US$47.8 billion. This amounts to a profit of ~$2 million an hour from the bowsers.

Meanwhile, Shell has increased its hostile bid for the central US gas producer, Barrett Resources, to US$60 per share. This amounts to a value for the company of approximately US$2 billion. Judging from its profit returns, it looks as though it can afford it.

BHP/Billiton Merger Goes Ahead

Meanwhile back in Melbourne, the BHP-Billiton merger took a step further to completion when shareholders voted overwhelmingly to accept the proposal.

As a result, BHP Billiton will form the world's second largest mining company with a combined market value of $57 billion. The merger will be achieved through a duel-listed structure on the Australian and London stock exchanges. The new company will have an annual revenue of about $33 billion and a profit of about $3.5 billion. The headquarters will be in Melbourne and Paul Anderson will be CEO until 2002.

On the other side of the ledger, the Billiton directors will get $143 million in share bonuses as a result of the merger.

It turns out that the new entity will be more than 60 percent foreign owned, and it remains to be seen how long the headquarters will remain in Melbourne.

Did WMC Miss Nickel Sulphide Deposit at Irwin Hills?

Redback Mining NL started drilling in April at the Irwin Hills nickel project located 100km east-southeast of Laverton in Western Australia. The area was previously explored by WMC, but according to Ross Ashton of Red Back WMC may have missed a significant nickel sulphide deposit at the site.

The target comprises a coincident ground TEM and IP anomalies, which correspond with anomalous nickel, copper and platinum/palladium surface geochemistry.

According to Ashton, the geophysical and geochemical anomalies are comparable to those developed over massive nickel sulphide deposits. The anomaly occurs within an 11km-long sequence of ultramafic lavas, forming part of a belt that includes the Windarra nickel sulphide deposits. We watch with interest.

Small Scale Processes in Geophysical Fluid Flows

By Lakshmi H. Kantha and Carol Anne Clayson

International Geophysics Series, Volume 67, Academic Press, 888 pages. ISBN 0-12-434070-9

Reviewer: Stewart Turner, Research School of Earth Sciences, Australian National University, Canberra

Most monographs and textbooks dealing with geophysical flows have concentrated on the larger scales of motion. This volume, on the contrary, gives a broad physical overview of the smaller scale processes, gathering together an impressive array of scattered material, which it is essential to understand before the larger scales can be treated adequately. In their preface the authors describe the treatment as 'elementary', but this undervalues the complexity and the detail of their presentation. Though there is not much new in the fundamentals, the treatment is appropriate for those with a background of mathematics and physics at graduate student level; fifty pages of references are provided for those who wish to follow up recent research in more detail.

The first chapter gives a clear introduction to Turbulence, leading up to a detailed discussion of various assumptions and techniques which have been used to incorporate turbulent mixing in large-scale models. The next three chapters are on the Oceanic Mixed Layer, the Atmospheric Boundary Layer, and the Surface Exchange Processes that link the two. These discussions are detailed and comprehensive, and together constitute about half the book. Observations, theories of particular processes, and numerical models are described thoroughly, with rather less discussion of laboratory experiments. The Atmospheric chapter treats stable and unstable conditions, flow over topography and over plant canopies, and cloud-topped layers. It is very helpful to have set out here the explicit contrasts between the ocean and atmosphere, and it is also shown how simple models can give fundamental understanding of significant physical processes.

Chapters 5 and 6 are on Surface Waves and Internal Waves, and again the common features and the differences are discussed. The theories of linear and finite amplitude surface waves are followed by a thorough treatment of resonant interactions and of the growth and propagation of waves generated by the wind. Wave breaking is also discussed clearly, and in each section the theoretical predictions are compared with surface and satellite observations. The internal wave chapter also concentrates on the ocean, where waves are ubiquitous, with scales that overlap with those of turbulent motions so that it is often difficult to separate the two. The 'salient characteristics' are first discussed (as they are in other chapters, but this opening overview is particularly effective here), followed by the governing equations. These lead to the discussion of small-scale waves propagating vertically along rays at an angle to the density surfaces, with and without rotation, and of trapped waves propagating along a pycnocline. Various generation, dissipation, interaction and mixing mechanisms are also discussed, in an ocean with specified density and mean velocity structures. Rapid and strong nonlinear interactions lead to an internal wave spectrum that has a universal shape and energy level in the deep ocean, as first described by Garrett and Munk in 1975, and the related observations and attempts at providing a theoretical explanation are discussed. There is also an interesting section on internal wave solutions.

I read chapter 7 on Double-Diffusive Processes in more detail than the others, since it is closest to my own research interests. These are processes that occur when two properties having different molecular diffusivities, such as heat and salt in the ocean, are distributed in such a way that they have opposing effects on the density. Hydrostatic stability alone is not enough to prevent the onset of rapid convective motions, which are easily observed but often counter-intuitive. The authors have presented good physical descriptions and discussions of ocean observations, theories and (especially in this chapter) of relevant laboratory experiments. However, my closer reading has detected a number of minor inaccuracies and several more serious editorial errors; Figure 7.1.1 is wrongly drawn, the right hand part of Figure 7.1.2 should be labelled just "diffusive convection", and Figure 7.1.10 has been rotated by 900 without comment, and its caption does not describe the case pictured.

The final chapter deals with Lakes and Reservoirs, concentrating on processes that are rather different from those in the ocean. These include the thermal bar, the formation of which depends on the fact that water has a density maximum at 4oC, and cabbeling, an instability due to the non-linearity of density as a function of temperature, especially at low temperatures. Three particular lakes are treated, evidently motivated by numerical models the authors themselves have worked on. Particularly interesting is the discussion of Lake Nyos in Cameroon, which can become density-stratified with a large concentration of dissolved carbon dioxide in the bottom layers, produced by volcanic activity and held in solution by the high pressure. In August 1986 the bottom water was lifted, resulting in a catastrophic release of pressure; an enormous volume of CO2 bubbled to the surface and flowed away from the lake down a valley, killing 1700 people.

The authors have taken great pains to make the book helpful and accessible to readers. In addition to the extensive list of references and a good index, a large array of information, such as physical constants and conversion factors, is assembled in three appendices. There is also a list of acronyms at the beginning of the book, and lists of symbols at the end of each chapter. The Foreword is by the distinguished oceanographer Walter Munk, from the Scripps Institution of Oceanography in La Jolla, California, and at the end there are about a dozen short scientific biographies of people who have contributed to the subjects covered. I can recommend this volume to anyone seeking a detailed survey of this subject and an introduction to its literature. At the price of A$269.50 (hardback edition) it will probably be bought only by libraries, but it is a worthy addition to the International Geophysical Series. (Incidentally, I note that the preceding Volume 66 entitled 'Numerical Models of Oceans and Oceanic Processes' is by the same authors, so their expertise and knowledge of this field is very broad.)