



# Teaching and training program undergraduate



## GEMOC's teaching program aims to:

- provide undergraduate and postgraduate students with a broad, integrative understanding of Earth architecture and processes, bridging the discipline boundaries of geology and geophysics
- train undergraduate and postgraduate students in new conceptual approaches and the applications of advanced technology, including geochemical analysis techniques and the integrated field and laboratory use of geographic information systems (GIS)
- develop international links in teaching programs (especially postgraduate) relevant to GEMOC's goals
- develop formal tailored course work components at postgraduate level which also can be packaged for distance education delivery and as short courses available to the mining industry
- enhance the pool of high quality geoscience graduates by restructuring academic programs to attract a new clientele

## HIGHLIGHTS 2003

### Curriculum Development

- Our tailored problem-based learning units GEOS116 Marine Geoscience and GEOS115 Earth Dynamics, Materials and the Environment continue to be well received by students. The format includes lectures, problem-based workshops and traditional skill-based practicals. The workshops are completed as group work projects and are modeled on real-life scenarios with the students adopting a role as part of a geoscience team. The success can be judged by comments from the end of year evaluation such as:

*"the only subject where you get to discuss ideas in a group and come up with team decisions which is important because it is how the real world works. I think it develops important skills"*

[Best aspect of the unit] *"studying real life/actual problems of today"*

*GEOS260 South coast field trip.*



- A team from the department, lead by Kelsie Dadd, was awarded \$5928 under the Macquarie University Teaching Development Grant program for a project entitled “Bringing the workplace into the classroom – the redesign of GEOS377 using Tailored Problem-based Learning and real workplace scenarios”. GEOS377 Environmental Geology is a core unit of the new Bachelor of Environmental Science in Environmental Geology.

- Nathan Daczko co-ordinated two units in 2003 - GEOS307 and GEOS389. GEOS307 Field Geology and Mapping was run in the Broken Hill region in conjunction with the University of Sydney for the first time in 2003. Field studies in the Broken Hill region allow students to gain experience mapping in a geological province not encountered before in their course. The unit attracted 10 students from the Department of Earth and Planetary Sciences in 2003 and current enrolments indicate an increase to 20 students in 2004. GEMOC’s John Ketchum attended as a demonstrator.



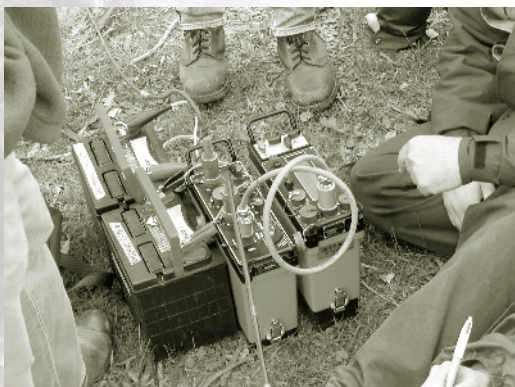
*Mapping an outcrop near Broken Hill, GEOS307 Field Geology and Mapping.*

- GEOS389 Special Interest Seminar was run under the name “Tectonics along the Pacific margin of the Australian plate in the last 100 or so million years” in New Caledonia. This type of unit is an excellent opportunity for students to experience first hand world-class exposures of a broad range of interesting rocks in an area of recent tectonic activity. The unit attracted 12 second and third year students. Nathan is currently developing our new unit GEOS230 Field and Laboratory Studies in Geoscience introduced after a review of second-year units.
- Simon Jackson revised GEOS314 Magmas, Fluids and Ore Deposits in 2003 around a new teaching team that included Simon Turner, Rhiannon George and Kirsty Tomlinson from GEMOC. The new team brings GEMOC’s world-class research into the third-year teaching curriculum.
- The use of computer packages and web interfaces in Earth and Planetary Sciences continues as a routine feature of content and skills delivery. Both geology and geophysics units incorporate packages used by industry into classroom and field teaching. Our portable computer lab allows students access to up-to-date computer software for use in both the classroom and field.

### **Teaching Infrastructure changes 2003**

- The existing aged XRD instrument was replaced using University equipment funds
- Field equipment was upgraded

## Teaching and training program: undergraduate



*Waiting for the gravimeter to finish its reading.*

### Geophysics teaching progress 2003

- Collaboration in teaching and research between GEMOC and Geophysics at the University of Sydney continues.
- The named degree, Bachelor of Geophysics, continued in 2002 after its inception in 1998 to increase the visibility of Geophysics. It has evolved into the advanced geophysics stream in the Bachelor of Science degree.
- The Bachelor of Technology in Exploration Geoscience has a Geophysics strand initiated in 1999, streamed from second year level (see flow sheet in *Appendix 6*).
- Use of an extensive pool of GPS units for undergraduate (and postgraduate) fieldwork continued.
- Extended implementation of new seismic, gravity GPS and resistivity equipment for student field projects in exploration, groundwater, environmental and engineering geophysics.
- Equipment upgrades funded by Macquarie University over the last five years have resulted in an excellent array of new instrumentation. Acquisitions include:
  - GEOMETRICS G856 Proton Precession Magnetometer
  - GEOSOFT, MODELVISION, EMVISION, ERMAPPER and Claritas software was either purchased or upgraded
  - Seismic trigger cable modifications
  - ABEM SAS4000 Resistivity System and an ABEM LUND system
  - ASHTECH Z-Xtreme Differential GPS system

### OUTCOMES AT MACQUARIE

The introduction of new units and restructuring of existing undergraduate units at Macquarie as described in each Annual Report has achieved the goals of attracting new clientele. However, this is within an environment of a contracting pool of science undergraduates. Despite this, GEMOC core units at 100 level have maintained average enrolments. Reorganisation of course structures



*New resistivity imaging system in action mapping subsurface waters (GEOS315 Environmental and Groundwater Geophysics).*

and acquisition of teaching infrastructure (computers, high-technology instruments, GIS units) have increased the visibility of geoscience and have resulted in the presentation of geoscience with an interdisciplinary and innovative approach using state-of-the-art technology and concepts.

**The following honours projects in GEMOC were completed in 2003:**

**Daniel Galda:** Determination of the elastic properties of alluvium

**Lachlan Gibbins:** A geophysical investigation of two upland swamps, Woronora Plateau, NSW Australia

**Kathleen McMahon:** Seismic reflection studies of the Amery Ice Shelf, East Antarctica

**Dan Nielsen:** A geological, geochemical and geophysical investigation of the Paleroo Creek area near Narrabri

**The following Honours projects are relevant to GEMOC in 2004:**

**Stephanie Carroll:** Cretaceous Granulites in Fiordland, New Zealand (mid-year)

**Kirsty Liddicoat:** Chemical and isotopic signatures of opal genesis at Lightning Ridge, NSW

**Teaching  
and  
training  
program**

**GEMOC  
honours**

GEMOC offers scholarships for students with excellent undergraduate records who are carrying out GEMOC-related projects.

## Teaching and training program

### GEMOC postgraduate



**G**EMOC POSTGRADUATE STUDENTS once more provided a high profile for our postgraduate training through 2003, including the Goldschmidt Conference in Kurashiki (Japan), the West Norway Eclogite Symposium in Selje (Norway), the 8<sup>th</sup> International Kimberlite Conference in Victoria (Canada) and the Hutton Symposium in Japan. Sonja Aulbach and Sonal Rege received travel grants from the Organising Committee to present papers at the peak mantle forum, the 8<sup>th</sup> Kimberlite Conference.



*Stephanie Touron  
in the stable isotope  
laboratory at the  
Univ. of Jean Monnet,  
St Etienne.*

GEMOC's international exchange program with the University of Jean Monnet, St Etienne continued. Stephanie Touron spent 3 months working in the stable isotope laboratory at St Etienne while her Macquarie supervisors (Sue O'Reilly and Bill Griffin) were there for 3 months' research. Guillaume Delpuch was in the final stages of thesis writing in anticipation of completion early in 2004.

#### completed

**Olivier Alard (PhD):** Trace element geochemistry and mantle domains, emphasis on PGE and Re/Os; *IPRS with MUIPRA stipend* (graduated 2001)

**Sonja Aulbach (PhD):** Depletion and metasomatic processes in cratonic mantle; *IPRS with MUIPRA stipend* (submitted October 2003)  
(see *Research Highlights*)

**Kari Anderson (PhD):** Defining the APWP for early to mid Palaeozoic eastern Gondwanaland: paleomagnetic pole information from the northern Tasman Orogen; *IPRS with MUIPRA stipend* (graduated 2003)

**Elena Belousova (PhD):** Zircon and apatite geochemistry: applications to petrology and mineral exploration; *APA and sponsorship by Rio Tinto* (graduated 2000)

**Eloise Beyer (PhD):** Contrasting characteristics of Proterozoic and Phanerozoic mantle types; *Field assistance from Ashton Mining* (graduated 2003)  
(see *Research Highlights*)

**Rondi Davies (PhD):** East Australian Diamonds: Characterisation and origin; *Sponsored by Rio Tinto, Kennecott Canada* (graduated 1999)

**Oliver Gaul (PhD):** Composition of the lithospheric mantle beneath Australia; *APAI collaborative with Stockdale Prospecting, CSIRO EM* (graduated 2000)

**Joanne McCarron (MSc):** Mantle xenoliths from Queensland and South Australia (graduated 1997)

See advertisement  
for GEMOC  
postgraduate  
opportunities at:  
[www.es.mq.edu.au/  
GEMOC/](http://www.es.mq.edu.au/GEMOC/)

**Bertrand Moine (PhD):** The role of fluids in the genesis, segregation and crystallisation of intraplate oceanic mantle magmas: implications for crustal accretion; *Co-tutelle with University of Jean Monnet* (graduated 2000)

**Mark Pirlo (PhD):** Australian groundwater geochemistry; applications to heat flow and exploration; *APA and Queen's Trust for Young Australians Award* (graduated 2003)

**Shixin Yao (PhD):** Chromite as a petrogenetic indicator in ultramafic rocks; *Collaborative with Rio Tinto* (graduated 2000)

**Xu Xisheng (PhD):** The lithospheric mantle beneath eastern China; *Formal exchange PhD, Nanjing and Macquarie* (graduated 2000)

#### current

**Steven Cooper (PhD):** Diamonds and mantle-derived minerals, NW Australia and South Australia (commenced part-time 2003)

**Guillaume Delpéch (PhD):** Isotopic characteristics of lithosphere processes beneath Kerguelen; *Co-tutelle with University of Jean Monnet, IPRS with GEMOC stipend and EURODOC scholarship* (commenced 2000)

**Raynald Ethien (PhD):** Origin of differentiated magmas from an oceanic island: petrology and geochemistry of volcanic and plutonic silicic rocks from Kerguelen Island (Indian Ocean); *Co-tutelle with University of Jean Monnet, St Etienne* (commenced 2001)

**Bin Guo (PhD):** An integrated geophysical investigation of the Hunter-Mooki and Peel Fault; *IPRS with MUIPRA stipend* (commenced 2001)

**Valeria Murgulov (PhD):** Crust-mantle evolution and metallogeny, eastern Australia; *APA* (commenced 2003)

**Kathlene Oliver (MSc):** Depth and subsurface shape of the Dundee Ignimbrite (part-time, commenced 2001)

**Will Powell (PhD):** Nature of the lithospheric mantle in the New England Region, NSW; *APA* (part-time, commenced 1997)

**Sonal Rege (PhD):** Trace-element geochemistry of diamonds; *IPRS with iMURS scholarship* (commenced 2002)

**Stephanie Touron (PhD):** Geochemical fingerprints of the mantle beneath the Massif Central; *IPRS with MURAACE scholarship* (commenced 2001)



*Mark Pirlo, Sue O'Reilly, Eloise Beyer and Bill Griffin at the May 2003 graduation ceremony.*

**Teaching and training program: postgraduate**

*Some of GEMOC's  
2003 postgraduate  
students: Will Powell,  
Stephanie Touron,  
Guillaume Delpech,  
Sonal Rege and Valeria  
Murgulov.*

**Esmé van Achterbergh (PhD):** Trace-element fingerprints of metasomatic processes in lithospheric mantle (part-time, commenced 1998)



**commencing 2004**

**Brad Bailey (PhD):** Law Dome: Ice and Crust Mass Balance Studies

**Kathleen McMahon (PhD):** Fracturing and deformation along the Amery Ice Shelf: A seismic study

**Luke Milan (PhD):** The emplacement, pressure-temperature-time path and structural evolution of lower crustal gneisses in Fiordland, New Zealand

**Nenad Nikolic (PhD):** Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway







## Technology development program

### Background

GEMOC's research, training and Industry Interaction programs require a high level of geochemical analytical technology, which is provided by the state-of-the-art facilities available to the Key Centre. Continual development of both technology and innovative analytical and microanalytical approaches is required to meet our research aims and the needs of our industry collaborators. GEMOC develops new analytical strategies as required, to determine the chemical and isotopic composition of geological materials (both solid and fluid) in solution and *in situ*. Special emphasis is being placed on the development of advanced *in situ* microbeam methods. These developments are transmitted to industry via open and collaborative research, through technology exchange visits and workshops, and as an integral part of the training program.

“Continual development of both technology and innovative analytical and microanalytical approaches is required to meet the research aims and the needs of our industry collaborators.”

*Everyone pitching in to help move the Nu MC-ICPMS.*

**T**HE ANALYTICAL INSTRUMENTATION and support facilities of the Macquarie University Geochemical Analysis Unit (GAU) represent a state-of-the-art geochemical facility. In 2004 this will be enhanced by the relocation of the stable-isotope operations of the former Centre for Isotope Studies, previously housed at CSIRO, North Ryde, to GEMOC.

- The GAU *contains*:
  - a Cameca SX-50 electron microprobe
  - a Cameca SX-100 electron microprobe (installed January 2003)
  - a Hewlett Packard 4500 ICPMS (dedicated to U-Pb analysis)
  - an Agilent 7500 ICPMS (industry collaboration)
  - a custom-built UV laser microprobe, usable on either ICPMS
  - two New Wave/Merchantek laser microprobes (266 nm and 213 nm) for the MC-ICPMS and ICPMS laboratories (industry collaboration)
  - a New Wave/Merchantek excimer (193 nm) laser microprobe, based on a Lambda Physik OPTex laser
  - a Nu Plasma multi-collector ICPMS
  - a Nu Plasma high resolution multi-collector ICPMS (installed November 2003)
  - a Spectro XLAB2000 energy-dispersive XRF with rocker-furnace sample preparation equipment



## Technology development program

Mathieu Choukroun  
(MSc intern from Ecole  
normale Supérieure,  
Paris) using the new  
Cameca SX-100  
electron microprobe.



- a LECO RC412 H<sub>2</sub>O-CO<sub>2</sub> analyser (delivered September 2003)
- clean labs and sampling facilities provide infrastructure for ICPMS, XRF and isotopic analyses of small and/or low-level samples
- Experimental petrology laboratories in GEMOC include piston-cylinder presses (9, 15 and 40 kb), hydrothermal apparatus, and controlled atmosphere furnaces.
- The Centre for Isotope Studies has provided access to extraction lines and gas-source mass-spectrometers for stable-isotope analysis of fluids and minerals; these facilities will be moved to GEMOC during 2004.

### THE GEMOC FACILITY FOR INTEGRATED MICROANALYSIS (FIM) AND MICRO GIS DEVELOPMENT

GEMOC is continuing to develop a unique, world-class geochemical facility, based on *in situ* imaging and microanalysis of trace elements and isotopic ratios in minerals, rocks and fluids. The Facility for Integrated Microanalysis now consists of four different types of analytical instrument, linked by a single sample positioning and referencing system to combine spot analysis with images of spatial variations in composition ("micro-GIS"). All instruments in the FIM have been operating since mid-1999. Major instruments are being replaced or upgraded in 2002-2004 through the \$5.125 million DEST Infrastructure grant awarded to Macquarie University with the Universities of Newcastle, Sydney, Western Sydney and Wollongong as partners.

#### the facility provides:

- The capability to image both major- and trace-element distribution in a sample, as an interpretive tool and as the basis for higher precision spot analysis of trace-element concentrations and isotopic ratios
- Co-registration of images and spot data from different instruments, and use of digitised images to locate spots with a precision of better than 5 µm
- Analytical capability for most elements of the periodic table at ppm to sub-ppb levels
- *In situ* isotopic-ratio measurement for a range of elements, at the precision required for geologically useful results
- New approaches to data interpretation through application of micro-GIS principles

**Electron Microprobe:** for imaging and point analysis of major and minor elements

**Scanning Nuclear Microprobe:** for imaging and point analysis of trace elements at ppm levels

**Laser-ablation ICPMS Microprobes:** for point analysis of a wide range of trace elements at low ppb levels

**Multi-collector Sector ICPMS with laser microprobe:** for high-precision *in situ* analysis of isotopic ratios

**Micro-GIS system:** A key aspect of the Facility is the co-registration of images and point analyses collected on all instruments. All data for a sample, from any of the instruments or from a bench microscope, are in the same coordinate system and can be overlaid in the computer to enhance interpretation.

When fully developed, images from one instrument will be read into the computer of another instrument and used to guide the analysis. Major-element maps from EMP, or trace-element maps from the nuclear microprobe, can be linked directly to images from petrographic or cathodoluminescence microscopes, BSE or SEM, or to spot analyses.

## CURRENT STATUS

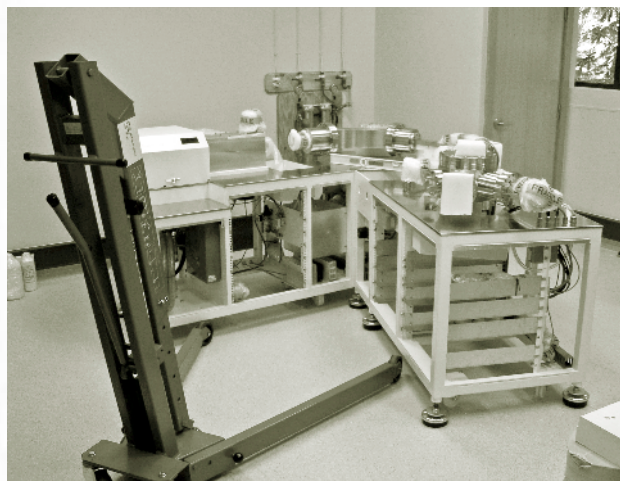
**Electron microprobe (EMP):** The original GEMOC EMP is a CAMECA SX50, installed in 1993; it routinely produced high-precision analyses of major and minor elements with a spatial resolution of one micron, as well as high-quality images of major-element (> 0.1 wt%) distribution over areas up to 45 x 45 mm, by stage-scanning with five fixed wavelength-dispersive spectrometers. In early 1999 the EMP was upgraded with an energy-dispersive X-ray detector to allow rapid and simultaneous mapping of all major elements. In early 2003 a new CAMECA SX100, with a similar configuration of spectrometers, was installed and the SX50 is now used almost entirely for the imaging and analysis of zircons, in connection with TerraneChron™ applications and basic research.

**Scanning nuclear microprobe (SNMP):** This instrument was built by Dr C. G. Ryan (with GEMOC funding contribution) as a separate beam line on the HIAF particle accelerator at CSIRO, North Ryde. The design incorporates several complementary types of detector, a new high-resolution probe-forming system and an innovative optical system, and provides both images of trace-element distribution and spot analyses, with a lateral resolution of 1-3 µm. Current capabilities cover micro-PIXE, micro-PIGE and quantitative element imaging. Due to the closure of CSIRO's North Ryde site during 2004, the SNMP beam line will be relocated to the accelerator facility at the University of Melbourne.

**Laser Ablation ICPMS microprobe (LAM-ICPMS):** The original GEMOC LAM was installed in December 1994 using a Perkin-Elmer ELAN 5100 ICPMS (later replaced by an ELAN 6000), attached to a UV laser ablation microprobe built for GEMOC by Memorial University, Newfoundland. In 1999 the ICPMS was replaced by a Hewlett Packard 4500, and in 2000 an Agilent 7500 ICPMS was added. These two instruments now routinely provide quantitative analyses of > 30 elements at sub-ppm levels in minerals, glasses and metals, as well as precise U-Pb dating of zircons. The laboratory currently uses three Nd:YAG LAM systems: a Quantel Brilliant laser that can deliver beams of either 266nm or 213nm light, a Merchantek LUV 266nm system, and a Merchantek/New Wave LUV213 nm system. Spatial resolution varies with the application, but typically is on the order of 30-40 µm. The LAM is fitted with a computer-driven sample stage to provide co-registration

*Installation of the  
second Nu Plasma  
begins....*

of X-Y coordinates with the other instruments. On-line data reduction with the GEMOC-developed "GLITTER" software enhances laboratory productivity and data interpretation; the software is marketed internationally by New Wave Research.



**Multi-collector LAM-ICPMS microprobe (MC-LAM-ICPMS):**

A fully-equipped Nu Plasma MC-ICPMS is an integral part of the Facility. This instrument combines a laser ablation micro-sampler, an Ar-plasma ionisation source, and a multi-collector magnetic-sector mass spectrometer, to provide high-precision *in situ*

analysis of isotope ratios in geological materials. The current laser is a New Wave 193nm system based on a Lambda Physik OPTex excimer laser. The MC-ICPMS also can be used in solution mode, with either a standard nebuliser or a desolvating nebuliser, to provide high-precision isotopic analysis of a wide range of elements, including many not accessible by standard thermal ionisation mass spectrometry. A second Nu Plasma instrument, with high-resolution capabilities and a retardation filter to enable U-series work, was installed late in 2003.

**Applications in use and under development include:**

**Laser Analysis (in situ point analysis)**

- U-Pb geochronology of zircons from igneous and metamorphic rocks
- Hf isotope analysis in zircon for studies of crustal generation, mantle evolution and crust-mantle interaction
- Re-Os dating of sulfides in mantle-derived xenoliths
- Nd isotope analysis in apatites, titanites and other REE-rich minerals
- Sr isotope analysis of carbonates, feldspars, apatites, pyroxenes
- Pb isotope analysis of sulfides and silicates
- Stable isotope ratios of Fe, Mg, Zn, Cu and other cations in appropriate minerals from hydrothermal systems and mantle rocks
- Multi-element trace element analysis of silicates, sulfides, oxides and diamonds

**Solution Analysis**

- Re-Os — determination of mantle depletion ages and isochron ages in whole rocks, ilmenites and chromites; dating of sulfide assemblages in ore bodies
- Lu-Hf — crustal genesis, mantle metasomatism; Lu-Hf dating of garnet peridotites, eclogites, granulites; basalt genesis

- Rb-Sr, Sm-Nd, U-Pb, Pb-Pb — faster and simpler than TIMS; simplified low-blank chemistry, no time-dependent mass fractionation, hence greater precision
- U, Th-series analysis – for dating of young processes, ranging from magma genesis to weathering and erosion
- Multi-element analysis of trace elements in whole-rock samples

## PROGRESS IN 2003

### 1. Facility for Integrated Microanalysis

**a. Electron Microprobe:** A fully optioned Cameca SX-100 electron microprobe with five crystal spectrometers and an energy-dispersive spectrometer, to replace GEMOC's aging but still highly functional SX-50 instrument, arrived in late December 2002, and was installed in January 2003. The energy-dispersive spectrometer has been returned for repairs, but the instrument is otherwise performing well.



### b. Laser-ablation ICPMS microprobe (LAM):

During 2003, the LAM laboratory produced large volumes of data for eight Macquarie PhD thesis projects, several projects carried out by international visitors and Honours students, in-house funded research projects and industry collaboration. These projects included the analysis of trace elements in the minerals of mantle-derived rocks, in sulfide minerals and in a range of unusual matrices. *Over 5000 U-Pb analyses of zircons were carried out*, related to projects (including *TerraneChron™* applications) in South America, Scandinavia, Mongolia, Turkey, China and Australia. The LAM laboratory also routinely provides data for projects related to mineral exploration (diamonds, base metals, Au), as a value-added service to the industry. New developments included further improvements in the quantitative *in situ* analysis of diamonds, as part of Sonal Rege's PhD project, supported by DeBeers, on the trace-element signatures of diamonds (see *Research Highlights*).

The 4500 instrument is now dedicated primarily to U-Pb dating of zircons, where its stability and ease of operation provide a high throughput.

**c. MC-ICPMS:** A multi-collector magnetic sector ICPMS for *in situ* (laser-ablation) and solution analysis of isotopic ratios was installed in November 1998. The instrument is the Nu Plasma, designed and manufactured by Nu Instruments of Wrexham, UK. The instrument was producing good data only a few days after installation, and has continued to do so. Merchantek EO (now New Wave Research) has provided a 266 nm UV laser microprobe (under a collaborative agreement; see

“Over 5000 U-Pb analyses of zircons were carried out, related to projects (including *TerraneChron™* applications).”

*Tin Tin Win from CSIRO using the LAM-ICPMS for zircon dating.*

Peter Wieland  
preparing samples for  
isotopic analysis.

“Major [MC-ICPMS] applications during 2003 (see Research Highlights) included the high-precision analysis of Hf in zircons to trace lithosphere evolution, ... the analysis of copper and iron isotope compositions in minerals from ore bodies, the analysis of Sr isotopes in carbonate fossils for stratigraphic control, and Re-Os dating of single grains of Fe-Ni sulfides in mantle-derived rocks.”

below) for use with the MC-ICPMS and a 213 nm laser microprobe was purchased in 2000. During 2002 the MC-ICPMS was fitted with a New Wave/Merchantek excimer (193 nm) laser microprobe, based on a Lambda Physik OPTex laser. This has been used mainly for the analysis of Hf isotopes in zircon, where its different absorption characteristics have provided somewhat greater spatial resolution and beam intensity than were available using the 213 nm laser.

Major applications during 2003 (see *Research Highlights*) included the high-precision analysis of Hf in zircons to trace lithosphere evolution and magma-mixing



histories in granitic rocks, the analysis of copper and iron isotope compositions in minerals from ore bodies, the analysis of Sr isotopes in clinopyroxene phenocrysts from lavas, and Re-Os dating of single grains of Fe-Ni sulfides in mantle-derived rocks.

We carried out Re-Os studies on alpine-type peridotites from the Norwegian and Swedish Caledonides and xenoliths from the Kerguelen oceanic plateau, S. Africa, eastern China and Taiwan. A study of U-Pb and Hf-isotope systematics of zircons in late-Proterozoic sediments in southern Norway, continued from 2002, is providing a new view of the tectonics of southern Scandinavia.

Further developments were made in 2003 for the in-situ analysis of Mg isotope compositions in mantle olivine and other phases in mantle peridotites. This involved the characterisation of potential standard materials and the investigation of the matrix effects on isotopic fractionation. Detailed studies were undertaken on olivine, pyroxene and amphibole in spinel peridotites from the Massif Central (France) and from Western Victoria (Australia), with the results providing further evidence of significant Mg isotopic fractionation in metasomatised samples.

The rapid growth in the use of the *TerraneChron*<sup>TM</sup> application (see *Research Highlights*), coupled with the demand for *in situ* Re-Os analysis and stable isotope analysis, has led to severe competition for instrument time on the MC-ICPMS. An order was placed early in 2003 for a second instrument, funded by the DEST infrastructure grant, and this instrument was installed late in 2003.

**d. Scanning Nuclear Microprobe:** The pending closure of the CSIRO North Ryde site forced the shutdown of the SNMP in late 2003. While the removal of the accelerator to the Clayton (Melbourne) site has been discussed, little progress has been made. The beam line has been dismantled, and will be re-installed on the University of Melbourne accelerator during 2004. It is anticipated that it will be able to operate for 2-3 days/week, and negotiations regarding access for GEMOC projects will take place once the SNMP is operative again.

**e. Laboratory development:** Funding from the DEST infrastructure grant contributed toward the building of a new suite of clean-room laboratories on the second floor of building E5B, which include facilities for the work on U-series chemistry to be carried out by Dr Simon Turner and his group starting in 2003. Construction began in September 2003, and the facilities are scheduled for completion by the end of March 2004.

**f. Software:** Chris Ryan further refined the GLITTER (GEMOC Laser ICPMS Total Trace Element Reduction) software, our on-line interactive program featuring linked graphics and analysis tables. This package provides the first real-time interactive data reduction for LAM-ICPMS analysis, allowing inspection and evaluation of each result before the next analysis spot is chosen. Its capabilities include the on-line reduction of U-Pb data. The use of GLITTER has greatly increased both the flexibility of analysis, and the productivity of the laboratory. New Wave Research now market the software together with their laser microprobe equipment; GEMOC provides customer service and backup through Macquarie Research Limited. Eleven copies of GLITTER were sold worldwide in 2003, and the software appears to have achieved industry-standard status; more than 30 copies are in use worldwide, in forensics and materials science, as well as earth science applications.

## 2. Laser development

GEMOC continues to benefit from an industry partnership with New Wave Research (formerly Merchantek EO), a major US manufacturer of laser ablation systems, which has made Macquarie its Alpha Test Site. New Wave donated their 266 nm Nd:YAG UV laser ablation sampling system to GEMOC and their new 213 nm system was delivered early in 2000. Both lasers can be coupled to the Nu Plasma MC-ICPMS, allowing high precision isotope ratio determinations to be performed on minerals *in situ*. The mobility of the probes has allowed them to be used on the quadrupole ICPMS instruments as well, in a range of applications. A Merchantek/New Wave Research 193 nm excimer system based on a Lambda Physik OPTex laser was delivered in March 2002 and was finally commissioned late in the year.

The 213 nm laser is now used for most of the U-Pb work, especially where small grains are being analysed, while the excimer system is used mainly for Hf-isotope analysis. A major upgrading of the laser park will take place in 2004, with the purchase of three new systems.



*Bill Griffin and Suzy Elhlou ponder startling results from the LAM-ICPMS*

### 3. Energy Dispersive XRF

A Spectro XLAB2000 energy-dispersive X-ray spectrometer was installed in November 2000 in a joint venture with Tasman Resources. This instrument utilises the polarisation of scattered X-rays to substantially reduce backgrounds and enhance detection limits. The XLAB2000 uses a specially designed 300 W palladium X-ray tube that improves its performance for the lighter trace elements, and also for major elements, relative to the earlier instrument. In addition, this spectrometer is fitted with a silicon detector, of a type recently developed, that eliminates the low-energy "tail" from the lightest elements, and enables all major elements to be measured in a fused glass to levels below 0.01%. The capability of the instrument to provide major element analyses of a quality at least comparable to the more expensive conventional crystal spectrometers has been thoroughly evaluated and confirmed. This instrument provides highest-quality data for major elements and for most trace elements to sub-ppm levels. The operation of the equipment is enhanced by a 100 position sample loader, one of the first to be installed on a Spectro instrument, and the purchase of a rocker furnace for sample preparation. During 2003 over 5000 samples were analysed for major and trace elements, providing data to student theses, in-house research projects, and industry collaborators.

### 4. Solution analysis

The Agilent 7500 ICPMS is regularly used to provide trace-element analyses of dissolved rock samples for the projects of GEMOC researchers and students, and external users, supplementing the data from the XRF.

The in situ analysis of the Rb-Sr, Lu-Hf, Sm-Nd and Re-Os systems by laser ablation microprobe has required the development of corrections for isobaric overlaps (eg  $^{87}\text{Rb}$  on  $^{87}\text{Sr}$ ), and has demonstrated that these corrections can be done with very high precision in the Nu Plasma MC-ICPMS. This has allowed us to simplify the ion-exchange chemistry traditionally used to obtain clean element separations for standard mass-spectrometry analysis. A new scheme for the dissolution of rocks, separation of Sr, Nd, Hf and Pb, and isotopic analysis using the MC-ICPMS in solution mode provides precise whole-rock isotopic analyses that are faster, simpler and ultimately cheaper than those obtained by traditional methods.

During 2003 we further developed methods for extracting Re and Os from rock samples and the analysis of the Os samples on the MC-ICPMS by sparging the oxidised Os directly into the ICPMS torch. The method now routinely provides analyses with a precision and accuracy comparable to the best TIMS analyses, but much more rapidly. The technique was applied to suites of mantle-derived peridotite and eclogite xenoliths from several localities, and to the Re-Os dating of sulfide-rich rocks from ore deposits.

A new LECO RC412  $\text{H}_2\text{O-CO}_2$  analyser (delivered September 2003) replaces an outdated unit, and will provide high-quality analyses to complete whole-rock analyses by XRF and solution-ICPMS.



## 5. Centre for Isotope Studies (CIS)

The Centre for Isotope Studies (CIS) was a consortium operated by the geoscience departments of the New South Wales Universities, CSIRO Exploration and Mining, and Petroleum Resources using jointly-purchased mass-spectrometers housed at the CSIRO in North Ryde. The facility allowed staff and students to obtain both radiogenic and stable isotopic analyses and used technical staff jointly funded by the University members; Dr Richard Flood of GEMOC has been University Consortium Convenor.

GEMOC has developed its own clean laboratories to prepare solutions for radiogenic isotope analysis by MC-ICPMS, but has used the stable isotope separation facilities at North Ryde. CIS was one of the rare laboratories where staff and students could obtain C, O, N, S and D analyses including the routine determination of O in silicates. Dr Anita Andrew developed techniques for C-isotope analysis of diamonds using very small sample sizes (0.1 mg), which allows analysis of microdiamonds or multiple fragments of different zones of small stones. This is now an essential part of GEMOC capabilities.

With the closure of the CSIRO's North Ryde site in 2004, Dr Andrew will move the stable isotope facilities to GEMOC, where they will form a self-funded entity, and GEMOC will continue to benefit from this collaboration.

GEMOC continues to benefit from strategic alliances with Agilent, Nu Instruments and New Wave Research.

# Industry interaction



## INDUSTRY INTERACTION, TECHNOLOGY TRANSFER AND COMMERCIALISATION PROGRAM

**G**EMOC RELIES on a vigorous interaction with the mineral exploration industry at both the research and the teaching/training levels. The research results of the Centre's work are transferred to the industry and to the scientific community by:

- collaborative industry-supported Honours, MSc and PhD projects
- short courses relevant to the industry and government sector users, designed to communicate and transfer new technologies, techniques and knowledge in the discipline areas covered by the Key Centre
- one-on-one research collaborations and shorter-term consultancies on industry problems involving national and international partners
- provision of high quality geochemical analyses with value-added interpretations to industry and government organisations, extending our industry interface
- use of Macquarie Research Limited consultancies, which employ and disseminate the technological developments carried out by the Centre
- GLITTER, an on-line data-reduction program for Laser Ablation ICPMS analysis developed by GEMOC and CSIRO GEMOC participants, is available commercially through New Wave Research
- collaborative relationships with technology manufacturers (more detail in the section on *Technology Development*):
  - GEMOC (Macquarie) is the Agilent Technologies ICPMS Australian demonstration site
  - GEMOC (Macquarie) is the international Alpha test site for New Wave Research Lasers



*Agilent Technologies  
representatives  
Tony Crocker and  
Toshiaki Matsuda  
with GEMOC's Norm  
Pearson and Bill  
Griffin.*

## SUPPORT SOURCES

GEMOC industry support includes:

- direct funding of research programs
- "in kind" funding including field support (Australia and overseas), access to proprietary databases, sample collections, digital datasets

- collaborative research programs (eg ARC SPIRT (now Linkage) Projects, APA Industry and PhD program support)
- assistance in the implementation of GIS technology in postgraduate programs
- participation of industry colleagues as guest lecturers in senior courses (eg Bachelor of Technology)
- extended visits to Macquarie by industry personnel for interaction and research
- ongoing informal provision of advice and formal input as members of the Advisory Board

### ACTIVITIES IN 2003

*TerraneChron*<sup>TM</sup> studies (see *Research Highlights*) have been adopted by a large segment of the global mineral exploration industry. This methodology, currently unique to GEMOC, requires the integration of data from three instruments (electron microprobe, LAM-ICPMS and LAM-MC-ICPMS) and delivers fast, cost-effective information on the tectonic history (with ages) of regional terranes.

Collaborative research with Kennecott Canada Inc., continued within the Lithosphere Mapping strand, following the very successful SPIRT project “Lithosphere Mapping and Diamond Exploration”. This involved the synthesis of results from analysis of heavy mineral concentrates from more than 25 localities scattered around North America, and the correlation of the data with seismic tomography and other geophysical data (Publication #348). Results of the SPIRT project were released as planned at the 8<sup>th</sup> International Kimberlite Conference in Vancouver in June 2003.

Nine Industry Reports were completed for collaborative and consulting projects.

An ARC SPIRT project (2001-2003) sponsored by WMC used gravity data to interpret effective elastic thickness and integrate this with tectonic analysis and geochemical data across Australia.

A new ARC Linkage Project with WMC was funded for 2004-2006. This project is titled “Global Lithosphere Architecture Mapping”. Planning and workshop sessions at Macquarie with participants from WMC and GEMOC, and a visit by Macquarie staff to WMC in Perth, were key activities in 2003. Dr Graham Begg spent significant research time at GEMOC through 2003 as part of the close collaborative working pattern for this project.

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



## Industry interaction

Professor J. Harris (on behalf of de Beers) provided samples for the PhD project of Sonal Rege aimed at developing a methodology for the trace-element analysis of diamonds.

The exploration consulting group GeoDiscovery continued to work with GEMOC to develop *TerraneChron*<sup>TM</sup>, a novel approach to terrane analysis (see *Research Highlights*). A GeoDiscovery/Macquarie collaborative project supported the initiation of this project, and another collaborative project, supported by BHP-Billiton, began early in 2003 (see summaries of current industry projects below).



*The TerraneChron<sup>TM</sup>  
Team: Elena  
Belousova, Ayesha  
Saeed, Kirsty  
Tomlinson and  
Eloise Beyer.*

Dr Steve Walters visits Macquarie to participate in this collaboration.

Many companies have provided high levels of in-kind support in the form of samples: these include access to diamonds and xenoliths through Rio Tinto and Kennecott Canada, suites of xenoliths from Ashton Mining of Canada and heavy mineral concentrates from numerous sources including BHP, DeBeers Australia, Monopros and several small companies.

Rio Tinto supplied samples for pilot studies of garnets, chromites and pyroxenes from kimberlites on the Dharwar Craton of India; the results were used to support a successful proposal for a Macquarie University Collaborative Grant (2004).

A pilot study on detrital zircons from Paleozoic sediments was carried out with the New South Wales Geological Survey; the results were used to support a successful proposal for a Macquarie University Collaborative Grant (2004).

Numerous industry visitors spent varying periods at GEMOC in 2003 to discuss our research and technology development (see visitor list, *Appendix 3*).

DIATREEM continued to provide LAM-ICPMS analyses of garnets and chromites to the diamond-exploration industry on a routine basis, in cooperation with CSIRO, North Ryde.

GEMOC publications, preprints and non-proprietary reports are available on request for industry libraries.



## CURRENT INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

**T**HESE ARE brief descriptions of current GEMOC projects that have direct cash support from industry and timeframes of at least one year. Projects are both national and global.

GEMOC's industry collaborative projects are designed to develop the strategic and applied aspects of the basic research programs based on understanding the architecture of the lithosphere and the nature of Earth's geodynamic processes that have controlled the evolution of the lithosphere and its important discontinuities. Most of the industry collaborative projects rely on geochemical information from the Geochemical Analysis Unit in GEMOC and especially on novel methodologies developed by (and some unique to) GEMOC.

Geochemical data on crustal and mantle rocks are being integrated with tectonic analyses and large-scale datasets (including geophysical data) to understand the relationship between lithosphere domains and large-scale mineralisation.

The new methodologies of using mantle sulfides to date mantle events, and of characterising crustal terrane development using U-Pb dating and Hf isotopic compositions of zircons provides more information for integration with the geophysical modelling. *TerraneChron*<sup>™</sup> (see *Research Highlights*) is proving an important new approach to characterising the tectonic history and crustal evolution of terranes on the scale of 10 – 100 km as well as delivering a cost-effective exploration tool to the mineral (and potentially petroleum) exploration industry.

### Proterozoic crustal evolution: Development of a global comparative library of Event Signatures linked to mineral endowment

*Supported by a matching Macquarie University Collaborative grant (2002-2003)*

*Industry Collaborator: BHB-Billiton*

**Summary:** This project is aimed at understanding processes of Proterozoic crustal formation. We will measure the U-Pb ages, Hf isotope ratios and trace-element patterns of detrital zircons from selected Proterozoic terranes to study the timing, nature and sources of magmatic rocks. The Event Signature for each region will be compared with our data from geologically similar districts, eg Mt Isa block (Australia) and Arivalli Craton (India), and event styles will be correlated with differences and similarities in known mineralisation styles. The project will contribute to a unique global 'library' of Event Signatures with application to area selection for mineral exploration.



*Elena Belousova  
collecting zircons with  
Steve Walters near  
Broken Hill.*

### **Lithosphere mapping beneath the Dharwar Craton, India**

*Supported by a matching Macquarie University Collaborative grant (2004)*

*Industry Collaborator: Rio Tinto*

*Summary:* The project uses major- and trace-element analysis of mantle-derived minerals in kimberlites to map vertical and lateral variations in the composition and thermal state of the lithospheric mantle across the Archean Dharwar Craton in central India. The kimberlites are 900-1200 million years old, and may provide information on a relatively unmodified lithospheric root. Comparison with geophysical data (today's situation) will help to define the fate of this root during India's northward movement after its separation from Gondwanaland. The results will be directly relevant to diamond exploration models for the Dharwar Craton, and for other areas in India.

### **Global Lithosphere Architecture Mapping**

*Supported by ARC Linkage (2004-2006)*

*Industry Collaborator: WMC*

*Summary:* Compositional domains in the subcontinental lithospheric mantle reflect the processes of continental assembly and breakup through Earth's history. Their boundaries may focus the fluid movements that produce giant ore deposits. Mapping these boundaries will provide fundamental insights into Earth processes and a basis for the targeting of mineral exploration. We will integrate mantle petrology, tectonic synthesis and geophysical analysis to produce the first maps of the architecture of the continental lithosphere, to depths of ca 250 km. These maps will provide a unique perspective on global dynamics and continental evolution, and on the relationships between lithosphere domains and large-scale mineralisation.

### **Continental Flood Basalts: geochemical discrimination with relevance to exploration for nickel and platinum-group elements**

*Supported by a matching Macquarie University Collaborative grant (2004)*

*Industry Collaborator: WMC*

*Summary:* A major proportion of magmatic Ni- platinum group element (PGE) deposits are hosted in mantle-plume-derived continental flood basalts (CFB). Therefore, geochemical discrimination of CFB from other mantle-derived rocks and identification of Ni-PGE-prospective CFB are significant for Ni-PGE exploration. This project is exploring existing geochemical databases for mantle-derived rocks to provide user-friendly practical discrimination parameters to identify CFB-related mafic rocks and to evaluate their Ni and PGE economic potential. The research will also further constrain the role of mantle plumes in formation and evolution of subcontinental lithosphere and the behaviour of sulfides during the process of mantle evolution.

## **Where was Baltica? Testing continental reconstructions with TerraneChron™**

*Supported by a matching Macquarie University Collaborative grant (2003-2004)*

*Industry Collaborator: University of Oslo and Norwegian Geological Survey*

**Summary:** Norway represents the western margin of the ancient landmass of Baltica, which was partly destroyed in the Caledonian Orogeny ~550-400 million years (Ma) ago. Its position before 600 Ma is debated. This project is using U-Pb dating and Hf-isotope analysis of zircons in basement rocks in SW Norway and in far-transported thrust sheets (nappes) derived from the vanished western margin of Baltica, to reconstruct the geological history of this margin. The results will allow evaluation of models for continental assembly, and will be relevant to studies of the provenance of sediments in the oil/gas basins of the North Sea.

## **Testing Ordovician-Devonian tectonic models for the Lachlan Orogen**

*Supported by a matching Macquarie University Collaborative grant (2004)*

*Industry Collaborator: NSW Geological Survey*

**Summary:** This project combines the TerraneChron™ technology developed at GEMOC with tectonic and structural concepts developed at the Geological Survey of NSW, to understand the plate-tectonic evolution of SE Australia. U/Pb dating and Hf-isotope analysis of detrital and primary zircon grains will shed light on potential terrane accretion and on the timing of crustal growth and will be used to test published models of the Ordovician-Devonian tectonic development of Eastern Australia. This in turn will help to understand the nature of the interaction between the Australian plate and the proto-Pacific margin of the Gondwana supercontinent.

## **Crustal evolution in southern Norway: U-Pb and Hf-isotope analysis of zircons from bedrock, sediments and modern drainages**

*Supported by a matching Macquarie University Collaborative grant (2002-2003)*

*Partners: Geological Survey of Norway and the University of Oslo*

**Summary:** The broad-scale evolution of the Proterozoic crust of southern Norway is being investigated, using U-Pb, Hf-isotope and trace-element analysis of zircons from selected bedrock units and the overlying Neoproterozoic Sparagmite sedimentary sequence. The results will provide an "Event Signature" for comparison with similar data from more strongly mineralised Proterozoic crust elsewhere. Signatures from small modern drainages in the study area will be compared with those from the rock samples to test the usefulness of this approach for the study of crustal evolution in glaciated areas. The results will enhance the technique's applications to mineral and energy exploration.

## Industry interaction

*Bruce Chappell, Neil Williams, Shunso Ishihara, Alan White and Phil Blevin at the Ishihara Symposium.*



### Lithospheric architecture of Australia: relevance to location of giant ore bodies

*Supported by an ARC SPIRT grant (2001-2003)*

*Industry Collaborator: WMC*

*Summary:* This research project is designed to test the concept that giant magmatic and hydrothermal ore bodies are localised by major structural discontinuities that extend through the Earth's lithosphere. Modelling of geophysical data across the Australian continent is defining regional trans-lithospheric domains and their boundaries. Tectonic analysis and geochemical data on crustal and mantle rocks are defining the age and composition of the upper mantle beneath each domain, and the history of crust-mantle interaction (magmatism, extension, compression). This history will be integrated with information on the timing and style of large ore deposits to understand the relationship between lithosphere domains and large-scale mineralisation. The focus of this project was expanded in 2002 to include the detailed analysis of lithosphere structure and evolution worldwide, using seismic tomography and other geophysical datasets.

### Igneous metallogenic systems of eastern Australia

*Supported by AMIRA (Project P515)*

*Industry Collaborators: Newcrest, Rio Tinto, Delta, GA, NSWGS, QDME, Triako Normandy*

*Summary:* The research part of this project was completed in 2002. The final outcome in 2003 was a three-day symposium on granites, "The Ishihara Symposium: Magmas to Mineralisation", held at Macquarie from 22-24 July 2003. The initial suggestion for this

meeting came from representatives of the companies and surveys that sponsored AMIRA projects of Phil Blevin and Bruce Chappell. The symposium was named in honour of Dr Shunso Ishihara who has been at the forefront of developing ideas on the relationships between granites and mineralisation. More than 100 participants included academics, students, survey geologists and mineral exploration geologists. Abstracts for the symposium were published as Geoscience Australia Record 2003/14 and GA is also making available adaptations of PowerPoint

presentations of many of the talks. The Ishihara Volume from the Conference will be published as an issue of the Japanese journal Resource Geology in September 2004.





## GEMOC's international links

### BACKGROUND

**G**EMOC has strong international links and these increased and changed significantly through 2003. These links were based dominantly in Asia for the first three years, including China, Japan, Mongolia, Myanmar, Thailand and the former USSR, but have since broadened to include substantial collaborative programs in France, Norway, Germany, United Kingdom, Canada and the USA.

### EXAMPLES OF ACTIVE FUNDED PROJECTS IN ASIA

- geophysical analysis of China Geotraverses (including gravity modelling)
- nature and geophysical signature of the lithosphere in southeastern China
- crust-mantle interaction in southeastern China: the origin of the Yanshanian Granites and evolution of southeastern China
- trace element and isotopic characteristics of zircon as indicators of granite magma evolution
- nature of the lithosphere in northwestern China (Tianshan Mountains in Xinjian)
- metallogenesis of southeastern China
- crustal evolution, basaltic volcanism and basin development, north China
- mantle processes in the mantle wedge above the subduction zone in Japan
- thermal contrasts and paleogeotherms in Siberia, Mongolia, eastern China
- diamond exploration, tectonism, and geophysical nature of the lithosphere, Siberia and East Asia
- mantle terranes and tectonic analysis, Siberia
- lithosphere extension and geodynamic processes in east Asia (including the Taiwan region)

### FUNDED COLLABORATIVE PROJECTS COMMENCED OR ONGOING IN 2003 INCLUDE:

- The time scales of magmatic and erosional cycles, with Professor C. Hawkesworth (Bristol University), Dr M. Reagan (University of Iowa) and Dr J. Kirchner (University of California).



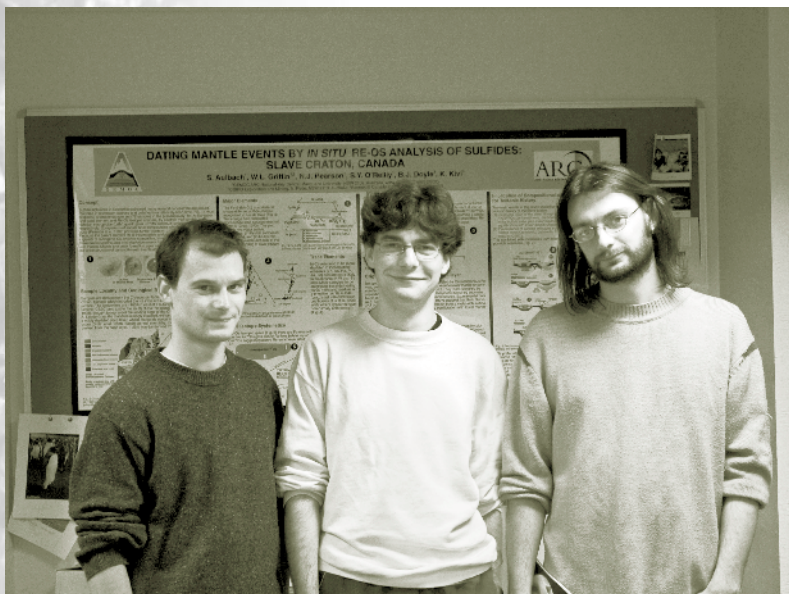
*The North African Workshop Team, University of Jean Monnet, St Etienne (Bill Griffin, Mohammed Abdelsalam, Sue O'Reilly, Peter Bowden and Jean-Yves Cottin).*

## GEMOC's international links

*Some of the French Connection: Guillaume Delpech, Mathieu Choukroun and Raynald Ethien.*

- The nature of lithosphere extension in the Taiwan region and implications for geodynamics in eastern China, with Professor S-L Chung, National University of Taiwan, relevant to the research project of Dr Kuo-Lung Wang (Macquarie University Research Fellow)
- Analysis of off-craton lithospheric mantle in East Central Asia Orogenic Belt, with Dr V. Malkovets, Novosibirsk
- *TerraneChron*<sup>TM</sup> analysis of the Amazon Craton, with WMC Resources
- Canary Islands lithosphere and volcanism with Prof. E.-R. Neumann (Oslo)
- Tectonic domains in southern Norway using *TerraneChron*<sup>TM</sup> with Prof. T. Andersen (University of Oslo) and Dr B. Bingen (Norwegian Geological Survey)
- Participation in the *RV Sonne* cruises to investigate the nature of the Campbell Plateau, Southern Ocean with Drs Karsten Gohl and Kaj Hoernle (Alfred Wegener Institute, Bremerhaven)
- Characteristics of the lithospheric mantle wedge in the Luzon-Taiwan subduction zone
- Collaboration continued with Professors A. Giret and J.-Y. Cottin of the

University of Jean Monnet, St Etienne (with reciprocal funding from both sides). A formal agreement between the two universities includes PhD exchange, academic exchange and research collaboration relevant to the nature of the lithosphere in the Kerguelen Archipelago, Crozet Islands and Hoggar. Three PhD programs related to this project are ongoing with Guillaume Delpech and Stephanie Touron (both funded by an International Postgraduate Research Scholarship (IPRS) and a French government Co-tutelle Scholarship) and Raynald Ethien (funded by a Co-tutelle Scholarship).



- Lithosphere studies in the Massif Central of France commenced in collaboration with the Universities of Jean Monnet (St Etienne) and Blaise Pascal (Clermont-Ferrand). The postgraduate program of Stephanie Touron (funded by an IPRS, a RAACE award and a Co-tutelle Scholarship) addresses this topic. Sue O'Reilly and Bill Griffin visited the University of Jean-Monnet for 3 months collaborative research in 2003 while Sue O'Reilly was a recipient of a CNRS Visiting Director of Research Award.
- Hf isotopic composition of rutiles in the South African lithosphere with M. Choukroun (Ecole Normale Supérieure, Paris) and Prof. J.B. Dawson (University of Edinburgh)

- Sulfides and the PGE budget in the mantle beneath the Massif Central with Prof. J.-L. Bodinier (Université Montpellier) and Prof. J.-P. Lorand (National Natural History Museum, Paris)
- Composition and crystal chemistry of mantle amphiboles with Dr M. Tiepolo, Dr R. Vance and Prof. R. Oberti from the University of Pavia, Italy
- *In situ* Sr isotope analysis of marine fossils to constrain stratigraphic/tectonic reconstruction of terranes in New Zealand, with Dr C. Adams (Institute of Geological and Nuclear Sciences, New Zealand)
- Interpretation of the lithosphere structure of the Global Geoscience Transect 21 with Professor Yuan Xuecheng of the China Geological Survey
- Igneous rocks, mineral deposits and tectonic setting: southeastern China and eastern Australia. This collaboration with Nanjing University has expanded from an AusAID grant under the ACILP scheme.
- Lithosphere Mapping and crustal evolution in southeastern China (with Professor Xu Xisheng, Nanjing University, funded by the Chinese National Science Foundation)
- Lithosphere studies in China (with Professor Jianping Zheng). This follows on from a project with a consortium of participating institutions in a 5-year National Priority Program funded by China NSF from 1997.
- Lithosphere structure of North America (with Kennecott Canada)
- Inclusions in diamonds from Canadian lithosphere (with Kennecott Canada Exploration Inc.)
- Trace elements in diamonds from the South African lithosphere (with de Beers)
- Lithosphere Mapping and crustal evolution in the Dharwar Craton, India (with Rio Tinto and Dr E. Babu (National Geophysical Research Institute, Hyderabad) funded by a Boyscast fellowship from India)
- Age and magma sources of Chilean Cu-porphyrries, with Codelco (Chile)
- Collaboration continued with Dr Scott E. Johnson at the University of Maine, funded by an NSF grant to Johnson, with Ron Vernon as collaborator, working on the San Jose pluton, Baja California, Mexico, and with Dr Scott R. Paterson at the University of Southern California, working on metamorphic-deformation problems in the Cascade Range, Washington. This project is being funded by an NSF grant to Vernon at USC, which also supports an MS student (Luke Jensen).

Refer to the *Research Program* and *Postgraduate* sections of this Report for details of other projects.

*GEMOC participants also have a wide range of other research collaborations with colleagues in UK, USA, Europe (France, Germany, Norway, Italy) as described in the section on Research Programs and in Appendix 5.*

## **WAS THE FUNDING STRATEGY FOR GEMOC CONTINUATION AFTER 2001 SUCCESSFUL?**

GEMOC's business plan has proved to be a successful blueprint, resulting in viable funding to continue GEMOC's activities beyond the Commonwealth funding period that ended in 2001.

### **Key elements of funding continuation include:**

- Macquarie University support of \$100,000 per annum
- Macquarie Vice-Chancellor's grant to support Geophysical Modelling development
- ARC Program Grant 2002-2006 for basic research component
- DEST Systemic Infrastructure Initiative Grant (\$5.125 million) for 2002-2004
- Industry funding is increasing through substantial collaborative ventures and value-added consulting
- Independent Research Fellowships to support Postdoctoral Fellows
- Continuation of existing funding sources for other ongoing activities such as postgraduate scholarships, undergraduate teaching development and pilot research projects.

### **Summary of strategy outcomes**

- Staff: 2 new academic staff members continuing, new academic staff appointment
- Postgraduate funding strategy exceeded goals
- Strategy for equipment and analytical funding exceeded goals

Macquarie University support has been exceptional in all areas including cash, in-kind and space guarantees, and in policy support. Macquarie's Research Strategic Plan recognises GEMOC's research programs as Areas of Excellence (lithosphere and planetary evolution and metallogeny; isotopic and global geochemistry; and paleomagnetism, geodynamics and geophysical modelling) and GEMOC as a Centre of Excellence.

### **Strategy for ongoing Geochemical Analysis Unit funding**

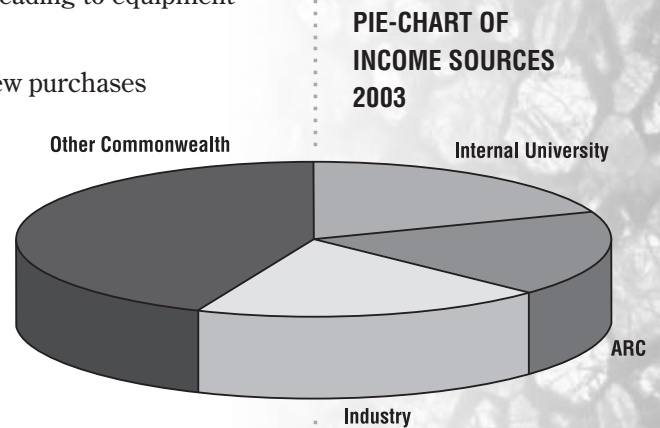
GEMOC's outstanding analytical facilities are vital to our innovative research programs and to attracting research and industry income. This technology concentration also represents a high-budget item in terms of maintenance, running costs, replacement and especially for new purchases to maintain frontline developments. Funding strategies in place include:

- User-pays system for running, maintenance and development costs
- University annual contributions through competitive schemes and capital equipment allocations
- Annual contribution from the Department of Earth and Planetary Sciences
- Macquarie University's guarantee of a strategic plan to ensure the integrity, maintenance and appropriate staffing of the Geochemical Analysis Unit
- Collaborative project building with industry partners

- Delivery of new exploration tools to industry through novel analytical methodologies
- Research and Development ventures with manufacturers leading to equipment replacement
- Applications to funding schemes for matching funds for new purchases
- Provision of services to external clients including industry
- Industry capital investment in return for access equity, negotiated intellectual property and collaborative rates

### GEMOC INCOME 2003

This is a summary of 2003 Income. A full audited statement of detailed expenditure and income is provided to DETYA every March. *No in-kind support is included.*



	<b>\$1000</b>
<b>ARC</b>	
<i>Discovery, SPIRT, Fellowships</i>	814.2
<b>OTHER COMMONWEALTH</b>	
<i>Postgraduate awards</i>	122.5
<i>DEST Systemic Infrastructure</i>	1900.0
<b>INDUSTRY</b>	
Collaborative Research grants (MUECRG, AMIRA)	275.3
Collaborative and commercial through MRL	324.5
Other Industry	312.9
<b>INTERNAL UNIVERSITY</b>	
<b>Annual Key Centre Contribution</b>	150.0
<b>Internal competitive schemes</b>	
Fellowships	153.6
Research grants	168.8
Vice-Chancellor Development Grant	100.0
Postgraduate awards	73.9
Postgraduate research grants	6.5
Infrastructure (RIBG)	61.1
Capital Equipment	133.3
GAU maintenance (Department)	30.0
<b>TOTAL</b>	<b>4626.6</b>

- BENEFITS TO AUSTRALIA**
- Scientific innovation relevant to National Priority Areas 1 (Goal 3: Developing Deep Earth Resources) and 3 (Goal 1: Breakthrough Sciences)
  - Excellence in training of our future generation of geoscientists
  - Enhanced industry links nationally and internationally
  - Improved criteria for exploration by Australian mining companies both on- and off-shore
  - Technological innovation (scientific advances, intellectual property, commercialisation, value-added consulting services)
  - Enhanced international links

## Appendix 1: Participants

### GEMOC PARTICIPANTS 2003

#### MACQUARIE UNIVERSITY

#### Department of Earth and Planetary Sciences

##### *Academic Staff*

##### *(Teaching and Research)*

- Dr Kelsie Dadd (Physical vulcanology, geochemistry, tectonics) 100%
- Dr Nathan Daczko (Structural and metamorphic geology, tectonics, geodynamics) 100%
- Dr Richard Flood (Volcanic geology, application of magnetic fabrics to reconstruction of volcanic terrains) 100%
- Professor W. L. Griffin, Program Leader (Technology development and industry liaison) 80%
- Dr Simon Jackson (Trace element geochemistry, metallogeny) 100%
- Dr Mark Lackie (Rock magnetism, paleomagnetic reconstructions) 30%
- Professor Suzanne Y. O'Reilly, Director (Crust and mantle evolution, lithosphere modelling) 100%

##### *Research Staff*

- Dr John Adam 40%
- Dr Elena Belousova 100%
- Ms Tara Deen 100%
- Dr Lev Natapov 100%
- Dr Yvette Poudjom Djomani 100%
- Dr Rhiannon George 100%
- Dr Vladimir Malkovets 100%
- Emeritus Professor Trevor Green 100%
- Professor Simon Turner 100%
- Emeritus Professor John Veevers 30%

- Emeritus Professor Ron Vernon 20%
- Dr Kuo-Lung Wang 100%
- Dr Ming Zhang 100%

##### *Adjunct Professors*

- Professor Bruce Chappell (Granite petrogenesis, geochemistry)
- Professor W. L. Griffin
- Dr John Hronsky (WMC Resources Ltd)
- Professor Paul Morgan (University of Northern Arizona, Geophysics and tectonics)
- Professor Mike Etheridge
- Professor Else-Ragnhild Neumann
- Professor Xisheng Xu

##### *Visiting Professors*

- Professor Tom Andersen (University of Oslo)
- Professor Jean-Yves Cottin (University Jean-Monnet, St Etienne)
- Dr Yong-Joo Jwa
- Associate Professor Ian Metcalfe (Tectonic reconstructions in Asia: Gondwana breakup)
- Professor Nicholas Fisher (Statistics, quality management)
- Dr Phil Schmidt (see CSIRO)

##### *Visiting Fellows*

- Dr Gilles Chazot (University of Clermont-Ferrand)
- Associate Professor Ian Metcalfe (Tectonics, Asian terrain reconstructions, Gondwana breakup)

##### *Honorary Associates*

- Dr Natsue Abe
- Dr Kari Anderson
- Ms Sonja Aulbach
- Dr Graham Begg
- Dr Phillip L. Blevin (Igneous metallogeny, ore deposit studies)
- Ms Rosa Maria Bomparola

- Professor Hannes Brueckner
- Dr Robert Bultitude
- Dr Gilles Chazot
- Mr David Clark (CSIRO)
- Professor Kent Condie
- Dr Richard Glen
- Dr Karsten Gohl (Seismic studies and RV Sonne Cruise program)
- Dr Michel Grégoire (Geochemistry)
- Dr Jingfeng Guo (Mineral exploration in Asia; mantle sulfides, sapphire origin)
- Dr Bram Janse (Diamond exploration)
- Dr Mel Jones
- Dr Felix Kaminsky
- Associate Professor Ian Metcalfe
- Dr Bertrand Moine
- Dr Geoff Nichols
- Dr Boris Panov
- Dr Mark C. Pirlo
- Dr Peter Robinson
- Dr Chris Ryan (CSIRO)
- Dr Stirling Shaw (Granitoids and crustal genesis)
- Dr Simon Shee
- Dr Zdislav Spetsius
- Dr Nancy van Wagoner
- Dr Steve Walters (Crustal terranes)
- Dr Xiang Wang
- Mr Bruce Wyatt (Mantle petrology, diamond exploration)
- Ms Chunmei Yu
- Professor Jin-Hai Yu
- Professor Jianping Zheng (Geochemistry, China lithosphere)

##### *Professional Staff*

- Ms Manal Bebbington (rock preparation) 50%
- Ms Eloise Beyer (Geochemist) 40%
- Ms Suzy Elhlou (Scientific Officer) 100%
- Dr Oliver Gaul (Research Officer) 80%

Dr Stuart Graham (Geochemist until July 2003) 100%  
Ms Sally-Ann Hodgekiss (Research Officer, Design consultant) 50%  
Dr John Ketchum (Geochemist) 100%  
Ms Carol Lawson (XRF, Laboratories) 100%  
Ms Valeria Murgulov (Geochemist) 40%  
Ms Leigh Newton (Administrator) 100%  
Dr Norman Pearson (Manager, GAU) 100%  
Dr Ayesha Saeed (Geochemist) 100%  
Dr Kirsty Tomlinson (Geochemist) 100%  
Mr Peter Wieland (Geochemist) 100%  
Mr William Powell (Research Assistant) 40%

#### **FORMAL COLLABORATORS**

##### ***University of Wollongong***

Professor Allan Chivas (DEST Systemic Infrastructure partner)

##### ***Monash University***

Dr Peter Betts  
Dr David Giles  
Dr Bruce Schaefer

##### ***University of Newcastle***

Dr W. Collins (DEST Systemic Infrastructure partner)

##### ***University of Sydney***

Dr G. Clark (DEST Systemic Infrastructure partner)  
Dr Dietmar Muller

##### ***University of Western Sydney***

Professor Peter Williams (DEST Systemic Infrastructure partner)

##### ***CSIRO Division of Exploration and Mining***

Dr Anita Andrew (Stable isotopes)  
Mr D. Clark (Paleomagnetism, magnetic modelling)

Dr N. Evans (PGE geochemistry and Re/Os systematics)  
Dr Brent McInnes (Cu/Au metallogeny)  
Dr C. G. Ryan (Proton microprobe, fluid analysis)  
Dr P. Schmidt (Rock magnetism, terrane evolution)  
Ms Tin Tin Win (Hydrothermal systems, mantle petrology)

##### ***Australian National University (Research School of Earth Sciences)***

Professor Brian Kennett  
Professor Gordon Lister

##### ***AGSO***

Dr Barry Drummond (Geophysics)  
Dr L. Wyborn (Crustal evolution, metallogeny through time, implementation of GPS/GIS)

##### ***Geological Survey of Western Australia***

Dr D. Nelson (zircon U-Pb/Hf isotopes)  
Dr I. Tyler (zircon U-Pb/Hf isotopes)

##### **OTHER COLLABORATORS ON PROJECT BASIS**

Dr Bernard Bingen (Geological Survey of Norway, Trondheim)  
Professor J.-L. Bodinier (Université Montpellier, France)  
Professor Chen-Hong Chen, (National Taiwan University)  
Professor Chen Daogong (University of Science and Technology of China, Hefei)  
Dr Sun-Ling Chung (National Taiwan University)  
Mr B. Doyle (Kennecott Canada)  
Dr Yuriy Erinchek (VSEGEI)  
Professor Weiming Fan (Resource and Environment Department, Chinese Academy of Sciences)

Professor A. Giret (Université Jean Monnet, St Etienne)

Mr K. Kivi (Kennecott Canada)

Dr T.-L. Knudsen (Geologisk Museum, Norway)

Dr Lai Shaocong (Northwestern University, Xi'an)

Dr L. M. Larsen (Greenland Geological Survey)

Dr J.-P. Lorand (Museum National d'Histoire Naturelle)

Professor Fengxiang Lu (China University of Geosciences at Wuhan)

Professor Ma Hongwen (China University of Geosciences at Beijing)

Professor Boris Panov (Donetsk State Technical University)

Professor S. R. Paterson (University of Southern California)

Dr Patrice Rey (University of Sydney)

Dr Peter Robinson (Geological Survey of Norway, Trondheim)

Dr Z. Spetsius (ALROSA, Mir)

Professor O. T. Tobisch (University of California, Santa Cruz)

Associate Professor Wang Xiang (Nanjing University)

Professor P. F. Williams (University of New Brunswick)

Professor Xue Jiyue (Nanjing University)

Professor Yuan Xuecheng (China Geological Survey)

Professor Zhou Xinmin (Nanjing University)

##### ***Technology Partners***

Agilent Technologies (Hewlett Packard)

New Wave Research

Spectro Instruments

Nu Instruments

## Appendix 2: Publications

A full list of GEMOC Publications is available at

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

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## Appendix 3: Visitors

### GEMOC VISITORS 2003 (Excluding Participants in Conferences and Workshops) Macquarie

Dr Chris Adams (Institute of Geological & Nuclear Sciences, New Zealand)  
Prof. Tom Andersen (University of Oslo)  
Dr Graham Begg (Western Mining Resources Limited, Perth)  
Mr Robert Bills (Western Mining Resources Limited, Perth)  
Dr Jon Blundy (University of Bristol, U.K.)  
Mr Nigel Brand (Anglo American, WA)  
Mr Mathieu Choukroun (PhD student, Universite St Etienne, France)  
Dr Richard Glen (Geological Survey of NSW, New South Wales, Australia)  
Dr Chris Hatton (De Beers South Africa)  
Dr Yong-Joo Jwa (Gyeongsang National University, Korea)  
Mr Chris Lay (New Wave Research Co. Ltd)  
Prof. T. M. Mahadevan (DST-DCS Newsletter Editor, India)  
Dr Suzanne McEnroe (Geological Survey of Norway, Trondheim)  
Mr Malcolm Norris (Western Mining Resources Limited, Perth)  
Dr Chris Oates (Anglo American, Canada)  
Prof. Boris Panov (Donetsk State Polytechnic University, Ukraine)  
Dr Peter Robinson (Geological Survey of Norway, Trondheim)  
Dr Bruce Schaefer (Monash University, Melbourne, Australia)

Dr Simon Shee (DeBeers Exploration Australia Ltd)  
Dr Steve Walters (GeoDiscovery Group, Queensland, Australia)  
Dr Xiaolin Xiang (Chinese Academy of Sciences, P. R. China)  
Prof. Xisheng Xu (Nanjing University, P. R. China)  
Ms Chunmei Yu (China University of Geosciences)  
Prof. Jianping Zheng (China University of Geosciences)

### EXTERNAL USERS OF THE GEOCHEMICAL ANALYSIS UNIT FACILITIES IN 2003

(Note: this does not include commercial or contract work through Macquarie Research Limited)

Dr Chris Adams, Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand  
Prof. Tom Andersen, University of Oslo, Norway  
Mr Manish Arora, Faculty of Dentistry, University of Sydney  
Dr Tim Baker, School of Earth Sciences, James Cook University, Townsville  
Ms Rosa-Maria Bomparola, Univeristà degli Studi di Siena, Italy  
Dr Graziella Caprarelli, Dept of Environmental Sciences, University of Technology, Sydney  
Mr Michael Carew, School of Earth Sciences, James Cook University, Townsville  
Mr Raynald Ethien, Universite Jean Monnet, St Etienne, France  
Mr Mathew Greentree, School of Earth and Geographical Sciences, University of Western Australia

Mr Bryce Healy, Department of Geology, University of Newcastle  
Dr Florence Le Hebel, Dept of Geosciences, University of Sydney  
Ms Panatree Lomthong, Dept of General Science, Kasetsart University, Bangkok, Thailand  
Dr Suzanne McEnroe, Geological Survey of Norway  
Dr Terry Mernagh, Geoscience Australia, Canberra  
Dr Bruce Mountain, Institute of Geological and Nuclear Sciences, Taupo, New Zealand  
Dr Niels Munksgaard, School of Science, Charles Darwin University  
Ms Kylie Prendergast, School of Earth Sciences, James Cook University, Townsville  
Mr Anthony Reid, School of Earth Sciences, Melbourne University  
Dr Peter Robinson, Geological Survey of Norway  
Mr Florian Schröter, Dept of Geosciences, University of Sydney  
Dr Keith Sircombe, School of Earth and Geographical Sciences, University of Western Australia  
Ms Tin Tin Win, CSIRO Exploration and Mining, North Ryde  
Dr Xiaolin Xiong, Guangzhou Institute of Geochemistry, China Academy of Sciences, Guangzhou, China  
Ms Chunmei Yu, China University of Geosciences  
Prof. Jianping Zheng, China University of Geosciences

## Appendix 4: Abstract titles

### TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2003

Full abstracts available at  
<http://www.es.mq.edu.au/GEMOC/>

#### GEOLOGICAL SOCIETY OF AMERICA 38<sup>TH</sup> NORTHEASTERN SECTION MEETING, HALIFAX, NOVA SCOTIA, CANADA, 27-29 MARCH 2003

##### Emplacement-related microstructures in the deformed carapace of a tonalite pluton: evidence for fast chamber construction

S. E. Johnson<sup>1</sup>, R. H. Vernon<sup>2</sup> and  
P. Upton<sup>1</sup>  
1. Dept. of Geological Sciences,  
University of Maine, Orono, USA,  
2. GEMOC, Macquarie

##### Evidence for fast magma chamber construction: the deformed carapace of the San Jose tonalite pluton, Mexico

S. E. Johnson<sup>1</sup>, R. H. Vernon<sup>2</sup> and  
P. Upton<sup>1</sup>  
1. Dept. of Geological Sciences,  
University of Maine, Orono, USA,  
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#### 5<sup>TH</sup> INTERNATIONAL SYMPOSIUM ON APPLIED ISOTOPE GEOCHEMISTRY, HERON ISLAND, QUEENSLAND, AUSTRALIA, 26-30 MAY 2003

##### *In-situ* determination of high precision isotope ratios by Laser Ablation-Multicollector-Inductively Coupled Plasma Mass Spectrometer (LA-MC-ICP-MS): Application to Cu and Fe isotopes in ore minerals

S. E. Jackson<sup>1</sup>, S. Graham<sup>1</sup> and  
D. Gunther<sup>2</sup>  
1. GEMOC, Macquarie, 2. Laboratory  
for Inorganic Chemistry, ETH  
Honggerberg, Zurich, Switzerland

#### ALICE WAIN MEMORIAL WEST NORWAY ECLOGITE FIELD SYMPOSIUM 2003, SELJE, WESTERN NORWAY, 21-28 JUNE 2003

##### Origin of Western Gneiss Region garnet peridotites: refertilisation of Archean lithosphere? Evidence from the Almklovdalen peridotite body

E. E. Beyer, W. L. Griffin, S. Y. O'Reilly  
and N. J. Pearson  
GEMOC, Macquarie

#### 8<sup>TH</sup> INTERNATIONAL KIMBERLITE CONFERENCE, VICTORIA, CANADA, 22-27 JUNE 2003

##### The lithospheric mantle beneath the Buffalo Head Terrane, Alberta: xenoliths from the Buffalo Hills kimberlites

S. Aulbach<sup>1</sup>, W. L. Griffin<sup>1,2</sup>,  
S. Y. O'Reilly<sup>1</sup> and T. E. McCandless<sup>3</sup>  
1. GEMOC, Macquarie, 2. CSIRO  
Exploration and Mining, North Ryde,  
3. Ashton Mining Canada Inc., North  
Vancouver, Canada

##### Origins of eclogites beneath the Central Slave Craton

S. Aulbach<sup>1</sup>, W. L. Griffin<sup>1,2</sup>,  
N. J. Pearson<sup>1</sup>, S. Y. O'Reilly<sup>1</sup>, K. Kivi<sup>3</sup>  
and B. J. Doyle<sup>4</sup>  
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Exploration and Mining, North Ryde,  
3. Kennecott Canada Exploration Inc.,  
Thunder Bay, Canada, 4. Kennecott  
Canada Exploration Inc., Vancouver,  
Canada

##### Inclusions in diamonds from the K10 and K14 kimberlites, Buffalo Hills, Canada: Diamond growth in a plume?

R. M. Davies<sup>1,2</sup>, W. L. Griffin<sup>2,3</sup>,  
S. Y. O'Reilly<sup>2</sup> and T. E. McCandless<sup>4</sup>  
1. American Museum of Natural  
History, New York, USA, 2. GEMOC,  
Macquarie, 3. CSIRO Exploration and  
Mining, North Ryde, 4. Ashton Mining  
of Canada, Canada

##### Geochemical characteristics of microdiamonds from kimberlites at Lac de Gras, Central Slave Craton

R. M. Davies<sup>1,2</sup>, W. L. Griffin<sup>2,3</sup>,  
S. Y. O'Reilly<sup>2</sup> and B. J. Doyle<sup>4</sup>  
1. American Museum of Natural  
History, New York, USA, 2. GEMOC,  
Macquarie, 3. CSIRO Exploration and  
Mining, North Ryde, 4. Kennecott  
Canada Exploration Inc., Canada

##### Geochemistry and Ar-Ar dating of upper Holocene volcanic rocks from Kerguelen islands (Indian Ocean)

R. Ethien<sup>1,2</sup>, G. Feraud<sup>3</sup>, M. C. Gerbe<sup>1</sup>,  
J. Y. Cottin<sup>1</sup>, S. Y. O'Reilly<sup>2</sup> and A. Giret<sup>1</sup>  
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Geochimie, UMR-CNR "Magma set  
Volcans", Universite Jean Monnet-  
Saint-Etienne, France, 2. GEMOC,  
Macquarie, 3. CNRS, "Geosciences  
Azur", Universite de Nice Sophia-  
Antipolis, France

##### Mineralogical and geochemical characteristic of a unique mantle xenolith from the Udachnaya kimberlite pipe

S. Kuligin<sup>1</sup>, V. Malkovets<sup>1</sup>,  
N. Pokhilenko<sup>1</sup>, M. Vavilov<sup>1</sup>,  
W. L. Griffin<sup>2,3</sup> and S. Y. O'Reilly<sup>3</sup>  
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##### Geochemical and isotopic evidence of a kimberlite-melnoite-carbonatite genetic link

S. Graham<sup>1</sup>, D. Lambert<sup>1,3</sup> and S. Shee<sup>1,4</sup>  
1. VIEPS, Monash University,  
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3. NSF, USA, 4. De Beers Australia  
Exploration Limited, Australia

##### Lithospheric mapping beneath the North American plate

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B. J. Doyle<sup>3</sup>, K. Kivi<sup>3</sup> and  
H. G. Coopersmith  
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## Appendix 4: Abstract titles

### **Peridotites from the Grib kimberlite pipe, Arkhangelsk, Russia**

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### **Cratonic conditions beneath Arkhangelsk, Russia: Garnet peridotites from the Grib kimberlite**

V. Malkovets<sup>1,2,3</sup>, L. Taylor<sup>2</sup>, W. L. Griffin<sup>3</sup>, S. Y. O'Reilly<sup>3</sup>, N. Pearson<sup>3</sup>, N. Pokhilenko<sup>1</sup>, E. Verichev<sup>4</sup>, N. Golovin<sup>5</sup> and K. Litasov<sup>6</sup>

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### **Eclogites from the Grib kimberlite pipe, Arkhangelsk, Russia**

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### **Taking the pulse of the Earth: lithosphere events tracked by *in-situ* geochronology**

S. Y. O'Reilly and W. L. Griffin  
GEMOC, Macquarie

### **Magnesium isotopic composition of olivine from the lithospheric mantle**

N. J. Pearson<sup>1</sup>, W. L. Griffin<sup>1,2</sup>, S. Y. O'Reilly<sup>1</sup> and G. Delpech<sup>1</sup>

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### **Pyropes and chromites of the Snap Lake/King Lake kimberlite dyke system in relation to the problem of the southern Slave Craton lithospheric mantle structure and composition**

N. Pokhilenko<sup>1,2</sup>, W. L. Griffin<sup>3,4</sup>, N. Shimizu<sup>5</sup>, C. McLean<sup>1</sup>, V. Malkovets<sup>2,3</sup>, L. Pokhilenko<sup>2</sup> and E. Malygina<sup>2</sup>

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### **Geophysical analysis of the lithosphere beneath the Slave Craton**

Y. H. Poudjom Djomani<sup>1</sup>, S. Y. O'Reilly<sup>1</sup>, W. L. Griffin<sup>1,2</sup> and B. J. Doyle<sup>3</sup>

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### **Diamond inclusions from Snap Lake, NWT Canada**

P. Promprated<sup>1</sup>, L. Taylor<sup>1</sup>, C. Floss<sup>2</sup>, V. Malkovets<sup>1</sup>, M. Anand<sup>1</sup>, W. L. Griffin<sup>3</sup>, N. Pokhilenko<sup>4</sup> and N. Sobolev<sup>4</sup>

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### **Trace element analysis of diamond by LAM ICPMS: preliminary results**

S. Rege<sup>1</sup>, R. M. Davies<sup>1,2</sup>, W. L. Griffin<sup>1,3</sup>, S. E. Jackson<sup>1</sup> and S. Y. O'Reilly<sup>1</sup>

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### **Late Vendian aerial alkaline volcanism in Winter Coast kimberlite area (Arkhangelsk Diamondiferous Province)**

V. S. Shchukin<sup>1</sup>, S. M. Sablukov<sup>2</sup>, L. I. Sablukov<sup>2</sup>, E. A. Belousova<sup>3</sup> and W. L. Griffin<sup>3</sup>

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### **Diamond formation and mantle metasomatism: A trace element perspective**

T. Stachel<sup>1</sup>, S. Aulbach<sup>2,3</sup>, G. P. Brey<sup>2</sup>, J. W. Harris<sup>4</sup>, I. Leost<sup>2</sup>, R. Tappert<sup>1,2</sup> and K. S. (Fanus) Viljoen<sup>5</sup>

1. University of Alberta, Canada, 2. Universitat Frankfurt, Germany, 3. GEMOC, Macquarie, 4. University of Glasgow, UK, 5. De Beers GeoScience Centre, South Africa

### **Melt inclusions from the deep Slave lithosphere: Constraints on the origin and evolution of mantle-derived carbonatite and kimberlite**

E. van Achterbergh<sup>1,2</sup>, W. L. Griffin<sup>1,2</sup>, S. Y. O'Reilly<sup>1</sup>, C. G. Ryan<sup>2</sup>, N. J. Pearson<sup>1</sup>, K. Kivi<sup>3</sup> and B. J. Doyle<sup>4</sup>

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**Natural trace element distribution between immiscible silicate and carbonate melts imaged by nuclear microprobe**

E. van Achterbergh<sup>1,2</sup>, C. G. Ryan<sup>2</sup>, W. L. Griffin<sup>1,2</sup> and S. Y. O'Reilly<sup>1</sup>  
1. GEMOC, Macquarie, 2. CSIRO Exploration and Mining, North Ryde

**Geochemical characteristics of mantle xenoliths from Penghu Islands, Taiwan Straits, SE Asian Margin**

K. Wang<sup>1</sup>, S. Y. O'Reilly<sup>1</sup>, W. L. Griffin<sup>1,2</sup>, S. Chung<sup>3</sup> and W. Juang<sup>4</sup>  
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**The Brockman Creek kimberlite, East Pilbara, Australia**

B. A. Wyatt<sup>1</sup>, M. Mitchell<sup>2</sup>, S. R. Shee<sup>2</sup>, W. L. Griffin<sup>3</sup>, N. Tomlinson<sup>4</sup> and B. White<sup>5</sup>  
1. De Beers Exploration Inc., Canada, 2. De Beers Australia Exploration Limited, Australia, 3. GEMOC, Macquarie, 4. GeoScience Centre, De Beers, South Africa, 5. University of Melbourne, Australia

**MAGMAS TO MINERALISATION: THE ISHIHARA SYMPOSIUM, MACQUARIE UNIVERSITY, NORTH RYDE, AUSTRALIA, 22-24 JULY 2003**

**Metallogeny of granite rocks**

P. Blevin  
GEMOC, Macquarie

**Paleozoic granite metallogeny of eastern Australia**

P. Blevin  
GEMOC, Macquarie

**Granites of the southern New England orogen**

C. J. Bryant<sup>1</sup>, B. W. Chappell<sup>2</sup> and P. Blevin<sup>2</sup>  
1. Dept. of Geology, Australian National University, Canberra, Australia, 2. GEMOC, Macquarie

**From Tuttle and Bowen onwards**

B. W. Chappell  
GEMOC, Macquarie

**Causes of variation in granite suites**

B. W. Chappell  
GEMOC, Macquarie

**High and low-temperature granites**

B. W. Chappell  
GEMOC, Macquarie

**Towards a unified model of granite petrogenesis**

B. W. Chappell  
GEMOC, Macquarie

**Granites of the Lachlan Fold Belt**

B. W. Chappell  
GEMOC, Macquarie

**Mesozoic granites and associated mineralisation in South Korea**

Y.-J. Jwa  
GEMOC, Macquarie

**Gravity and granites**

M. A. Lackie<sup>1</sup>, B. T. Bailey<sup>1,2</sup> and M. A. Edmiston<sup>1,3</sup>  
1. GEMOC, Macquarie, 2. Gmomic Exploration Services, Townsville, QLD, 3. Coffey Geosciences, North Ryde, NSW

**THIRD STATE OF THE ARC CONFERENCE (SOTA III), MOUNT HOOD, OREGON, 16-21 AUGUST 2003**

**Experimentally-determined trace element characteristics of aqueous fluid from partially dehydrated mafic oceanic crust at 3.0 GPa, 650-700°C**

T. H. Green and J. Adam  
GEMOC, Macquarie

**THE 5<sup>TH</sup> HUTTON SYMPOSIUM ON THE ORIGIN OF GRANITES AND RELATED ROCKS, TOYOHASHI, JAPAN, 2-6 SEPTEMBER 2003**

**Lithium isotopes and granite petrogenesis**

C. Bryant<sup>1</sup>, B. W. Chappell<sup>2</sup>, V. Bennett<sup>1</sup> and M. McCulloch<sup>1</sup>  
1. Research School of Earth Sciences, ANU, Canberra, 2. GEMOC, Macquarie

**Towards a unified model for granite genesis**

B. W. Chappell  
GEMOC, Macquarie

**Silica-oversaturated volcano-plutonic association in the Rallier du Baty Peninsula, Kerguelen Island: time and space relations and magma genesis**

R. Ethien<sup>1</sup>, M. C. Gerbe<sup>1</sup>, J.-Y. Cottin<sup>1</sup>, G. Feraud<sup>2</sup>, S. Y. O'Reilly<sup>3</sup> and B. Moine<sup>1</sup>

1. Universite Jean Monnet & UMR CNRS "Magmas et Volcans", Saint Etienne, France, 2. Universite de Nice-Sophia Antipolis, Geosciences Azur, Nice, France, 3. GEMOC, Macquarie

**A reconnaissance Lu/Hf investigation of the New England batholith Eastern Australia**

R. H. Flood and S. E. Shaw  
GEMOC, Macquarie

**Preservation of zircon U-Pb ages through high-grade metamorphism and magma genesis**

I. S. Williams<sup>1</sup>, B. W. Chappell<sup>2</sup>, D. W. Maidment<sup>1</sup> and I. S. Buick<sup>3</sup>  
1. Research School of Earth Sciences, ANU, Canberra, 2. GEMOC, Macquarie, 3. Department of Earth Sciences, La Trobe University, Bundoora, VIC

#### Appendix 4: Abstract titles

##### 13<sup>TH</sup> V. M. GOLDSCHMIDT

CONFERENCE, KURASHIKI, JAPAN,  
7-12 SEPTEMBER 2003

##### LA-ICP-MS: a mature technology?

S. E. Jackson  
GEMOC, Macquarie

##### Paleozoic upper mantle of the southern frame of the Siberian platform: Structure and composition

V. G. Malkovets<sup>1</sup>, A. A. Gibsher<sup>1</sup>,  
Y. D. Litasov<sup>2</sup>, S. Y. O'Reilly<sup>3</sup> and  
W. L. Griffin<sup>3</sup>

1. Institute of Mineralogy and Petrography, Novosibirsk, Russia,  
2. Institute of Geology, Novosibirsk, Russia, 3. GEMOC, Macquarie

##### New data on mantle metasomatism beneath the Deves, France

S. Touron<sup>1,2</sup>, S. Y. O'Reilly<sup>1</sup>, C. Renac<sup>2</sup>,  
C. Chazot<sup>3</sup> and J. Y. Cottin<sup>2</sup>

1. GEMOC, Macquarie, 2. Universite Jean Monnet St-Etienne, France,  
3. CNRS, Clermont-Ferrand, France

##### Proterozoic mantle lithosphere beneath the extended margin of the South China block: In situ Re-Os evidence

K.-L. Wang<sup>1</sup>, S. Y. O'Reilly<sup>1</sup>,  
W. L. Griffin<sup>1,2</sup>, S.-L. Chung<sup>3</sup> and  
N. J. Pearson<sup>1</sup>

1. GEMOC, Macquarie, 2. CSIRO Exploration & Mining, North Ryde,  
3. Department of Geosciences, National Taiwan University, Taiwan, R. O. C.

##### Re-Os isotopes in sulfides of mantle peridotites from SE China: age constraints and evolution of lithospheric mantle

X. Xu<sup>1,2</sup>, W. L. Griffin<sup>2</sup>, S. Y. O'Reilly<sup>2</sup>  
and N. J. Pearson<sup>2</sup>

1. State Key Laboratory for Mineral Deposits Research, Department of Earth Sciences, Nanjing University, Nanjing, China, 2. GEMOC, Macquarie

##### Trace element partitioning between natural clinopyroxene, garnet and plagioclase under liquid condition

J. Yu<sup>1</sup> and S. Y. O'Reilly<sup>2</sup>

1. Dept. Earth Sciences, Nanjing University, Nanjing, China,  
2. GEMOC, Macquarie

##### SGTSG FIELD MEETING KALBARRI 2003, KALBARRI, WESTERN AUSTRALIA, 22-26 SEPTEMBER 2003

##### Extension along the Australian-Pacific transpressional transform plate boundary near Macquarie Island

N. Daczko<sup>1,2</sup>, K. L. Wertz<sup>1,2</sup>, S. Mosher<sup>1</sup>,  
M. F. Coffin<sup>2,3</sup> and T. Meckel<sup>1,2</sup>

1. Department of Geological Sciences, University of Texas at Austin,  
2. Institute for Geophysics, University of Texas at Austin, 3. Ocean Research Institute, University of Tokyo & Institute for Frontier Research on Earth Evolution, Japan Marine Science & Technology Centre

##### AMERICAN GEOPHYSICAL UNION FALL MEETING, SAN FRANCISCO, USA, 8-12 DECEMBER 2003

##### Constraints on the mechanism and timing of sediment recycling beneath the Tonga-Kermadec arc from Be isotopes

R. George<sup>1</sup>, S. Turner<sup>1</sup>, J. Morris<sup>2</sup>,  
C. Hawkesworth<sup>1</sup> and J. Ryan<sup>3</sup>

1. GEMOC, Macquarie, 2. Department of Earth & Planetary Sciences, Washington University, Saint Louis, USA, 3. Department of Geology, University of South Florida, Tampa, USA

##### U-series isotopes and the time scales of magmatic processes

C. J. Hawkesworth<sup>1</sup>, D. W. Peate<sup>2</sup>,  
S. P. Turner<sup>3</sup> and R. M. George<sup>3</sup>

1. University of Bristol, Bristol, UK, 2. Danish Lithosphere Centre, Copenhagen, Denmark, 3. GEMOC, Macquarie

##### Calculating Upper Mantle Heat Flow Values Using Xenolith P-T Data and Temperature-Dependent Thermal Conductivity Estimates

P. Morgan<sup>1</sup> and S. Y. O'Reilly<sup>2</sup>

1. Northern Arizona University, Dept. Geology, USA, 2. GEMOC, Macquarie

##### Constraints on melting processes beneath subduction zones from U-Pa disequilibria

M. Regelous<sup>1</sup>, S. P. Turner<sup>2</sup>,  
C. J. Hawkesworth<sup>2</sup>, T. Elliot<sup>1</sup> and  
K. Rostami<sup>2</sup>

1. Dept. of Earth Sciences, University of Bristol, UK, 2. GEMOC, Macquarie

##### Navajo garnetites and rock-wall interaction in the mantle

D. Smith<sup>1</sup> and W. L. Griffin<sup>2</sup>

1. University of Texas at Austin, USA,  
2. GEMOC, Macquarie

##### Extreme Pb-Ra disequilibria observed in arc lavas: Implications for the time scales of magma degassing

S. Turner

GEMOC, Macquarie

## Appendix 5: Funded research projects

### GRANTS AND OTHER INCOME FOR 2003

Funding Source	Investigators	Project Title	Amount
Macquarie University Host Institution Support	O'Reilly	GEMOC Matching	\$100,000
Macquarie University Vice Chancellor's Special Fund	O'Reilly	Geodynamic Modelling	\$100,000
ARC Discovery	O'Reilly, Griffin, Gohl, Morgan, Cottin, Neumann, Xu	How has the continental lithosphere evolved? Processes of assembly, growth, transformation and destruction	\$329,926
ARC Discovery	Walter	Palaeobiology of hydrothermal mineral deposits	\$73,317
ARC Discovery	Belousova	Crustal evolution in Australia: Ancient and young terrains	\$101,695
ARC Discovery	Veevers	Mapping under ice – crustal evolution in Antarctica & the assembly of Gondwanaland	\$61,419
ARC LIEF	O'Reilly, Griffin, Braun et al.	An inference engine for complex earth systems (ANU lead institution)	\$190,000
ARC SPIRT	O'Reilly, Griffin, Hronsky, WMC	Lithospheric architecture of Australia: relevance to location of giant ore bodies (with industry contribution)	\$125,601
ARC	Turner	Federation Fellowship	\$296,934
DEST SII	O'Reilly	Advanced technology for a clever geoscience future in Australia	\$1,900,000
MURF	Wang	Geochemical characteristics of mantle xenoliths from Taiwan and Penghu Islands, SE China: Implications for mantle process and geodynamics	\$83,685
MURF	Malkovets	Evolution of the upper mantle beneath the Siberian Craton and the Siberian Platform	\$69,998
MURDG	Wang	Lithosphere extension in East Asia: tectonic and geochemical consequences	\$19,900
MURDG	Jackson	Isotopic fractionation of the ore minerals (Cu, Zn, Fe): Mechanisms and significance	\$13,000
MURDG	Green	Behaviour of antimony, molybdenum and tungsten in Earth's crust-mantle system - an experimental examination of their geochemical character	\$4,024

## Appendix 5: Funded research projects

Funding Source	Investigators	Project Title	Amount
MURDF	Etheridge	Risk and value management in mineral exploration	\$130,451
RIBG	O'Reilly	A high pressure asher	\$61,126
Capital Equipment	Lackie	Upgrade of teaching PC lab	\$16,133
Capital Equipment	Lackie	Real-time differential GPS total station	\$85,300
EPS	GEMOC	GAU Maintenance contribution	\$30,000
PGRF	Aulbach	Depletion and metasomatic processes in the lithosphere mantle	\$1,500
PGRF	Touron	Mapping geochemical domains in the mantle beneath the Massif Central (France)	\$4,000
PGRF	Rege	Trace elements in diamond	\$4,000
IPRS	Delpech	Isotopic characteristics of lithosphere processes beneath the Kerguelen Plateau	\$18,009
IPRS and MUIPRA	Guo	An integrated geophysical investigation of the Hunter-Mooki and Peel Faults	\$38,809
IPRS and MUIPRA	Aulbach	Depletion and metasomatic processes in the cratonic mantle	\$38,809
IPRS and MURAAACE	Touron, O'Reilly	Geochemical fingerprinting of the Massif Central (France) mantle	\$38,809
IPRS and iMURS	Rege, O'Reilly	Trace elements in diamonds: genetic and forensic implications	\$38,809
APA	Murgulov	Crust-mantle evolution and metallogeny, E. Australia	\$18,009
8IKC Conference Travel Grant	Aulbach	The lithospheric mantle beneath the Buffalo Head Terrane, Alberta: Xenoliths from the Buffalo Hills kimberlites	\$2,765
8IKC Conference Travel Grant	Rege	Trace element analysis of diamond by LAM ICPMS: preliminary results	\$2,765
8IKC Conference Travel Grant	Graham	Geochemical and isotopic evidence of a kimberlite-melnoite-carbonatite genetic link	\$2,765
EURODOC	Touron	Isotopic studies of the French Massif Central ultrabasic-basic xenoliths: source of the Tertiary-Quaternary volcanism, mantle metasomatism and 4D Mapping of the continental lithosphere	\$6,250
EURODOC	Delpech	Isotopic studies of Kerguelen ultrabasic-basic xenoliths: characterisation of the sources of magmatism and metasomatism beneath an oceanic plateau	\$6,250

Funding Source	Investigators	Project Title	Amount
MUECRG	Griffin, University of Oslo, Norwegian Geological Survey	Where was Baltica? Testing continental reconstruction with <i>TerraneChron</i> <sup>TM</sup> (including industry contribution)	\$85,308
MUECRG	Griffin, O'Reilly, Walter, BHP	Proterozoic crustal evolution: Baseline development of a global comparative library of Event Signatures linked to mineral endowment (including industry contribution)	\$100,000
MUNS	Daczko	Melt escape and trace-element partitioning during high-pressure partial melting in the lower crust, northern Fiordland, New Zealand	\$18,615

#### FUNDED RESEARCH PROJECTS FOR 2004

Funding Source	Investigators	Project Title	Amount
Macquarie University Host Institution Support	O'Reilly	GEMOC Key Centre Contribution	\$120,000
ARC Discovery	O'Reilly, Griffin, Gohl, Morgan, Cottin, Neumann, Xu	How has the continental lithosphere evolved? Processes of assembly, growth, transformation and destruction	\$285,000
ARC Discovery	Belousova	Crustal evolution in Australia: Ancient and young terrains	\$99,345
ARC Discovery	Turner	The time scales of magmatic and erosional cycles	\$100,000
ARC Discovery	Alard	Toward the use of metal stable isotopes in geosciences	\$140,000
ARC Linkage International	O'Reilly, Griffin, Cottin, Gregoire, Xu	How has the continental lithosphere evolved? Processes of assembly, growth, transformation and destruction	\$40,000
ARC Linkage Projects	O'Reilly, Griffin, WMC	Global lithosphere architecture mapping (including industry contribution)	\$190,000
ARC	Turner	Federation Fellowship	\$290,000
ARC	Daczko	The environmental and tectonic implications of volcanoclastic sedimentary deposits on Macquarie Island	\$79,000
DEST SII	O'Reilly	Advanced technology for a clever geoscience future in Australia	\$1,830,000
MUECRG	O'Reilly, Zhang, WMC	Continental flood basalts: geochemical discrimination with relevance to exploration for nickel and platinum-group elements (including industry contribution)	\$60,000
MUECRG	Griffin, O'Reilly, Rio Tinto	Lithosphere Mapping beneath the Dharwar Craton, India (including industry contribution)	\$60,800

## Appendix 5: Funded research projects

Funding Source	Investigators	Project Title	Amount
MUECRG	Griffin, Pearson, O'Reilly, Daczko, NSWGS	Testing Ordovician-Devonian tectonic models for the Lachlan group (including industry contribution)	\$50,000
MURIF	Smith, O'Reilly, Parfitt, Esselle	Inversion scattering, remote sensing and data inversion	\$247,681
MURF	Malkovets	Evolution of the upper mantle beneath the Siberian Craton and the Siberian Platform	\$66,949
MURF	Wang	Geochemical characteristics of mantle xenoliths from Taiwan and Penghu Islands, SE China: Implications for mantle process and geodynamics	\$32,482
MURDG	Wang	Lithosphere extension in East Asia: tectonic and geochemical consequences	\$19,555
MURDG	Jackson	Isotopic fractionation of the ore metals (Cu, Fe): Mechanisms and significance	\$16,700
MURDF	Etheridge	Mineral exploration risk	\$100,000
Nu Instruments	Griffin, O'Reilly	Postdoctoral Fellowship from Nu Instruments	\$312,929
Capital Equipment	Lackie	Frequency FM Equipment	\$42,000
Capital Equipment	Flood	Precision lapping & polishing machine	\$90,000
EPS	GEMOC	GAU Maintenance contribution	\$30,000
IPRS and MUIPRA	Guo	An integrated geophysical investigation of the Hunter-Mooki and Peel Faults	\$39,284
IPRS and MUIPRA	Touron	Geochemical fingerprinting of the Massif Central (France) mantle	\$39,284
IPRS and IMUPRA	Rege	Trace elements in diamonds: genetic and forensic implications	\$39,284
RAACE and iMURS	Daczko, Milan	The emplacement, pressure-temperature-time path and structural evolution of lower crust gneisses in Fiordland, New Zealand	\$39,284
APA	Murgulov	Crust-mantle evolution and metallogeny, E. Australia	\$18,484

ARC Research Projects initiated prior to 2003 are available at our website: <http://www.es.mq.edu.au/GEMOC/>  
Follow the Annual Report Link to Appendix 5 of the previous Annual Reports.

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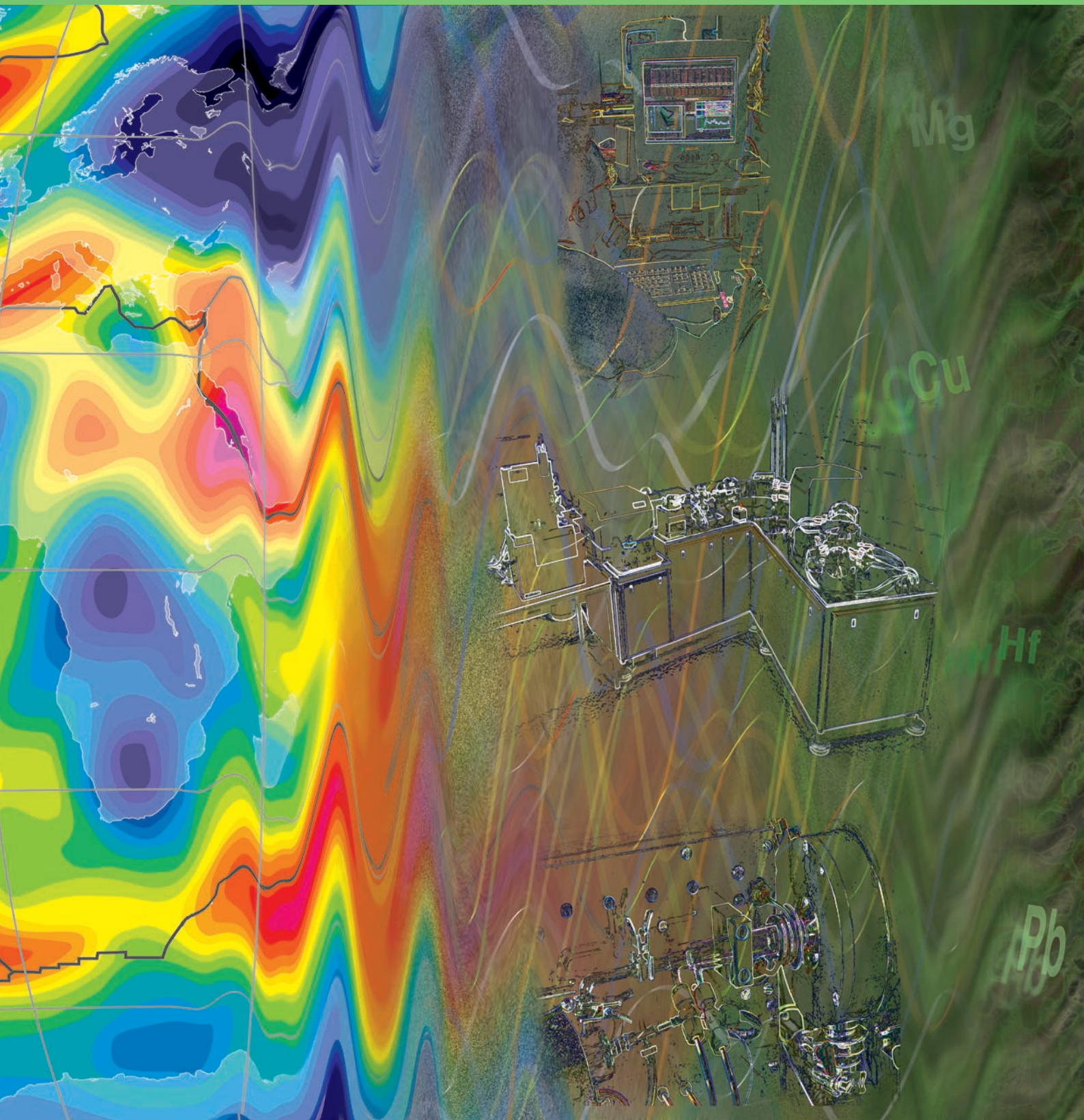
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## GLOSSARY

ACILP	Australia China Institutional Links Program
AGSO	Australian Geological Survey Organisation (now GA)
AMIRA	Australian Mineral Industry Research Association
ANU	Australian National University
APA (I)	Australian Postgraduate Award (Industry)
ARC (LGS)	Australian Research Council (Large Grant Scheme)
ARC LIEF	Australian Research Council Linkage Infrastructure Equipment & Facilities
AWI	Alfred Wegener Institute for Polar and Marine Research
CNRS	French National Research Foundation
CSIRO (EM)	Commonwealth Scientific Industrial Research Organisation (Exploration and Mining)
DEST (SII)	Department of Education, Science and Training (from 2002) (Strategic Infrastructure Initiative)
DETYA	Department of Education, Training and Youth Affairs (from 1998)
DIATREEM	Consulting company within MRL
EMP	Electron Microprobe
EPS	Earth and Planetary Sciences
EURODOC	The council for postgraduate students and junior researchers in Europe
GA	Geoscience Australia (formerly AGSO)
GAU	Geochemical Analysis Unit (Department of Earth and Planetary Sciences, Macquarie University)
GEOMAR	Research Center for Marine Geosciences
GIS	Geographic Information System
GLITTER	GEMOC Laser ICPMS Total Trace Element Reduction software
GPS	Global Positioning System
ICPMS	Inductively Coupled Plasma Mass Spectrometer
IMURS	International Macquarie University Research Scheme
IPEV	The French Polar Institute Paul Emile Victor
IPRS	International Postgraduate Research Scholarship
IREX	International Research Exchange Program of ARC
LAM-ICPMS	Laser Ablation Microprobe Inductively Coupled Plasma Mass Spectrometer
MC-ICPMS	Multi-Collector ICPMS
MRL	Macquarie Research Limited
MUECRG	Macquarie University External Collaborative Research Grants
MUIPRA	Macquarie University International Postgraduate Research Award
MUNS	Macquarie University New Staff Scheme
MUPGRF	Macquarie University Postgraduate Research Fund
MURAACE	Macquarie University Research Award for Areas and Centres of Excellence
MURD (F/G)	Macquarie University Research Development (Fund/Grant)
MURF	Macquarie University Research Fellowship
NERC	Natural Environment Research Council
NSF	National Science Foundation (USA)
NSWGS	New South Wales Geological Survey
ODP	Ocean Drilling Program (International Consortium)
PGRF	Postgraduate Research Fellowship
QDME	Queensland Department of Minerals and Energy
RAACE	Research Areas and Centres of Excellence Postgraduate Scholarships
RIBG	Research Infrastructure Block Grant
RSES	Research School of Earth Sciences at ANU
SPIRT	Strategic Partnership with Industry - Research and Training
USC	University of Southern California
XRD	X-Ray Diffraction



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