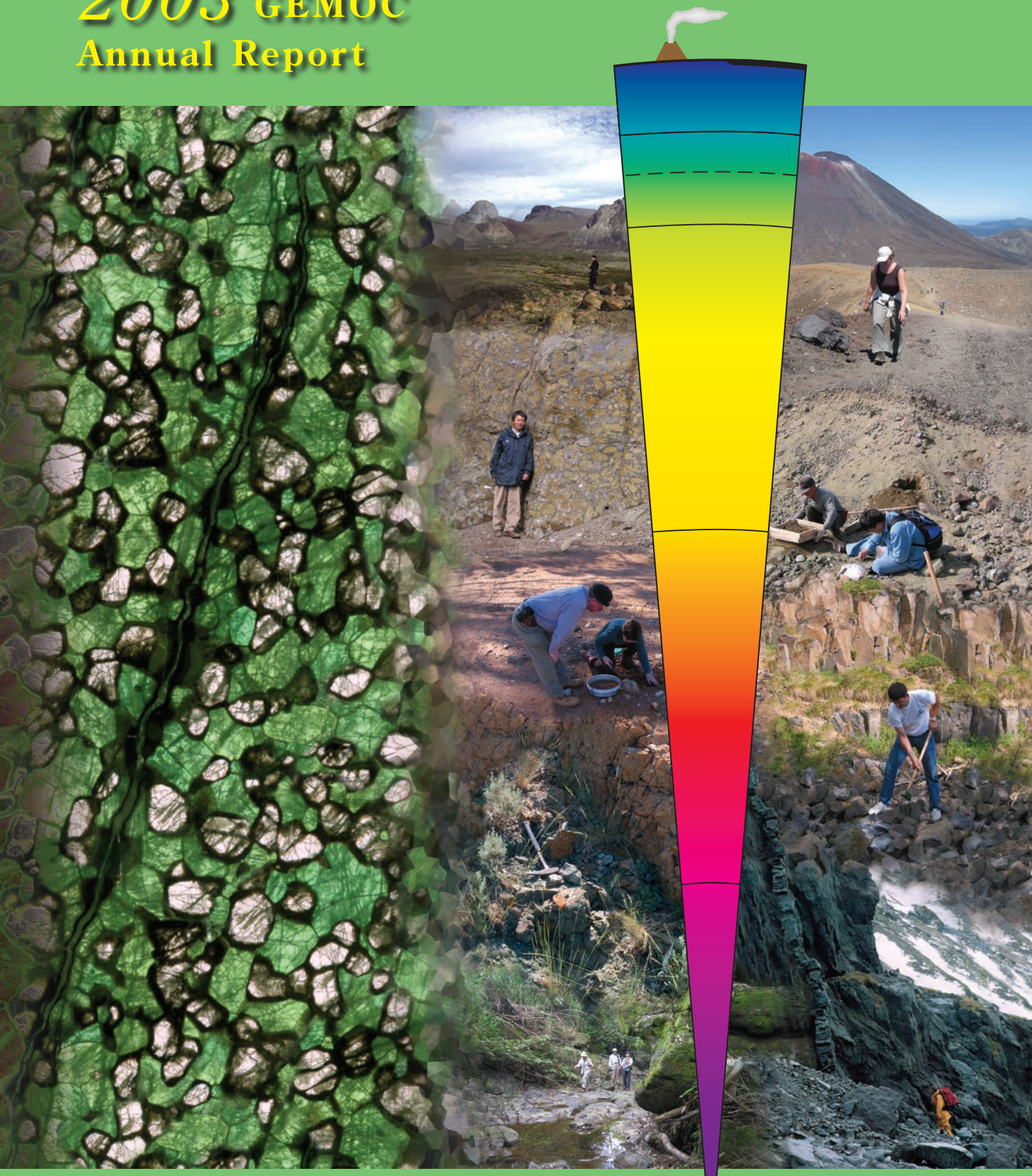
2003 GEMOC Annual Report



GEMOC

ARC National Key Centre
for the Geochemical Evolution
and Metallogeny of Continents

MACQUARIE
UNIVERSITY ~ SYDNEY

- GEMOC information is accessible on WWW at: http://www.es.mq.edu.au/GEMOC/

- Contact GEMOC via email at: gemoc@mq.edu.au

Contents

* Additional material available on web version at www.es.mq.edu.au/GEMOC/

Front Cover: This year's cover emphasises the scope of GEMOC's strategy to understand the way the Earth works: from fieldwork to geochemical analysis to technology development to geodynamic modelling – and from the micron to the global.

Established and supported under the Australian Research Council's Research Centres Program

Director's Preface

http://www.es.mq.edu.au/GEMOC/

THIS REPORT is required as part of GEMOC's formal annual accounting to the Australian Research Council. It summarises our activities for 2003 over the broad range of GEMOC activities, including research, technology development, strategic applications and industry interaction, international links and teaching (at both undergraduate and postgraduate levels). We invite you to read the sections of interest to you and would welcome your feedback.

This year we are experimenting with new ways of presenting our Annual Report. The hard copy no longer contains our complete report. The full version is available on our website (www.es.mq.edu.au/GEMOC/) by following the links to the 2003 Annual Report, which can be read online or downloaded as a pdf file. Sections that are only available electronically are highlighted in the Table of Contents and through the text. We enclose a survey to gauge your reaction to different presentation formats, and you can also email your opinion from the website.

As reported last year, GEMOC became self-supporting in 2002 (Commonwealth Key Centre funding for the 1995 round of Key Centres was limited to six years, with no extensions). Our funding now comes from a broad range of sources including the Australian Research Council schemes, industry collaborative projects, delivery of novel exploration methodologies and value-added products to industry, strategic partnerships with technology manufacturers, non-ARC government sources, and international links and alliances that provide reciprocal resources. A $5 million DEST Systemic Infrastructure grant (2002-2004) is allowing GEMOC to maintain its technological edge and develop new analytical applications in geochemistry.

A highlight of 2003 was the construction (to be completed early 2004) of high-quality serviced spaces to house instruments purchased under the DEST Systemic Infrastructure grant and to provide ultra-clean geochemical facilities; these include infrastructure for the development of the U-Series facility by Simon Turner and co-workers. This work will double the original laboratory space and, with the new instrumentation, will provide a unique national resource in integrated geochemical analysis. Large building projects always provide interesting scenarios both logistically and financially and the support of Macquarie University and especially of the Vice-Chancellor have been outstanding. The management talents and construction knowledge of Peter Squibb (from Macquarie Buildings and Grounds) have solved many problems.

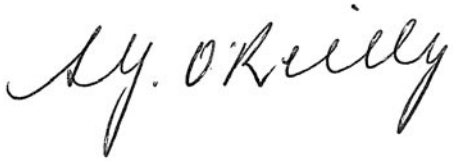
Research highlights for 2003 include the broadening of our programs beyond the original goals of understanding the lithosphere and the role of the lithospheric mantle in lithosphere evolution and metallogenesis. This has taken our research both deeper into the Earth, to address geodynamic processes below the lithosphere, and up into the crustal regime. Both of these directions have synergies with industry collaborative projects, illustrating GEMOC's philosophy of addressing fundamental "big questions" through basic research with parallel strategic and applied goals and with support from relevant technology development.

In addition, new ways of measuring the timing and rates of geological processes have provided more exciting possibilities. The maturing of the application of the Re-Os system for dating important mantle events (including lithosphere stabilisation times) using *in situ* analyses of tiny mantle sulfide grains now provides a method, currently unique to GEMOC, for understanding the timing of mantle processes. The *TerraneChron*™ methodology (see *Research Highlights*) is allowing us to track large-scale crustal tectonism, test styles of crust-mantle linkage and probe the nature and formation age of the hidden lower crust. The processes and time scales of magma formation, transport and differentiation beneath western Pacific island arc volcanoes, and the time scales and relative roles of physical and chemical erosion in Australian river basins are being evaluated with U-series methodologies.

GEMOC's wide-ranging contributions to national and international conferences and workshops by many staff and postgraduate students again emphasise our continuing multifaceted approaches to understanding the way the Earth works.

GEMOC continues to be strongly supported by the Vice-Chancellor and the Executive at Macquarie.

We look forward to another year of exciting new advances.



Introducing GEMOC




"[GEMOC] funding, like a good investment portfolio has a healthy diversity ... across competitive traditional schemes, ... to substantial industry collaborative projects, provision of value-added products to the mineral exploration industry and one-off opportunities such as the DEST Systemic Infrastructure Intitiative"

GEMOC'S STRATEGIC FOCUS

THE MAIN TARGETS of GEMOC's founding activities were defined to be large-scale problems related to lithosphere evolution and understanding the relevance of different types of crust-mantle domains to area selection for mineral exploration. These have broadened during 2003 to involve whole-mantle perspectives of geodynamics, and far-field and feedback effects involving the lithosphere.

Despite the coincidence of GEMOC's term with a time of increasingly contracting activities in the mineral exploration climate, our industry interaction has steadily increased and now forms a significant part of the ongoing funding. Our industry interaction is largely based in strong collaboration; interchange of concepts and discussions on GEMOC strategies relevant to industry needs is invaluable in maintaining our focus on industry relevance.

The increasing industry collaboration with funded projects related to lithosphere evolution and crustal generation studies has fulfilled one of our major strategic goals of delivering new tools and a new framework of terrane analysis to the minerals exploration industry. Some of these new tools and concepts are summarised in the *Research Highlights*, and the *Technology Development* section.

GEMOC's Context

A SHORT HISTORY OF GEMOC: The National Key Centre for the Geochemical Evolution and Metallogeny of Continents (GEMOC) formally commenced in January 1996 and was funded under the ARC Key Centre scheme for 6 years. Under the government regulations for this round of Key Centres, there was no provision for extension of Centre funding beyond the original six-year term. A detailed business plan was required in the application to demonstrate how the Centre could continue and maintain its identity after the Commonwealth funding term. This business plan has succeeded and the evolved GEMOC started its new phase in 2002 with an independent well-funded base for the next five years.

GEMOC'S FUNDING BASE FROM 2002: This funding, like a good investment portfolio, has a healthy, risk-minimising diversity ranging across competitive traditional schemes such as those available from the Australian Research Council, to substantial industry collaborative projects, provision of value-added products to the mineral exploration industry (see the section on *Industry Interaction*) and one-off opportunities such as the competitive DEST Systemic Infrastructure Initiative in 2002 that granted over $5 million to enable GEMOC's Technology Development Program to stay at the forefront (see the section on *Technology Development*).

GEMOC'S LINKAGES AND ALLIANCES: GEMOC was initially based on the pre-1995 collective profiles of the core participants at Macquarie and the networked group at ANU (Faculties), with collaborative links to CSIRO, AGSO (now Geoscience Australia (GA)) and colleagues at other Australian universities. GEMOC has significantly evolved and expanded from its original base with shifts in the original linkages. Interaction with CSIRO and GA has grown and transformed over the six years. Strong new national and international collaborative research links and programs have emerged and robust ongoing engagement with industry (mineral exploration and technology manufacturing) partners through collaborative projects has fulfilled one of GEMOC's original goals.

Mission

- **to create a new paradigm for the formation of metallogenic provinces by undertaking fundamental research on the evolution of the upper 200 km of the Earth's crust-mantle system, integrating petrological, geochemical and geophysical information**
- **to give the Australian minerals exploration industry a competitive edge into the 21st century by transferring this new knowledge base and the methodologies to the industry and to the next generation of students**

This Mission Statement is being revised to reflect the evolution of GEMOC's activities to consider Earth Geodynamics beyond the Lithosphere.

SCIENTIFIC PHILOSOPHY

GEMOC's distinctiveness lies in its interdisciplinary and integrated approach to interpreting Earth's lithosphere as a 4-dimensional dynamic system (in space and time).

This approach links...

petrology & geochemistry ~ geophysics ~ petrophysics ~ tectonics ~ numerical modelling

within the important contexts of...

time (the 4th dimension) and thermal state

to understand the significance of large-scale mantle and crustal domains and the processes that have formed and modified them.

The front cover for this 2003 Report emphasises this integration from field to laboratory to the global scale of our lithosphere studies as well as the interface with geophysical datasets. The present-day timeslice of the seismic character of the deep Earth cannot give us the time perspective to unravel over 4 billion years of Earth's evolution. However, this is provided by the petrological samples of the mantle delivered to the Earth's surface at different (and measurable) times by tectonism or magmatism.

Parallel advances in the integration of geophysical and geochemical information to model and image the lithosphere and its properties continue to be driven by our desire to solve more of the intriguing questions about how the Earth has evolved, especially now that we have developed many novel geochemical tools to date important events in the mantle and crust and have made so many fundamental new discoveries about the life and times of lithospheres (see *Research Highlights* and *Technology Development* sections). These advances mesh with end-user needs and the knowledge required to solve major geological problems.

"GEMOC's founding activities ... have broadened during 2003 to involve whole-mantle perspectives of geodynamics and far-field and feedback effects involving the lithosphere."

GEMOC Board meeting 2003 (details available at www.es.mq.edu.au/GEMOC/).

STRATEGIC OUTCOMES

These were the founding strategic aims in 1995 and are still serving GEMOC well even though there has been much evolution in our understanding and much development of novel methodologies to address these aims.

- **fundamental insights into the processes that create and modify the continental mantle and crust through time**
- **a better understanding of the assembly of the Australian continent and its geological architecture to 100-200 km depth through work in Australia and global analogues**
- **results and concepts exportable to other terrains, including Southeast Asia and other potentially resource-rich areas of interest to Australian exploration companies**
- **a new conceptual framework for understanding the localisation of economic deposits, that will influence exploration strategies for world-class ore deposits, and improve the competitiveness of the Australian exploration industry both on- and off-shore**
- **a realistic 3-D geological framework for the interpretation of lithospheric-scale geophysical datasets**
- **a training program for senior undergraduate and postgraduate students (and continuing education) that will help maintain the technological edge of the Australian mineral industry and improve the industry's ability to rapidly assimilate new concepts and methodologies**
- **new analytical strategies for determining the chemical and isotopic compositions of geological materials (including fluids)**
- **development of *in situ* analytical methods (including dating) to maximise information encoded in mineral zoning and to enhance interpretation of data using spatial contexts**
- **strategic and collaborative alliances with technology manufacturers in design and application innovation**

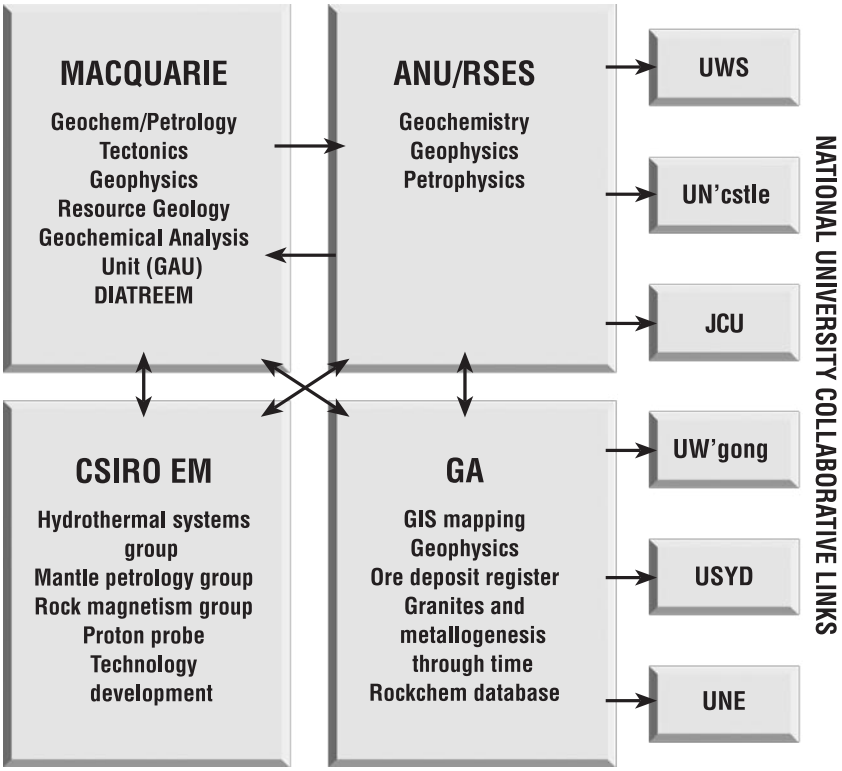
This report documents achievements of these goals

GEMOC participants

THE HOST INSTITUTION for GEMOC is Macquarie University (in the Department of Earth and Planetary Sciences).

There is a close collaboration with CSIRO Exploration and Mining (EM) (North Ryde) and GA (Geoscience Australia) across an increasingly broad range of projects.

Collaborative research, teaching and technology development links have been

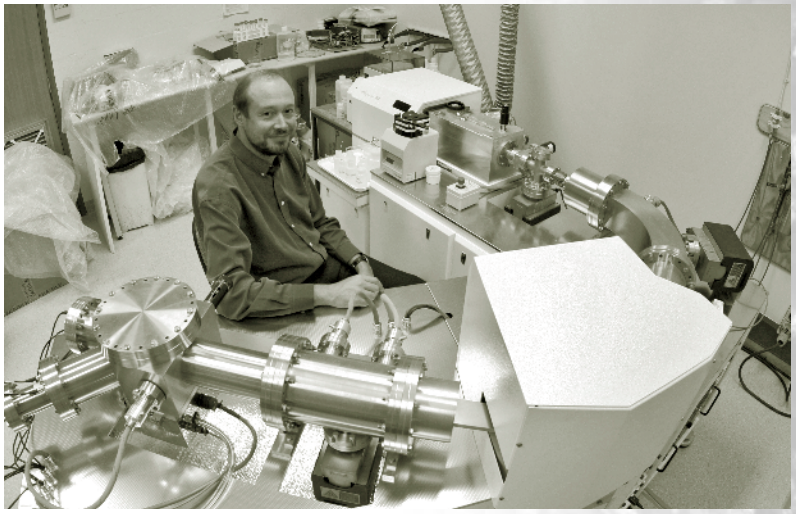


established with other universities nationally and internationally and these evolve as new alliances become relevant to new directions.

GEMOC has developed ongoing collaborative relationships with national and international industry and end-users such as Geological Surveys globally (eg Australian states, Canada, Norway).

GEMOC has a wide network of international research and teaching development partners and collaborators.

A full list of GEMOC participants and their affiliations is given in Appendices 1 and 3 at www.es.mq.edu.au/GEMOC/



Professor Simon Turner

CHANGES IN 2003

Dr Elena Belousova commenced an ARC Postdoctoral Fellowship, and **Dr Vladimir Malkovets** commenced his Macquarie University Research Fellowship (MURF).

Professor Simon Turner commenced a Federation Fellowship. He is setting up

Full details of GEMOC's Participants and Structure are at www.es.mq.edu.au/GEMOC/

a new laboratory and instrument facility to explore new frontiers related to time scales and rates of change that are fundamental to understanding natural processes and the development and testing of quantitative physical models in the Earth Sciences. Uranium decay-series isotope studies are revolutionising this field by providing time information in the range 100 -100,000 years, similar to that of many important Earth processes (see *Research Highlights*). This work will be relevant to eruption cycles of volcanoes, the Earth's carbon cycle, time scales and relative roles of physical and chemical erosion in Australian river basins as well as other environmentally important systems and processes.

Three other experienced geochemists, **Dr John Ketchum** (from the Royal Ontario Museum Geochronology Laboratory, Canada), **Dr Rhiannon George** (from Bristol University) and **Dr Kirsty Tomlinson** (with experience from the Canadian Geological Survey) also joined GEMOC in 2003 to enhance the geochemical expertise available and to assist in industry collaborative projects.

Dr Nathan Daczko was appointed to the academic staff of the Department of Earth and Planetary Sciences and is an active member of GEMOC. His expertise includes structural and metamorphic geology and geodynamics. Since his PhD at the University of Sydney, he spent 2 years as a postdoctoral Research Fellow at the Department of Geological Sciences and Institute for Geophysics, Jackson School of Geosciences, University of Texas (Austin) where he studied the geodynamic setting of the Australian Plate Margin using integration of petrologic, structural and geophysical datasets (see *Research Highlights*).

Dr Nathan Daczko camping at Lake Grave, Fiordland National Park, New Zealand - sandflies love the place (geologists think it is OK too).

GEMOC structure

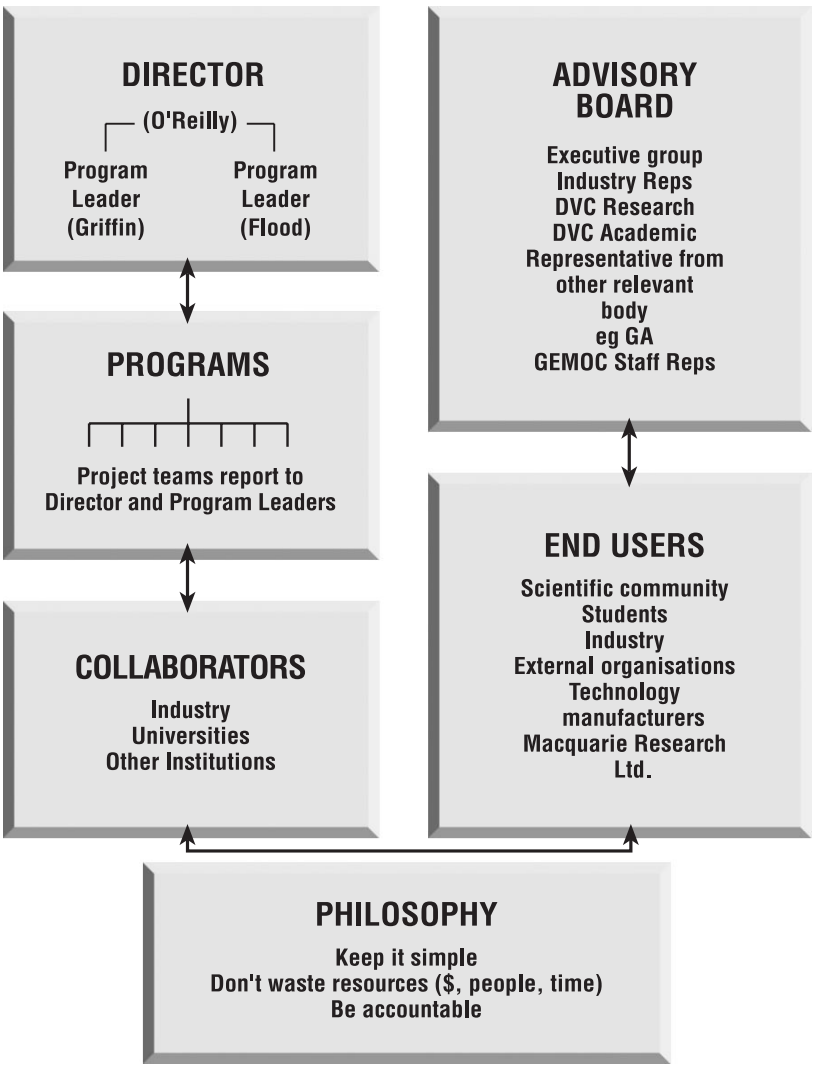
THE ORGANISATIONAL STRUCTURE of GEMOC is designed for efficiency, flexibility, and interaction. The financial management operates within Macquarie University's Finance System and within Macquarie Research Limited for commercialised products, consulting and some strategic collaborative research projects. The Teaching Program is incorporated into the teaching activities and strategies of the Department of Earth and Planetary Sciences at Macquarie to ensure that GEMOC interfaces in a positive way with the existing structures while retaining a clear identity and funding unit.

GEMOC has been reconfirmed as a Centre of Excellence and research concentration within Macquarie University, and three designated Areas of Excellence within Macquarie University's Research and Research Teaching Management Plan lie within GEMOC:

- lithosphere and planetary evolution and metallogeny
- isotopic and global geochemistry
- paleomagnetism, geodynamics and geophysical modelling

All of these align with GEMOC's mainstream foci. This University recognition allows for ongoing appropriate staffing and support arrangements.

MANAGEMENT STRUCTURE



2003 MANAGEMENT ROLES

Professor Suzanne O'Reilly is Director of GEMOC.

Ms Leigh Newton is GEMOC Administrator.

Dr Richard Flood is the coordinator of Teaching Programs at Macquarie and Head of the Department of Earth and Planetary Sciences from December 1999 (re-elected in 2002).

Professor William Griffin is seconded (80%) to GEMOC (through Macquarie University) from CSIRO in 2003. He is Adjunct Professor at Macquarie University and is the Program Leader responsible for Technology Development and Industry Interaction.

Simon Shee, Jon Hronsky, Lesley Wyborn (guest) and Sue O'Reilly at the 2003 GEMOC Advisory Board meeting.

Professor Simon Turner leads the development of the U-Series Geochemical Program.

Dr Norman Pearson is Manager of the Geochemical Analysis Unit at Macquarie.

Dr Kelsie Dadd is responsible for implementation of GIS-based teaching methodology in the Teaching Program and for promotional activities to attract students.

Dr Simon Jackson assists with ICPMS and laser microprobe development at Macquarie.

Ms Sally-Ann Hodgekiss is the GEMOC graphics and design consultant at Macquarie.

ADVISORY BOARD MEMBERS 2003

Changes were made to the Advisory Board in December 2002 to commence in 2003.

Professor Suzanne O'Reilly (Director) - *EPS Macquarie*

Professor William Griffin (Program Leader: Technology Development) - *EPS Macquarie*

Dr Richard Flood (Program Leader: Teaching) - *EPS Macquarie*

Professor Jim Piper – Deputy Vice-Chancellor (Research), *Macquarie*

Professor John Loxton – Deputy Vice-Chancellor (Academic), *Macquarie*

Dr Kelsie Dadd – *GEMOC, EPS Macquarie*

Adjunct Professor Michael Etheridge – Leader, Risk Assessment Group, interfaces with GEMOC's Tectonic Research program and the Predictive Mineral CRC, links with the Exploration Industry and Management Roles, *EPS Macquarie*

Dr Russell Korsch – *representative of Geoscience Australia (GA)*

Dr Richard Glen – *representative of Geological Survey of New South Wales*

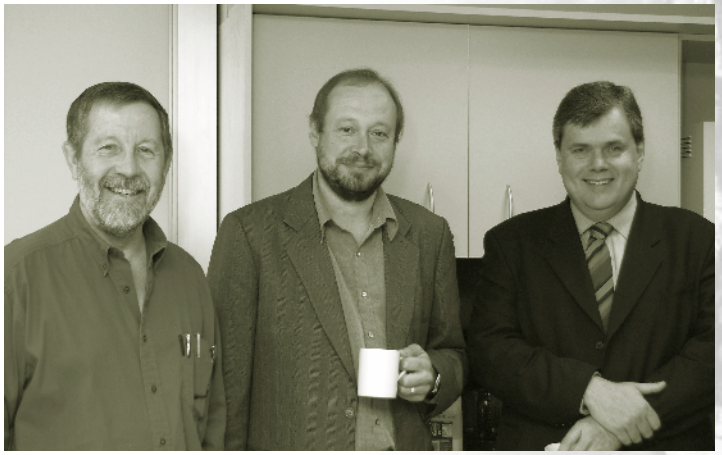
Dr Paul Heitherseay – *representative of PIRSA*

Dr Jon Hronsky – *industry member WMC (Perth)*

Dr Steve Walters – *industry member GeoDiscovery*

Dr Simon Shee – *industry member DeBeers Australia Exploration Ltd*

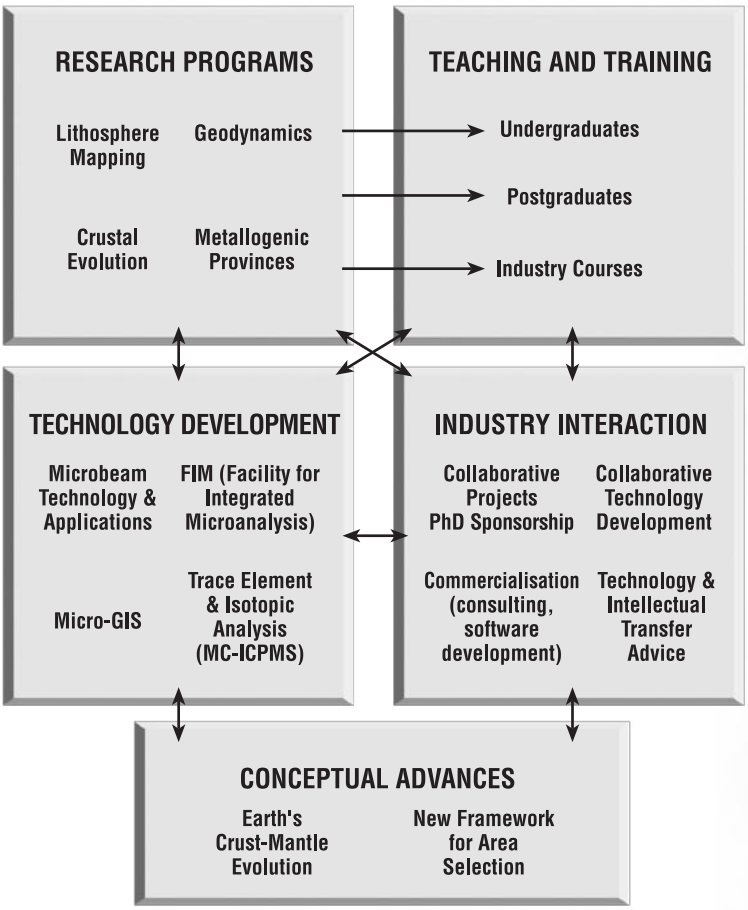
Dr Terry Mernagh – *from GA was invited as an observer to the 2003 Board meeting.*



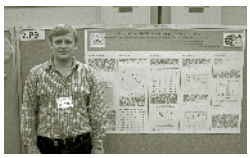
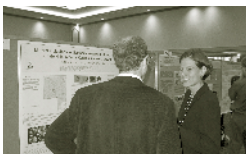
Bill Griffin, Simon Turner and Paul Heitherseay at the 2003 GEMOC Advisory Board meeting.

GEMOC programs

GEMOC'S PROGRAMS were set up to be interactive. Basic research strands are supported by parallel applied collaborative research with industry partners: these provide the impetus for technology development. This is, in turn, supported by strategic alliances with front-line instrument designers and manufacturers (eg Nu Instruments, Agilent, New Wave Research). Teaching and training benefit directly from these new advances. Technology development has been transferred to relevant end-users, applied in postgraduate research programs, and is the essential core that provides the data underpinning the conceptual advances about lithosphere architecture and evolution in GEMOC.



GEMOC communications 2003


GEMOC information, continually updated, is accessible at: www.es.mq.edu.au/GEMOC/

GEMOC WEB RESOURCES include details of this 2003 Annual Report, past Annual Reports, updated details on methods for new analytical advances and software updates (GLITTER), synthesised summaries of selected research outcomes (eg studies of eastern China lithosphere) and items for secondary school resources on the lithosphere and on diamond occurrence. In addition, undergraduate teaching is web-based.

AWARDS

Dr Nathan Daczko was awarded the inaugural Chris Powell Medal by the Structural Geology Specialist Group of the Geological Society of Australia.

Nathan Daczko being presented the inaugural Chris Powell Medal by Prof. Peter Cawood.

Professor Bill Griffin was Logan Club Distinguished Lecturer, Geological Survey of Canada in February 2003 with the title "Continental Roots: their life and times" and also gave the Keynote address at the Lithoprobe Workshop in Canada in February 2003.

Professor Bill Griffin was elected to the Royal Norwegian Society of Sciences and Letters in 2003. He has been a Fellow of the Norwegian Academy of Science and Letters for nearly 20 years.

GEMOC Director, Professor Sue O'Reilly was inducted into the Australian Academy of Science in May 2003 and gave a presentation "Journey to the Centre of the Earth". She was also awarded the position of visiting "Director of Research" by CNRS (France) and took this up as a 3 month research visit to the University Jean Monnet, St Etienne.

GEMOC was a Chief Investigator on a funded ARC Network Seeding Grant to foster further national networking (led by ANU, RSES).

PARTICIPATION IN WORKSHOPS AND CONFERENCES IN 2003

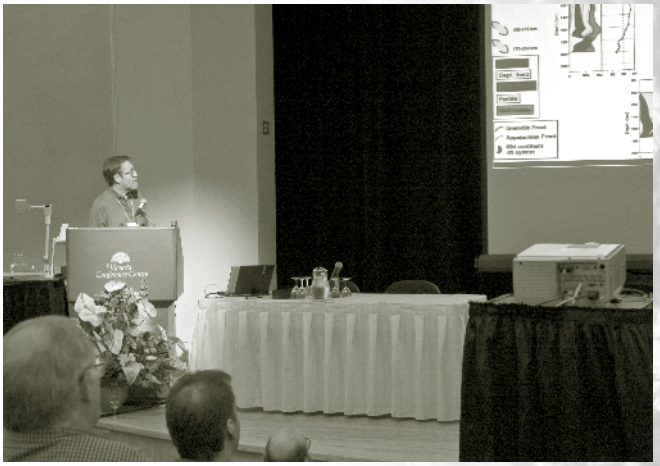
GEMOC staff and postgraduates were again convenors or invited speakers or presenters at peak geodynamic and geochemical conferences with over 30 presentations. International fora included: the West Norway Eclogite Field Symposium, the 8th International Kimberlite Conference, the 3rd State of the Arc Conference, the 13th V. M. Goldschmidt Conference, the 5th Hutton Symposium and the American Geophysical Union Fall Meeting. Sonja Aulbach, Sonal Rege and Stuart Graham received full travel grants from the Organising Committee to present papers at the 2003 8th International Kimberlite Conference in Vancouver in June. A full list of abstract titles for Conferences and Workshops attended is given in *Appendix 4* and on the GEMOC website where full-text versions of most of the abstracts can also be found.

A major achievement in 2003 was the successful bid by Australia to host the 2006 International Goldschmidt Conference, led by Professor Simon Turner.

The International Workshop and Symposium "Granites and Associated Metallogenesis" was held at Macquarie in July 2003, organised by Professor Bruce Chappell (see p 58 for more details).

Professor Simon Turner was a co-presenter, co-author and co-editor of the volume for the Mineralogical Society of America Short Course on Uranium Series Geochemistry.

The recognition of GEMOC's expertise in linking the micron with the global is evidenced by the co-convening by Sue O'Reilly of the session "Composition, Processes and Structure of the Mantle" for the 2003 Goldschmidt Conference in Japan and her co-editing of a Lithos issue (to be published in 2004) recording results from the session "Trace-element fingerprinting: laboratory studies and petrogenetic processes" which she co-convened for the 2002 Goldschmidt Conference.



Bill Griffin explains the SCLM to the masses at the 8th IKC.

Bill Griffin and Sue O'Reilly were appointed by the IUGG (International Union of Geology and Geodesy) to be co-convenors for a Special Session "Geophysical and geochemical imaging and modelling of continental roots and beyond: implications for the formation and evolution of continents" at the International Geological Conference in Florence in 2004.

SERVICE ROLES

In addition to another year on the Physics, Chemistry and Geosciences ARC Expert Advisory Committee, Professor Sue O'Reilly was also a member of the Academy of Science National Committee for Earth Sciences that prepared the *National Strategic Plan for the Geosciences in Australia*.

GEMOC participants are well-represented on editorial boards of international journals, on international expert panels for research evaluation (Canada, Sweden, UK) and on Boards of Geoscience Department and Centres nationally and internationally.

Dr Kuo-Lung Wang and Professor Xisheng Xu at the 2003 Goldschmidt conference, Japan.

VISITORS

GEMOC fosters links nationally and internationally through visits of collaborators to undertake defined short-term projects or short-term visits to give lectures and seminar sessions. Formal collaborative arrangements are facilitated by ARC Linkage grants with reciprocal funding from international collaborators.

Australian and international visitors are listed in *Appendix 3*.
They have participated in:

collaborative research, technology exchange, seminars, discussions and joint publications, collaboration in postgraduate programs.

Is GEMOC making a difference?

"[GEMOC has changed] the mineral exploration paradigm by delivering new concepts for exploration globally and in Australia"

Highlights of research program outcomes:

- Unique methodology for geochemical imaging of the lithosphere (4-D Lithosphere Mapping) developed to maturity and now being extended to whole-mantle perspectives
- New understanding of lithosphere formation mechanisms and changes through time (eg see *"The Deviant Archean" Research Highlight*)
- Unique methodologies developed for dating and fingerprinting regional crust and mantle events to test mantle-crust coupling through Earth's history - also a key to new exploration methods (see *Research Highlights*)
- Integration of petrological, geochemical and tectonic syntheses with geophysical data is revealing a unique image of the deep Earth (see *Research Highlights 2002*). This is emphasised by this year's cover image showing the sweep from fieldwork to laboratory geochemical and technological applications to interpretation of deep Earth architecture and composition.

Highlights of technology development outcomes:

- Focus on *in situ* analysis of important elements to parts per billion
- Unique method (*in situ* Re-Os) to date mantle events
- Unique method to track crustal histories (U-Pb dating and Lu-Hf and trace-element fingerprinting of zircons, rutiles): ***TerraneChron***™
- Delivery of rapid, cost-effective and user-friendly new methodologies and software in geochemical analysis
- Establishing the rates of geological processes both for the deep Earth and for surface processes using Uranium decay series dating

Highlights of teaching outcomes:

- Industry-standard training with development of new degree programs (eg Exploration Geoscience, Environmental Geoscience, Marine Geoscience)
- Hands-on undergraduate training in use of state-of-the-art techniques (GIS databases, imaging, geochemical techniques, geophysical measurements) with industry-standard instrumentation
- Vigorous postgraduate group with active international postgraduate exchange programs: (eg Nanjing University, University Jean-Monnet (St Etienne), University of Clermont-Ferrand, University of Oslo, University of Siena, Université Paris 7)
- Short-course programs for end-user information and technology exchange

Highlights of industry interaction outcomes:

- Changing the mineral exploration paradigm by delivering new concepts for exploration globally and in Australia derived from basic research and technology development
- Development of active partnerships in strategic and applied research with industry (exploration companies and technology manufacturers)
- Development of value-added consultancies and collaborative research programs using GEMOC's geochemical technologies and database

Other sections of this report provide the details of performance indicators and GEMOC's visibility

GEMOC's research program

SCIENTIFIC CONTEXT

THERMAL ENERGY transmitted through the mantle provides the energy to drive lithosphere processes. Mantle-derived fluids and the tectonic environment control element transfer across the crust-mantle boundary and control commodity distribution in the accessible crust. The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface. The Earth's interior can be mapped for rock types and their relationships using fragments of deep materials such as mantle rocks and diamonds, and the compositions of mantle-derived magmas.

The focus of GEMOC's research programs is the driving role of the mantle in Earth processes and its control of element concentration and distribution in the accessible crust. This bottom-up approach involves:

- Understanding the location of different types of metallogenic provinces by defining the links between:
  - mantle evolution, type and processes
  - crustal generation
  - large-scale tectonics
  - heat, fluid and element transport
- Integration of information across disciplines, especially petrology, geochemistry, geodynamics, geophysics and tectonics

The research aims

- **to understand from the "bottom-up" the processes that control the generation and modification of the crust-mantle system and to define the tectonic and geochemical processes that have created different crustal and mantle domains through time**
- **to map the spatial and temporal distribution of elements, rock types and physical and chemical conditions within this system**
- **to define the systematics of element redistribution in the mantle and crust during the critical liquid-crystal and vapour-liquid separation events**
- **to advance the modelling of the crust and lithospheric mantle from geophysical datasets, through integration of geophysical, petrological and geochemical information**
- **to produce and interpret maps of lithosphere thickness and lithospheric mantle type at the present day and for selected time (and location) slices through Earth's geological evolution**
- **to produce and interpret chemical tomography sections of lithospheric mantle in time and space where global datasets can be constructed**
- **to provide a new framework for area selection for a wide spectrum of economic deposits, by linking these models and processes to the formation of metallogenic provinces**
- **to develop collaborative links with international institutions and researchers relevant to GEMOC's goals**
- **to define the timing of events and processes in the crust and mantle to understand crust-mantle linkages**

"The focus of GEMOC's research programs is the driving role of the mantle in Earth processes and its control of element concentration and distribution in the accessible crust."

RESEARCH PROGRAM

The *Research Highlights* section gives an overview of major progress in 2003.

The Research Program for 2004 follows the topics of the funded projects listed in *Appendix 5*. Summaries of funded basic research projects are listed below and some of the collaborative industry research projects are summarised in the section on *Industry Interaction*.

The research program for the first six years focused on four strands: the current Research Program is pushing into new conceptual and technology frontiers, building on our intellectual capital from the first phase of GEMOC. *Additional details on the Research Programs are given at www.es.mq.edu.au/GEMOC/*

> "the current Research Program is pushing into new conceptual and technology frontiers, building on our intellectual capital from the first phase of GEMOC"

• Lithosphere Mapping

provides the fundamental data for defining mantle domains in terms of composition, structure and thermal state. Lithosphere profiles built up by this information are interpreted in the context of geophysical datsets (especially seismic tomography) to extrapolate laterally. Relating lithospheric domains to refined models of tectonic evolution will help to define the large-scale evolution of mantle processes through time, and their influence on the development of the crust and metallogenic provinces. The nature of mantle fluids and the mantle residence and abundances of siderophile, chalcophile and noble elements, sulfur, carbon, oxygen and nitrogen and timescales of magmatic processes are keys to understanding the transfer of mineralising elements into the crust.

• Geodynamics

uses stratigraphic, tectonic, and geophysical data to interpret the history and causes of continental assembly and disruption, with a special focus on Australia, East Asia and major cratons (Siberia, Africa, Canada, South America, India). It provides the fundamental framework to link the research on crustal and mantle processes with the localisation and development of metallogenic provinces.

• Crustal Generation Processes

seeks to understand the large-scale processes that have created and modified continental crust, how these processes may have changed through time, and how crustal processes influence the concentration and localisation of economically important elements. The role of crust-mantle interaction in granite genesis, coupled crust-mantle formation and its influence on tectonism, and transport of elements across the crust-mantle boundary link to the Lithosphere Mapping and Metallogenesis strands.

• Metallogenic Provinces

seeks to define the mantle and crustal reservoirs of economically important elements, the mechanisms by which elements can be extracted from the mantle and transported into the crust, and the mechanisms of fluid transfer in the crust and mantle. The emphasis is on understanding processes of regional scale, and relating these processes to the tectonic framework and the processes of mantle and crustal generation.

STRENGTHENING GEOPHYSICS

A major strategic goal of GEMOC is strengthening geophysics and bridging the geology/geophysics interface. During 2003 the following activities addressed this goal.

- Ms Tara Deen continued a Research Fellowship in geodynamic modelling at Macquarie University. This strengthens connections with Dr Dietmar Muller and Dr Patrice Rey at the University of Sydney.
- The strategic alliance with Dr Karsten Gohl of the Alfred Wegener Institute, Bremerhaven proceeded as planned on the mutually funded project collaboration "Structure and dynamics of a submarine continent: evolution of the Campbell Plateau", involving research cruises by the vessel RV Sonne that commenced in January 2003. Tara Deen was the GEMOC representative on the cruise and GEMOC will be involved in interpretation of mantle structure and composition and basalt geochemistry and origin with German colleagues. Dr Karsten Gohl made arrangements to spend 3 months at Macquarie in 2004 to advance this project.
- GEMOC had continuing access to the pool of seismic detectors, which formed part of the ARC Seismic Consortium (headed by the University of Adelaide/ Flinders University with Macquarie, Monash, Sydney, Queensland and ANU as partners and with strong support from GA) and which are now located in the ANSIR facility.
- Dr Yvette Poudjom Djomani, GEMOC Postdoctoral Fellow, continued her work in potential field geophysics (including gravity, magnetic and thermal modelling) in collaborative projects including the SPIRT project on Australian lithosphere studies with WMC. She will also be involved in the new ARC Linkage Project with WMC (Global Lithosphere Architecture Mapping) funded for 2004-2006.
- Collaboration with Professor Paul Morgan (Northern Arizona University, Flagstaff) continued in geophysical modelling.
- The published interpretation and documentation of the results of Global Geoscience Transect 21 (from the Philippine Sea to the Barents Sea) with the Geological Survey of China and the Institute for Gravity, Xi'an continued through 2003.
- Major advances were again made in understanding the interpretation of geophysical signatures of some types of large-scale lithosphere domains (eg Publications #322, 348 and presentations at conferences (see *Appendix 4*)).
- Professor Bill Griffin was invited as Keynote Speaker for the Copenhagen Symposium in February 2004 on Seismic Heterogeneity in the Earth's Mantle: Thermo-Petrologic and Tectonic Implications – with the title "Imaging petrological and thermal heterogeneity in the lithospheric mantle: implications for interpretation of geophysical data."
- Investigation of the paleomagnetism and rock magnetism of rocks from the Lachlan Fold Belt continued.
- Modelling of the density of different types and compositions of lithospheric mantle to assess mechanisms of mantle overturn and thinning in regions of

Part of the GEMOC/ WMC GLAM (Global Lithosphere Architecture Mapping) team.

different age, thermal structure and tectonic environment continued (eg Publication #303).

- Investigation of the Mooki and Peel Faults, and the Tamworth Belt using gravimetry continued (postgraduate project by Bin Guo).
- Investigation of the 3D shape of a stitching pluton in the New England Fold Belt was undertaken by Mark Lackie.
- Seismic studies of the Amery Ice Shelf in Antarctica continued in collaboration with Associate Professor Richard Coleman of the University of Tasmania.
- SPIRT funding continued on the project with WMC on recognition of lithospheric domains in Australia and integration with thermal and magnetic signatures and datasets: this work was also extended to southern Africa.
- A new ARC Linkage Project with WMC (Global Lithosphere Architecture Mapping) was funded for 2004-2006 and will extend integration of geophysics, geochemistry and geodynamics to interpretation of global tomography datasets.

RESEARCH PROJECTS FEEDING MAJOR PROGRAMS

Lithosphere Mapping

Geochemical structure and evolution of continental lithosphere and interpretation of geophysical data Research Highlights

U-series applications to timescales of lithosphere processes Research Highlights

Mantle terranes and cratonic roots: Canada, USA, southern Africa, Siberia, eastern China, Australia, Brazil, India Research Highlights

Gravity modelling of lithosphere terranes (regional elastic thickness)

Evolution of oceanic lithosphere: Kerguelen Plateau, Hawaii, Crozet Islands Research Highlights

Diamonds: origin and clues to lithosphere evolution and structure; Canada, Siberia, South Africa

Seismic imaging of Moho structure and integration with petrological data: Indian Ocean, Kerguelen Plateau

Basalts as lithosphere/asthenosphere probes

Thermal framework of the lithosphere: paleogeotherms, heat production, conductivity, thermal evolution

Experimental studies of mantle minerals: high pressure partition coefficients; role of accessory minerals in controlling mantle fluid compositions

Lithosphere extension processes and consequences in East Asia: Taiwan and eastern China regions Research Highlights

Constraints on the timing of depletion and fluid movements in lithospheric mantle of different ages, using a range of isotopic and trace-element methods, including Re-Os in mantle sulfides Research Highlights

The nature of lithospheric mantle in arc regions (Japan, Kamchatka, Philippines, Solomon Islands)

Tracking mantle plumes through time

Metal isotopes as tracers of lithosphere processes and Earth evolution

Crustal Evolution

Role of oceanic plateaus in oceanic and continental crustal formation: Kerguelen

Crustal evolution and metallogenesis, southeastern China

Evolution of continental crust: central Queensland; San Francisco Volcanic Field, Arizona; Peninsular Ranges batholith of Baja California, Mexico Research Highlights

Origin of granites and crustal genesis at continental margins: eastern Australia, southeastern China Research Highlights

Metamorphic reactions and mineral growth; microstructural processes in metamorphic rocks

Tracers of magmatic processes; trace elements in accessory minerals

Integrated U-Pb, Hf-isotope and trace-element *in situ* analysis of detrital zircons to characterise the magmatic history of major crustal terrains ("Event Signatures"): applications of *TerraneChron*™, South America, South Africa, Australia, India Research Highlights

Timescales of magmatic and erosional processes (U-series applications)

Hf-isotopic signatures of zircons (*in situ* LAM-ICPMS) as tracers of crust-mantle interaction in granites Research Highlights

Metallogenesis

Risk management in exploration

U-series applications to timescales of fluid movement

Metal isotope applications to ore genesis

Geochemistry of mantle sulfides Research Highlights

Chromite chemistry in mantle-derived magmas and residues

Resistate minerals and mineral exploration Research Highlights

Area selection and evaluation for diamond exploration

Lithosphere domains through time and location of ore deposits

Crust-mantle interaction, granites and metallogenesis through time Research Highlights

Sulfide and PGE budget of the mantle Research Highlights

Re-Os dating of mantle sulfides *in situ* and timing of mantle processes Research Highlights

Highly siderophile element (including platinum group element) concentrations in sulfides (LAM-ICPMS) Research Highlights

Zircon composition in mineral exploration Research Highlights

Groundwater geochemistry and aquifer lithology

Stable-isotope ratios of some important commodity elements (eg Cu, Fe, Zn, Mo) in a range of ore minerals and deposit types

Trace elements in diamonds - possible genetic indicators?

Geodynamics

Influence of mantle processes on crustal geology and topography: regional geotectonic analysis: Slave Craton (Canada), Siberia, eastern China, Australia, Kaapvaal Craton Research Highlights

Neoproterozoic earth history of Australia: Tectonics, isotope-, volcanic- and bio-stratigraphy

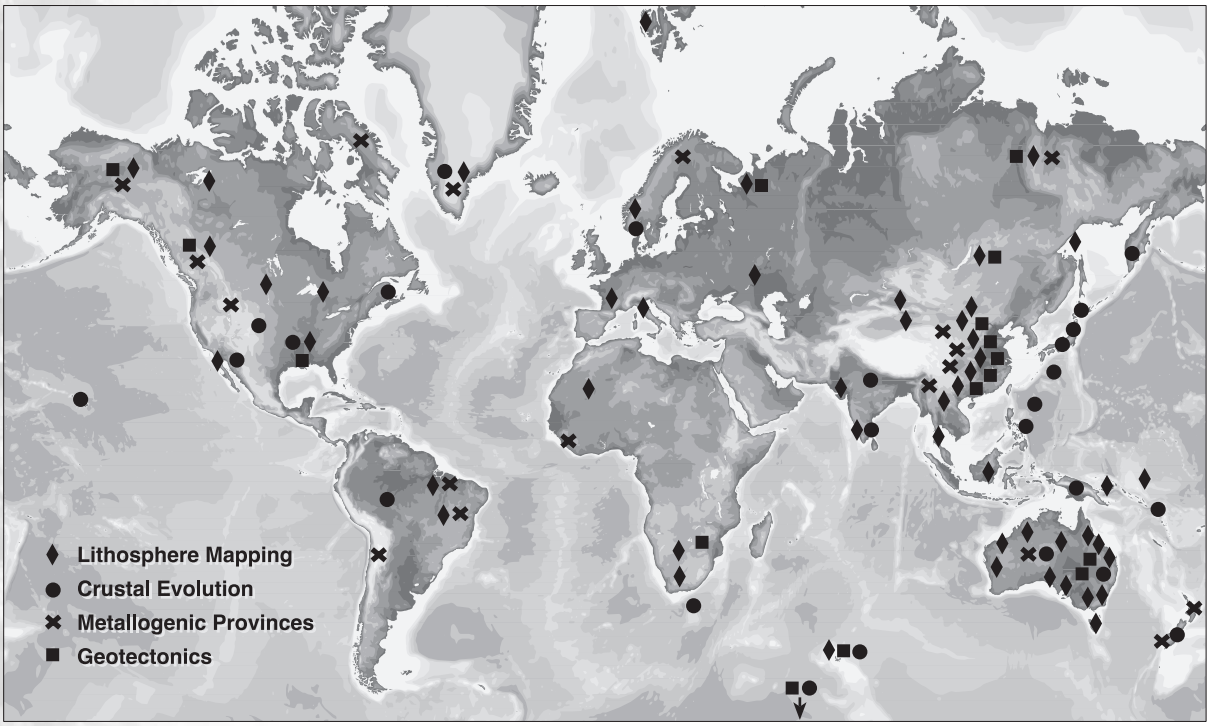
Tasman Fold Belt tectonism and regional volcanology: Tumut-Gundagai region; Louth area; central western NSW; central Queensland

Paleomagnetic studies of the northern New England Orogen

Geodynamic modelling of large-scale processes using constraints from 4-D Lithosphere Mapping results Research Highlights

Evolution of lithospheric composition and Earth geodynamics through time Research Highlights

WHERE IN THE WORLD IS GEMOC?



Funded basic research projects for 2004

Funded research projects within GEMOC are formulated to contribute to the long-term large-scale strategic goals and determine the short-term Research Plan. Summaries of these projects for 2004 are given here.

Toward the use of metal stable isotopes in geosciences

Olivier Alard: Supported by ARC Discovery

Summary: Metal stable isotopes (MSI: Mg, Fe, Cu, Zn, Ga) have enormous potential applications (basic and applied) in Geosciences and beyond. However the use of these elements as geochemical tracers and petrogenetic tools requires: (i) the definition of their isotopic composition in Earth's key reservoirs and in reference materials such as the chondritic meteorites; (ii) understanding and quantification of the causes of MSI fractionations during geological processes. By a unique combination of *in situ* and solution geochemical analytical techniques available now through frontier technology and method development, we aim to establish a conceptual and theoretical framework for the use of metal stable isotopes in Geosciences.

Crustal Evolution in Australia: Ancient and Young Terrains

Elena Belousova: Supported by ARC Discovery

Summary: The mechanisms of crustal growth and the processes of crust-mantle interaction will be studied in selected Archean, Proterozoic and Phanerozoic terrains in Australia, using a newly developed approach: the integrated, *in situ* microanalysis of Hf and Pb isotopic composition and trace-element patterns in zircons from sediments and selected igneous bodies. The results will provide new information on the evolution of the Australian crust, with wider implications for the development of global crust and mantle reservoirs. The outcomes will define crustal evolution signatures related to regional-scale mineralisation, and thus will be highly relevant to mineral exploration in Australia and offshore.

How has continental lithosphere evolved? Processes of assembly, growth, transformation and destruction

Sue O'Reilly and Bill Griffin (with 5 partner investigators): Supported by ARC Discovery and Linkage International

Summary: We will use new *in situ* analytical techniques, developed in-house, to date the formation and modification of specific volumes of the subcontinental lithospheric mantle, and to define the temporal and genetic relationships between mantle events and crustal formation. Quantitative modelling will investigate the geodynamic consequences of spatial and temporal variations in lithosphere composition and thermal state. Magmatic products will be used to assess the roles of mantle plumes and delamination in construction of the lithosphere, and xenolith studies will investigate the evolution of oceanic plateaus. The results will provide a framework for interpreting the architecture of lithospheric terranes and their boundaries.

The timescales of magmatic and erosional cycles

Simon Turner (with 4 partner investigators): Supported by ARC Discovery

Summary: Precise information on time scales and rates of change is fundamental to understanding natural processes and the development and testing of quantitative physical models in the Earth Sciences. Uranium decay-series isotope studies are revolutionising this field by providing time information in the range 100-100,000 years, similar to that of many important Earth processes. This project is to establish a dedicated Uranium-series research laboratory and to investigate (1) the processes and time scales of magma formation, transport and differentiation beneath western Pacific island arc volcanoes, (2) the time scales and relative roles of physical and chemical erosion in Australian river basins.

Isotopic fractionation of the ore metals (Cu, Zn, Fe): Mechanisms and significance

Simon Jackson: Supported by Macquarie University Research Development Grant

Summary: Utilising recent advances in laser and mass spectrometric technologies, it has been determined that the stable isotope ratios of important metals (eg Cu) exhibit significant variations in ore systems. However, little is known of the fractionating processes. The proposed project will determine the mechanisms that fractionate isotopes of Cu, Fe and Zn by: (a) building a data-base of isotopic signatures for rock types commonly associated with mineralisation, (b) study of selected active and ancient hydrothermal systems, (c) experimental studies. This information will allow metal isotopes to be applied to determining the genesis of, and, potentially, exploration for, ore deposits.

Evolution of the upper mantle beneath the Siberian Craton and the southern margin of the Siberian Platform

Vladimir Malkovets: Supported by Macquarie University Research Fellowship

Summary: This project will contribute new information and concepts about the formation of Earth's continents over the last 4 billion years. It will use geochemical techniques recently developed with state-of-the-art instrumentation in the GEMOC laboratories, and apply these techniques to unique suites of mantle-derived samples (xenoliths) from volcanic rocks across Siberia to investigate differences between mantle domains of different age and tectonic setting. The results will provide direct analogues for better understanding of mantle structure and mantle evolution beneath Australia, and will contribute to development of tectonic models relevant to the area selection process in mineral exploration.

Lithosphere extension in East Asia: tectonic mechanisms and geochemical consequences

Kuo-Lung Wang: Supported by Macquarie University Research Development Grant

Summary: This project seeks to better understand how continents pull apart (extend) and how the mantle part of the lithosphere (~200 km depth) responds. Novel Re-Os techniques will date mantle samples delivered to the surface in magmas; geochemical fingerprints of processes related to extension will be established. Integration of new geophysical data with geochemical results will constrain the lithosphere architecture. The East Asia region is an ideal natural laboratory and the results will be applicable to analogous tectonic scenarios globally and throughout geological time. The results will have particular relevance for unravelling the geological evolution of Phanerozoic eastern Australian lithosphere.

Melt escape and trace element partitioning during high-pressure partial melting in the lower crust, northern Fiordland, New Zealand

Nathan Daczko: Supported by Macquarie University Early Career Research Grant

Summary: This project aims to derive new constraints on processes of lower crustal (>30 km depth) melting and melt escape. It will test and expand upon the proposed hypothesis that the efficient segregation and transport of magma from the lower crust is controlled by fracture propagation, not just slow upwelling. It is impossible to directly observe active ascent mechanisms at such depths. This, as well as the heterogeneity and structural complexity of lower crustal source regions, has led to controversy. Integration of field relationships, petrological and geochemical analyses will define the parameters of lower crustal melting and improve our understanding of deep-Earth processes.