GEMOC's research program

SCIENTIFIC CONTEXT

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

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

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

The research aims

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

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

RESEARCH PROGRAM

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

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

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

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

• Lithosphere Mapping

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

• Geodynamics

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

• Crustal Generation Processes

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

• Metallogenic Provinces

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

STRENGTHENING GEOPHYSICS

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

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

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

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

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

RESEARCH PROJECTS FEEDING MAJOR PROGRAMS

Lithosphere Mapping

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

U-series applications to timescales of lithosphere processes Research Highlights

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

Gravity modelling of lithosphere terranes (regional elastic thickness)

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

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

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

Basalts as lithosphere/asthenosphere probes

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

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

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

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

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

Tracking mantle plumes through time

Metal isotopes as tracers of lithosphere processes and Earth evolution

Crustal Evolution

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

Crustal evolution and metallogenesis, southeastern China

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

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

Metamorphic reactions and mineral growth; microstructural processes in metamorphic rocks

Tracers of magmatic processes; trace elements in accessory minerals

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

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

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

Metallogenesis

Risk management in exploration

U-series applications to timescales of fluid movement

Metal isotope applications to ore genesis

Geochemistry of mantle sulfides Research Highlights

Chromite chemistry in mantle-derived magmas and residues

Resistate minerals and mineral exploration Research Highlights

Area selection and evaluation for diamond exploration

Lithosphere domains through time and location of ore deposits

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

Sulfide and PGE budget of the mantle Research Highlights

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

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

Zircon composition in mineral exploration Research Highlights

Groundwater geochemistry and aquifer lithology

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

Trace elements in diamonds - possible genetic indicators?

Geodynamics

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

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

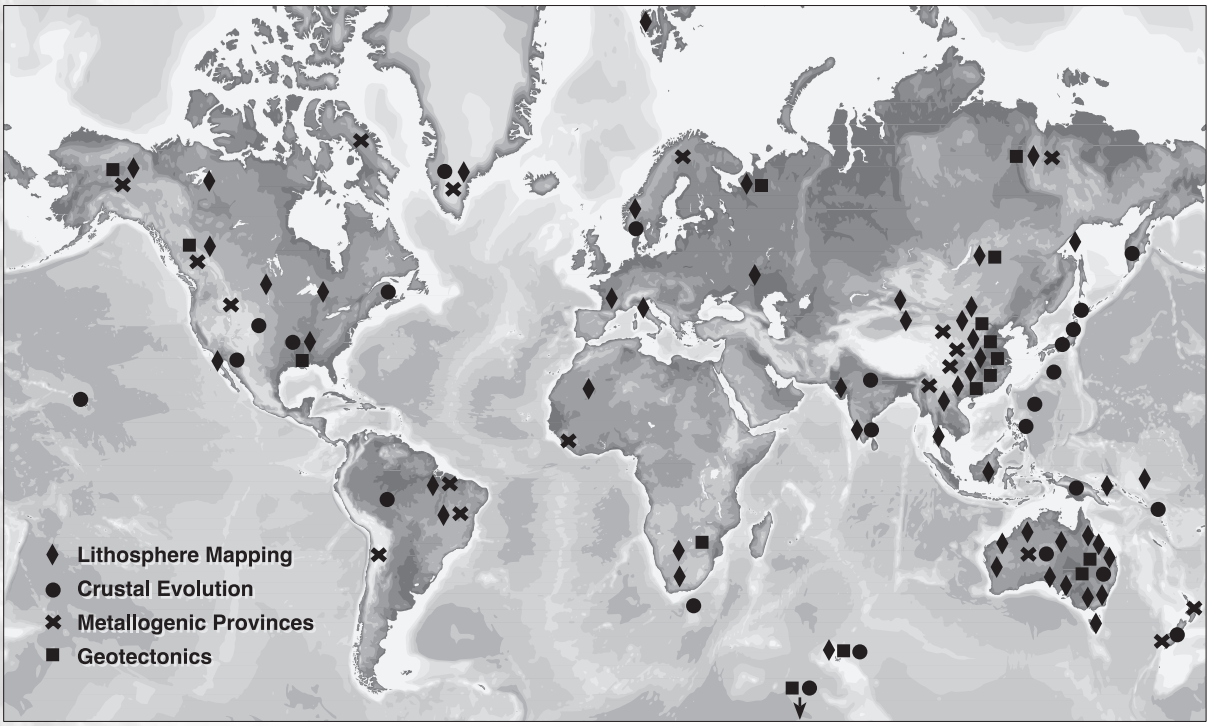
Tasman Fold Belt tectonism and regional volcanology: Tumut-Gundagai region; Louth area; central western NSW; central Queensland

Paleomagnetic studies of the northern New England Orogen

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

Evolution of lithospheric composition and Earth geodynamics through time Research Highlights

WHERE IN THE WORLD IS GEMOC?



Funded basic research projects for 2004

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

Toward the use of metal stable isotopes in geosciences

Olivier Alard: Supported by ARC Discovery

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

Crustal Evolution in Australia: Ancient and Young Terrains

Elena Belousova: Supported by ARC Discovery

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

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

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

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

The timescales of magmatic and erosional cycles

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

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

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

Simon Jackson: Supported by Macquarie University Research Development Grant

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

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

Vladimir Malkovets: Supported by Macquarie University Research Fellowship

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

Lithosphere extension in East Asia: tectonic mechanisms and geochemical consequences

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

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

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

Nathan Daczko: Supported by Macquarie University Early Career Research Grant

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