

Research School of Earth Sciences Annual Report 2007



"The gold may be gone, but all around Australia abandoned open pit mines have a silver lining: Their excellent exposures reveal the weathering history of our ancient landscapes. Meekatharra (mid west W.A.). B. Pillans

Research School of Earth Sciences 2007 Annual Report - Contents

- ∞ Directors Introduction
- ∞ Honours & Awards
- ∞ Staff & Students
- ∞ Research Activities
 - Earth Chemistry
 - Earth Environment
 - Earth Materials & Processes
 - Earth Physics
 - PRISE
- ∞ Research Support
 - Electronics
 - Engineering
- ∞ Publications
- ∞ New Grants
- ∞ National & International Links
- ∞ Staff Activities

Director's Introduction

2007 has again been a year of change. The review of the Department of Earth and Marine Sciences (DEMS) in May recommended the creation of a single discipline entity in Geosciences incorporating both RSES and DEMS. Following extensive discussion this recommendation was accepted by both parties. The Director and Dean of the College negotiated an arrangement with close integration to try to overcome the spatial separation of the two components on the ANU campus.

In September, ANU Council approved the creation of a new Research School of Earth Sciences incorporating the Department of Earth and Marine Sciences. The agreement includes an Education Contract between the School and the College of Science with respect to the provision of Undergraduate and Postgraduate Courses, as well as the Higher Degree Research program.

An Associate Director (Education) will report to both the Dean of the College and the Director of the School. The new structure comes into being at the beginning of January 2008, and we hope that the spirit of good will that infused this year's activities can continue through the inevitable problems that will come with the implementation of the merger.

In March 2007, RSES carried out a review of work in the area of Solid Earth Geophysics with a distinguished panel of external scientists in the School for most of a week. Components of the Earth Physics and Earth Materials areas combined to develop a comprehensive set of materials that were distributed in advance to the Review Committee. The Committee had a very busy schedule of interviews and presentations during their time in the School and produced a thorough report very quickly.

The Review endorsed the very high quality of the work in geophysics in the School and recommended that there should be further investment in the area of computational geophysics. As a result a search committee has been formed to investigate the possibility of an appointment across the full range of fields in which numerical simulation is important.

The high quality of work at RSES continues to receive external recognition. Prof. Brad Pillans has been elected as Honorary Fellow of the Royal Society of New Zealand (Hon FRSNZ) and Dr Ian Williams has been elected as a Fellow of the Academy of Technological Sciences and Engineering (FTSE) for his work on the development and commercialisation of the SHRIMP ion microprobe. At the European Geosciences Union meeting in Vienna in April, two sectional medals were awarded to RSES scientists.

The Gutenberg medal in Seismology was presented to Prof. Brian Kennett and the Bunsen Medal in Mineralogy to Prof. Hugh O'Neill. Professor O'Neill also shared the 2007 Bowen Award from the Volcanology, Geochemistry and Petrology Section of American Geophysical Union and this was awarded at the Fall Meeting in San Francisco in December.

Internal recognition has come through promotion of three members of RSES to Professor: Dr I Campbell, Dr T. Ireland and Dr M. Sambridge. In addition in the 2007 promotion round, Dr J. Mavrogenes was promoted to Level D and Dr N. Rawlinson to Level C.

The Accelerator Mass Spectrometer supported by 2005 ARC LIEF funds was commissioned at the end of February and is active use for ^{14}C dating. The geobiological mass-spectrometry facility on the top floor of Jaeger 2 came into full use in September. The modest Jaeger 5 building constructed to house SHRIMP RG is being extended to house the new SHRIMP SI that is under construction. An upper storey will provide a focus for the Planetary Sciences Initiative with a new microchemistry facility. Progress has been good and the building should be in use by mid-2008.

The number of grants funded through the Australian Research Council was down somewhat in 2007, but did include two very large grants in the areas of geodesy and tectonics. RSES was part of a successful consortium led by the University of Queensland that received support from LIEF funding for thermochronology work.

AuScope Ltd., has been established to administer the National Cooperative Infrastructure Strategy (NCRIS) funding for "Structure and Evolution of the Australian Continent", and ANU was the first institution to sign the participant agreement. RSES houses components of the Earth Imaging, Geospatial and Simulation & Modelling activities. Professors Lambeck and Kennett are on the AuScope Executive Committee as the Senior Scientists in the Geospatial and Earth Imaging Area. With AuScope support a new computer cluster TerraWulf II has been installed at RSES to provide a facility for geophysical inversion.

Further capital investment is under way in an absolute gravimeter and new seismic instrumentation. In Earth Imaging AuScope was able to supplement reflection work in North Queensland by Geoscience Australia and the Geological Survey of Queensland to provide multiple crossings of the enigmatic "Tasman Line".

Research at RSES mobilises a wide range of geological, geochemical and geophysical techniques and expertise to try to understand the nature of the Earth and its environment. The research is organised through the four main Research Areas: Earth Chemistry, Earth Environment, Earth Materials & Processes and Earth Physics, but many activities transcend area boundaries.

The following pages provide an account of many facets of the research activity of RSES undertaken in 2007.

B.L.N. Kennett

Honours & Awards

Earth Chemistry

Mrs. J.N. Avila received the Vice-Chancellor's Higher Degree Research Travel Grant award, The Australian National University, to do collaborative work with researchers from the Laboratory for Space Sciences, Washington University, St. Louis, USA.

Mrs. J.N. Avila received a travel grant award, from the University of Hawaii at Manoa, to participate in the Workshop on the Chronology of Meteorites and the Early Solar System, Hawaii, USA.

Dr I.S. Williams was elected a Fellow of the Australian Academy of Technological Sciences and Engineering.

Earth Environment

Ms S.C Bretherton received the joint 2007 Mervyn and Katalin Paterson Fellowship.

Dr K.E. Fitzsimmons received the inaugural Directors Prize for Scientific Communication from RSES.

Dr K.E. Fitzsimmons received a Student Travel Prize from the Australasian Quaternary Association for attendance at the INQUA Congress

Dr K.E. Fitzsimmons received a Student Award for contribution to regolith geoscience from the Cooperative Research Centre for Landscape Environments and Mineral Exploration.

Dr M.K. Gagan was Finalist for the Sherman Eureka Prize for Environmental Research.

Prof. M.T. McCulloch was received as a Fellow of the Geological Society of Australia, in December, for outstanding contributions to geological sciences.

Mr I. Moffat was appointed an adjunct associate lecturer in the Department of Archaeology, Flinders University.

Prof. B.J. Pillans was elected an Honorary Fellow of the Royal Society of New Zealand.

Dr P.C. Treble, British Council Exchange Award for Young Scientists, travel support to undertake collaborative study with Prof. Ian Fairchild at the University of Birmingham (UK) during October ñ December 2007.

Earth Materials & Processes

Prof S.F. Cox was the Society of Economic Geologists 2007 Distinguished Lecturer.

Professor D. Green was awarded the Gold Medal, 'The Geological Society of Japan International Prize', for research and international collaboration. The medal was presented at the annual meeting of The Geological Society of Japan held in Sapporo, Hokkaido.

Professor D. Green was elected as Fellow of the Geological Society of Australia.

Mr. I. Kovacs received the Outstanding Young non-Russian Researcher Award 2007 from the Russian Mineralogical Society.

Mr. G. Mallmann received a Vice-Chancellor's Travel Grant to participate in the 2007 AGU Fall Meeting in San Francisco, USA.

Emeritus Prof I. McDougall was awarded the Jaeger Medal by the Australian Academy of Science.

Emeritus Prof I. McDougall has been appointed Adjunct Professor in the School of Physical Sciences, the University of Queensland.

Prof. H. O'Neill was awarded the 2007 Robert Wilhelm Bunsen medal of the European Geosciences Union, for Geochemistry, Mineralogy, Petrology & Volcanology.

Prof. H. O'Neill has been awarded the 2007 N. L. Bowen Award of the American Geophysical Union.

Prof. H. O'Neill was elected a Fellow of the Geochemical Society.

Earth Physics

Dr F. Fontaine was awarded young talent 2007 of France's overseas department. The goal of this award is to provide an example of achievement to young people from France's overseas department. The idea is to promote young people who have reached an excellent level in a specialty different than music or sport.

Prof B.L.N. Kennett received the Gutenberg Medal from the European Geosciences Union for his work in seismology.

Prof K. Lambeck, was an invited participant in the Nobel Laureates Beijing Forum 2007: Energy and Environment, Beijing, China, 10-14 September 2007.

Prof K. Lambeck received an Honorary Professorship from the Graduate University of the Chinese Academy of Science.

Prof K. Lambeck was invited to present the 2007 Joseph Gentilli Memorial Lecture, University of Western Australia.

Prof K. Lambeck, Science Finalist, in The Bulletin Smart 100, 2007.

Dr. SCHELLART received the J. G. Russell award, awarded by the Australian Academy of Science in 2007 as a token of the community's regard for young Australian researchers in the fields of biology and physical sciences.

Dr P. Tregoning, Fellow of the International Association of Geodesy.

PRISE

Ms A. Rosenthal received a joint Mervyn and Katalin Paterson fellowship 2007 to attend 2008 Goldschmidt Conference, Vancouver and 9th International Kimberlite Conference, Frankfurt and to collaborate with specialists in both deformation, structure and Norwegian regional petrology/geology at Universiteit Utrecht.

Ms A. Rosenthal was awarded an ANU Travel Grant to cover the costs of conference registration, accommodation and living expenses at the Goldschmidt Conference 2007 (Cologne, Germany)

ACADEMIC STAFF

Director

B.L.N Kennett, Ma PhD ScD Cambridge, FRAS, FAA, FRS

Distinguished Professors

B.L.N Kennett, Ma PhD ScD Cambridge, FRAS, FAA, FRS

K. Lambeck, BSurv NSW, DPhil, DSc Oxford, FAA, FRS

Professors

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S.F. Cox, BSc Tasmania , PhD Monash

R.W. Griffiths, BSc PhD ANU, FAIP, FAA

R. Grün, Dip Geol, Dr.rer.nat.habil Köln, DSc ANU

T.M. Harrison, BSc British Columbia, PhD ANU, FAA (1 September 2007)

I.N.S. Jackson, BSc Qld, PhD ANU

G. Lister, BSc Qld, BSc (Hons) James Cook, PhD ANU

M.T. McCulloch, MAppSc WAIT, PhD CalTech, FAA

H.St.C. O'Neill, BA Oxford, PhD Manchester

B.J. Pillans, BSc PhD ANU

Senior Fellows

I. Buick, Bsc (Hons), MSc Adelaide, PhD Cambridge

G.F. Davies, MSc Monash, PhD CalTech

S. Eggins, BSc UNSW, PhD Tasmania

C.M. Fanning, BSc Adelaide

M.K. Gagan, BA UC Santa Barbara, PhD James Cook

M. Honda, MSc PhD Tokyo

T.R. Ireland, BSc Otago, PhD ANU

R.C Kerr, BSc Queensland, PhD Cambridge , FAIP

C. Lineweaver, BSc München, PhD Berkeley

M.S. Sambridge, BSc Loughborough, PhD ANU

I.S. Williams, BSc PhD ANU

Fellows

Y. Amelin, MSc, PhD Leningrad State University (from 29 March 2007)

R. Armstrong, BSc MSc Natal, PhD Witwatersrand

V.C. Bennett, BSc PhD UCLA

J.J. Brocks, Dip Freiburg, PhD Sydney
D.R. Christie, MA Toronto, PhD ANU (to 1 October 2007)
W.J. Dunlap, BA CarIcol, MS PhD Minnesota (to 19 April 2007)
J. Hermann, Dip PhD ETH-Zürich
A.M. Hogg, BSc ANU, PhD UWA (from 3 May 2007)
G. Hughes, BE ME Auckland, PhD Cambridge
J.A. Mavrogenes, BS Beloit, MS Missouri-Rolla, PhD Virginia Poly Tech
M. Norman, BS Colorado, PhD Harvard
R. Rapp, BA State University of New York, PhD Rensselaer Polytechnic Institute
A. Reading, BSc Edinburgh, PhD Leeds (to 15 February 2007)
E. Rhodes, BA DPhil Oxford (to 13 August 2007)
D. Rubatto, BSc MSc Turin, PhD ETH-Zürich
H. Tkalcic, Dip University of Zagreb, PhD University of California at Berkeley (from 18 January 2007)
P. Tregoning, BSurv PhD UNSW
G. Yaxley, BSc PhD Tasmania

Research Fellows

L. Ayliffe, BSc (Hons) Flinders, Grad Dip Adelaide, PhD ANU
A.L. Dutton, BA (Mus) Massachusetts, MSc PhD Michigan
M. Ellwood, BSc (Hons) PhD University of Otago
K. Evans, MA PhD Cambridge (to 1 May 2007)
S. Fallon, BA MS University of San Diego, PhD ANU
J. Kurtz, BSc MSc Louisiana State, PhD Arizona State (to 30 March 2007)
C. McFarlane, BSc Toronto, MSc Calgary, PhD Texas (to 2 August 2007)
C. Sinadinovski, BSc (Hons) MSc University of Zagreb, PhD Flinders University (to 14 September 2007)
P. Treble, BSc Wollongong, BSc PhD ANU

Postdoctoral Fellows:

P. Arroucau, PhD Nantes University (from 3 September 2007)
M. Aubert, PhD, Université du Québec
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Senior Visitors

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D.H. Green, BSc MSc DSc, DLitt(Hon) Tasmania, PhD Cambridge, FAA, FRS*
I. McDougall, BSc Tasmania, PhD ANU, FAA*
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* Emeritus Professor

Research Officers

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Marilee Farrer

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Teresa Heyne, BComm Deakin University

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Earth Environment – Susanne Hutchinson, BA La Trobe University

Earth Materials & Processes– Kay Provins

Earth Physics – Denise Steele

- Danica Fouracre (Prof Kurt Lambeck), BEnv.Des BA Hons UWA

PRISE – Brenda Armstrong, BSc UNISA

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Wayne Cook, Cert Geoscience CIT, BSc ANU

Derek Corrigan

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Ben Jenkins, BSc UTS, PhD ANU

Damien Kelleher, Assoc Dip Cartog CIT

Leslie Kinsley, BSc Gra Dip Sc ANU

Harri Kokkonen, BAppSc CCAE

Andrew Latimore

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Graham Mortimer, BSc PhD Adelaide

Charles Norris, BSc ANU

Shane Paxton

Anthony Percival

Tristan Redman (from 23 July 2007) Trainee

Craig Saint

Hideo Sasaki (from 23 July 2007) Trainee

Scott Savage

Norman Schram, Dip EIE SAIT

Dean Scott

Heather Scott-Gagan, BSc Sydney

Stefan Sirotjuk, Assoc Dip TAFE (to 5 July 2007)

Brendan Taylor (to 20 April 2007)

David Thomson

Carlyle Were

Andrew Welsh, BAppSc CCAE

Andrew Wilson

Geoffrey Woodward

Igor Yatsevich, BEng Tashkent Polytec Inst, PhD Russian Academy of Sciences

Xiaodong Zhang, PhD LaTrobe

Research Activities

Earth Chemistry

Earth Chemistry introduction

The chemistry and isotope chemistry of natural materials is highly indicative of provenance and process throughout geological history. Our studies range in time from the earliest solar system through to processes that are actively taking place today, and in scope from planetary systems to individual molecules. Active areas of research centre on planetary studies, metamorphic and igneous geochemistry and geochronology, geochemistry of life processes, and chronology of all processes encompassed.

Most of our analytical work involves detailed analysis on the microscale, or concentrating trace elements from larger samples for high precision analysis. Isotopic systems can reveal both the nature of the processes involved (stable isotopes) as well as the timing of events (radiogenic isotopes), while chemical abundances can reflect protolith contributions and processes affecting various systems including biologic systems. As revealed in this year's research contributions, analytical work can be applied to topics in tectonics, ore genesis, metamorphic petrology, paleoclimate, paleoecology and regolith dating.

Highlights

Commissioning of Dr Brock's paleobiogeochemistry laboratory has gradually taken place in 2007, with installation of mass spectrometers and operation of the chemistry laboratory. In early 2007, it was announced that an extension to the J5 (SHRIMP RG) Building was to be funded by the Chancelry. The project involves doubling the length of the extant building and adding a second floor to house offices, common room, and geochemistry laboratories. The ground floor allows an extension to the SHRIMP RG lab that will eventually house both SHRIMP SI and SHRIMP II. Building completion is expected in mid 2008. Construction of SHRIMP SI is now awaiting the completion of the building. In February 2007, Earth Chemistry ran an intensive course on Mass Spectrometry in Earth Sciences for RSES postgraduate students and staff. The course was well attended (~25 participants) and highlighted the need for continuing training.

In mid 2007, a stable isotope workshop was held to mark the achievement of subpermil reproducible stable isotope analyses on SHRIMP II. Guests at the workshop included Dr Marc Chaussidon and Dr Etienne Deloule of CRPG, Nancy, France, and Dr Doug Rumble of Carnegie Institution, Washington DC, USA. The meeting was attended by ANU researchers and other scientists from around Australia.

Personnel

Dr Marnie Forster was successful in her ARC request for an ARF and has joined Earth Chemistry for 2008. Dr Forster's research focuses on the interrelationships between microstructure development and geochronology. Following the successful installation of the C-14 accelerator-mass spectrometer, Dr Stewart Fallon will be joining Earth Chemistry in 2008. PhD studies were completed by Frances Jenner, Julien Celerier, Amos Aikman and Antti Kallio. Congratulations Doctors. Postgraduate studies were commenced by Tanya Ewing, Seann McKibbin, Rong Shi, and Richard Schinteie.

ARC

Professor Ian Campbell was successful in his ARC DP proposal for platinum-group elements in felsic rocks. A successful collaborative bid to ARC LIEF between ANU, University of Queensland (lead organization) and The University of Melbourne will see a new SEM especially configured for geological materials installed at RSES.

Probing *s*-process conditions in AGB stars: Constraints from Ba and Eu isotopes on presolar SiC grains

Janaina N. Avila¹, Trevor R. Ireland¹, Frank Gyngard², Peter Holden¹, Ernst Zinner², Vickie Bennett¹, Sachiko Amari²

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The *s*-process occurs in red giant stars of low- to intermediate-mass ($M \sim 0.8\text{--}8 M_{\odot}$) during the asymptotic giant branch (AGB) phase of evolution [1], and operates in conditions of low neutron density (of the order of $10^7 - 10^8 \text{ cm}^{-3}$) with timescale for neutron capture much longer than that of any beta-decay. Depending on neutron density and temperature, some unstable nuclei with long half-lives can capture neutrons rather than decay. In these cases, the *s*-process path splits into two branches, modifying the final abundances of nuclei affected by these branching points. In the helium intershell, neutrons are released by $^{13}\text{C}(\alpha, n)^{16}\text{O}$ and $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$ reactions during interpulse and thermal pulse phases, respectively. Although the ^{22}Ne neutron source represents only a few percent of the total exposure, it suffices to modify the abundance patterns of several temperature- and neutron density-dependent branchings[2].

Since Eu isotopes are significantly affected by the branching at ^{151}Sm , and Ba isotopes by the branching at ^{134}Cs , Eu and Ba isotopic ratios can be used to investigate temperature and neutron density of *s*-process sites. The β -decay rate of ^{151}Sm and ^{134}Cs are highly susceptible to temperature, making the isotopes affected by these branching points good thermometers.

Eu and Ba isotopic ratios were measured, simultaneously, in presolar SiC grains from the Murchison meteorite using SHRIMP RG at RSES, ANU. The analyzed single grains are from mainstream population, which formed during mass loss from AGB carbon stars. As can be seen from fig. 1a, the $\text{fr}(^{151}\text{Eu})$ is slightly sensitive to temperature and neutron density during the *s*-process[3]. The $\text{fr}(^{151}\text{Eu})$ values obtained in this study for single SiC grains range from 0.593 to 0.643, except for one single grain, which has a $\text{fr}(^{151}\text{Eu})$ value of 0.331 (fig. 1b). According to Arlandini et al.[2], the *s*-process signature in AGB stars yields $\text{fr}(^{151}\text{Eu})$ values of 0.541 and 0.585 for the stellar and classical models, respectively. Our results are slightly higher than those values, but are notably different from the Solar System value of 0.478. Since $\sim 95\%$ of Eu in the Solar System is expected to originate from *r*-process[2], the value of 0.478 can be used as a *r*-process reference. The presolar SiC grains studied here are highly depleted in ^{134}Ba , except for one single grain (fig. 1b).

Both Eu and Ba isotopic data indicate high contribution from $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$ neutron source in the final abundance patterns of presolar SiC, which can be explained by low neutron density and low temperature conditions.

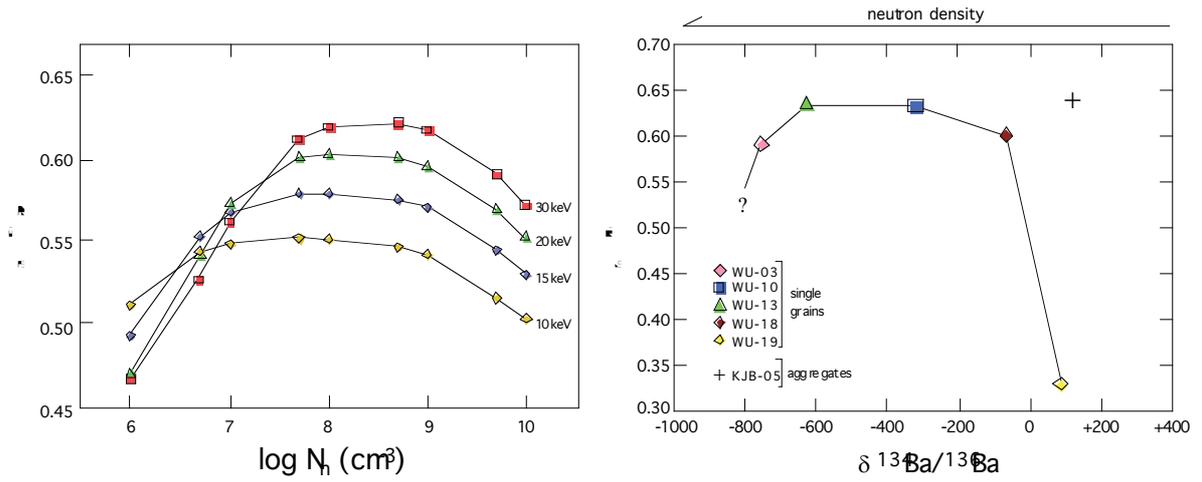


Figure 1. a) The $fr(^{151}\text{Eu})$ calculated for four temperatures ($kT = 30 \text{ keV}$, 20 keV , 15 keV and 10 keV) as a function of neutron density (N_n) [3]. b) Plot of $fr(^{151}\text{Eu})$ vs. $\delta^{134}\text{Ba}/^{136}\text{Ba}$ on SiC aggregate and single presolar SiC grains.

- Busso, M., Gallino, R., and Wasserburg, G.J., (1999) Annual Reviews in Astronomy and Astrophysics, 37, 239-309.
 Arlandini, C., Käppeler, F., Wisshak, K., Gallino, R., Lugaro, M., Busso, M., and Straniero, O. (1999) Astrophysics Journal, 525, 886-900.
 Aoki, W., et al, (2003), Astrophysics Journal, 592, L67-L70.

Molecular Fossils and Environmental Genomics

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Life in the Precambrian was dominated by bacteria and archaea, organisms that rarely leave diagnostic cellular remains in the fossil record. However, hydrocarbon biomarkers, the molecular fossils of natural products such as lipids and pigments, can yield a wealth of information about Precambrian ecosystems. Biomarkers often retain the diagnostic carbon skeleton of their biological precursors and may survive in sedimentary rocks for hundreds of millions of years. Many biomarkers are diagnostic for specific microbial groups such as methanogens, methanotrophs or phototrophic bacteria and, thus, may give information about ancient biodiversity. For instance, biomarkers discovered in mudstones that were deposited in a seaway in northern Australia 1,640 Ma ago describe a marine habitat that was fundamentally different from ecosystems observed later in Earth history. In this ancient sulfidic marine basin, eukaryotic algae were either insignificant or absent, and primary production was dominated by phototrophic green and purple sulfur bacteria. Generally, biomarkers can answer outstanding questions about Precambrian ecology and evolution, such as how ecosystems responded to the oxygenation of the atmosphere ~2.4 billion years ago, or how life responded to massive glaciations in the Neoproterozoic.

However, there is a major obstacle that hampers the application of biomarkers as palaeoenvironmental proxies: the incomplete knowledge of the lipid biosynthetic capacity of living organisms. According to some estimates, less than 1% of microorganisms can be isolated from the environment and grown in pure culture, and the biomarker content of these uncultivated microbes remains almost always unknown. Detecting and describing the lipids and pigments produced by the 99% of microorganisms that can not yet be cultured would boost the value of biomarkers extracted from ancient rocks.

This great challenge might be solved in the coming years by combining lipid research with environmental genomics and microbial community proteomics. In a pilot study, we collected lake water from hypersaline Lake Tyrrell (Fig. 1) to reconstruct nearly complete genomes and lipid profiles of the dominant archaea and bacteria. We are currently sequencing the DNA of the collected samples at the J. Craig Venter Institute. The genomes will be screened for genes involved in lipid and pigment biosynthesis and matched with corresponding lipids detected in the same sample. This way we can assign individual lipids to microorganisms even if they evade isolation. Ultimately this technique will help us to understand the phylogenetic distribution of biomarkers in the tree of life, even from microorganisms that currently remain unknown. The intricate knowledge of the lipid biosynthetic machinery of present ecosystems will then serve to elucidate new biomarkers and biomarker patterns in ancient sedimentary rocks.

At Lake Tyrrell, we will then compare the lipids of living microorganisms with fossils lipids extracted from mud in the lake bed (Fig. 2). The lake bed of Lake Tyrrell is up to 6 meters thick and was deposited over a time span of about 120,000 years. We have found that even relatively complex lipids such as Archaeol from halophilic (salt-loving) Archaea are preserved in the lake sediments. These biomarkers may yield an important terrestrial record of Australia's past salinities and precipitation.



Figure 1. In winter, Lake Tyrrell in outback Victoria contains up to ~50 cm of water with salt concentrations at saturation level (~330 g/L). The brine is coloured pink from pigments of halophilic microorganisms.



Figure 2. Jill Banfield and Simon George search for biomarkers in the lake bed of Lake Tyrrell. The mud contains high concentrations of molecular fossils of salt-loving microorganisms. The lake bed is up to 6 meters deep, and the deepest layers were deposited ~120,000 years ago when the lake was probably 12 meters deep and contained fresh water.

Brocks, J. J. and Banfield, J. (2007) Molecular Fossils and Early Life. *Geochimica Cosmochimica et Acta*, 71(15), A123.

Discovery of a new high-temperature borosilicate mineral: boromullite

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New research this year has focussed on the characterisation of a new borosilicate mineral, named boromullite. The sole occurrence of this mineral is in a sequence of unusually boron-rich, low-pressure (~3kbar) granulite-facies metapelites from Mt. Stafford, central Australia. Boromullite is a prismatic, colourless mineral that occurs as bundles of prisms up to 0.4 mm long, typically as fringes or overgrowths on aggregates of sillimanite or as narrow overgrowths around embayed prisms of werdingite, another rare borosilicate mineral (known from only 6 localities worldwide). Boromullite and sillimanite are locally intergrown on a fine (1-100µm) scale (Fig. 1). The boron-rich granulites additionally contain Fe-cordierite, potassium feldspar, biotite, hercynite and ilmenite, with other B-rich minerals (grandidierite and tourmaline) present locally.

Boromullite is compositionally heterogeneous on even a 1-5 micron scale (Fig. 1) and in the type specimen ranges in composition from $Mg_{0.00}Fe_{0.01}Al_{4.36}Si_{1.22}B_{0.40}O_{9.60}$ to $Mg_{0.00}Fe_{0.02}Al_{4.60}Si_{0.68}B_{0.70}O_{9.47}$ (Fig. 1). Structural refinements of the holotype crystal shows that it corresponds to a 1:1 polysome of Al_2SiO_5 and Al_5BO_9 modules (Fig. 2). Module 1 has the topology and stoichiometry of sillimanite and carries all the Si, whereas module 2 is a type of mullite defect structure in which Si is replaced by B in triangular coordination and by Al in tetrahedral coordination, i.e., Al_5BO_9 . The holotype crystal has a measured composition of $Mg_{0.01}Fe_{0.02}Al_{4.44}Si_{0.97}B_{0.57}O_{9.47}$. Boromullite is the first recorded natural analogue of a group of $B_2O_3-Al_2O_3-SiO_2$ phases ("boron-mullites") that have previously been synthesised experimentally and that are of relevance to the ceramics industry.

Boromullite at Mt. Stafford formed during anatexis of B-rich metapelitic rocks under granulite facies conditions ($T \geq \sim 790^\circ C$, $P \sim 3.6$ kbar), mostly from the reaction of werdingite with sillimanite/andalusite, but possibly in some cases from the incongruent melting of werdingite. It also occurs as feathery intergrowths within coarse-grained blocky prismatic sillimanite (Fig.1), raising the possibility that it may also be a previously unrecognised prograde mineral in boron-rich rocks.

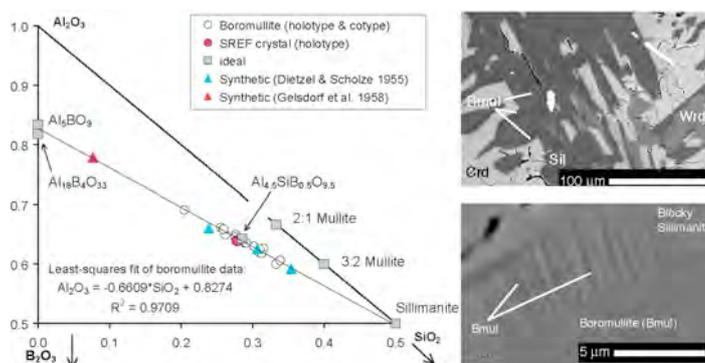


Figure 1: a) compositional variation in type sample 2006-MST22 (circles) and "boron-mullite" synthesized in the presence of melt (triangles); b) and c) BSE images of boromullite

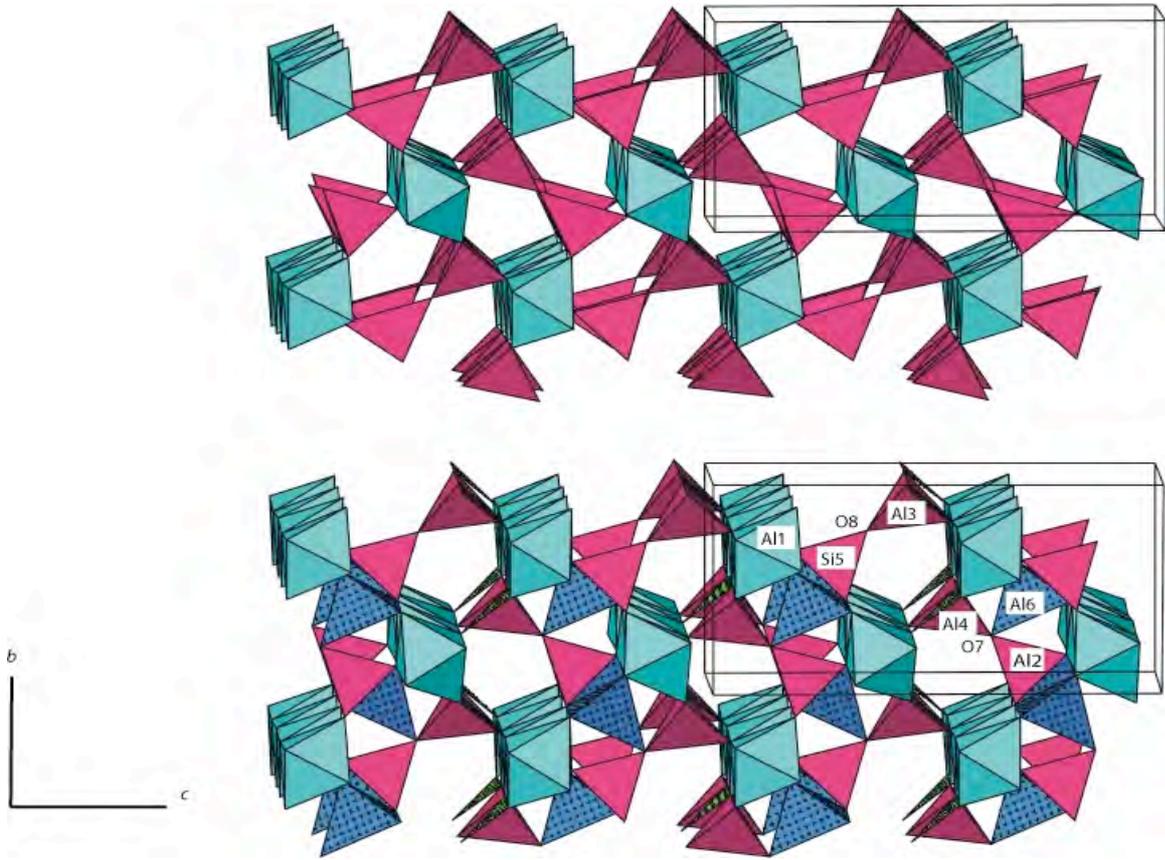


Figure 2: The polysomatic structure of the bromullite holotype crystal.

SHRIMP U–Pb xenotime and Re–Os molybdenite dating of the Molyhil scheelite-molybdenite skarn, northeastern Arunta region, central Australia

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SHRIMP U–Pb xenotime and Re–Os molybdenite geochronology was undertaken on samples from the Molyhil scheelite-molybdenite skarn deposit in central Australia, with the aim of constraining the timing of mineralisation. In situ SHRIMP U–Pb xenotime analyses were carried out on xenotime within a thin section of endoskarn. The xenotime occur as overgrowths on euhedral zircon as well as single irregularly shaped crystals. Re–Os concentrations were determined by isotope dilution mass spectrometry undertaken by Dr Robert Creaser (University of Alberta) on a sample of ore-zone molybdenite.

New SHRIMP xenotime $^{206}\text{Pb}/^{238}\text{U}$ matrix correction procedures developed during this study build on those previously reported by Fletcher et al. (2000) and Fletcher et al. (2004) and provide for further confidence in SHRIMP xenotime $^{206}\text{Pb}/^{238}\text{U}$ age determinations. Similar to previous studies, contrasts in chemical composition especially U was found to be the cause of significant $^{206}\text{Pb}/^{238}\text{U}$ fractionation. The matrix correction procedures involve the concurrent SHRIMP analysis of three chemically distinct xenotime standards during each analytical session. Electron microprobe (WDS) analyses of the xenotime prior to SHRIMP analysis, allows for the $^{206}\text{Pb}/^{238}\text{U}$ fractionation of the standards to be measured and corrected according to their chemical composition. The derived correction factors are then applied to the 'unknown' xenotime samples.

Concordant to near-concordant SHRIMP (RG) analyses range from ~1710–450 Ma. The oldest xenotime has a $^{207}\text{Pb}/^{206}\text{Pb}$ age of ~1710 Ma. There is also $^{206}\text{Pb}/^{238}\text{U}$ age groupings at ~760 Ma and ~660 Ma, and individual $^{206}\text{Pb}/^{238}\text{U}$ xenotime ages at ~560 Ma, 500 Ma and 450 Ma. There is no apparent relationship between xenotime ages and their textural settings. Interestingly, all xenotime in the sample have a very similar chemical composition, Th/U ratio and chondrite normalised REE pattern. The Molybdenite Re–Os analysis gave a model age of 1720.7 ± 8 Ma (95% confidence).

The ~1720 Ma age of the ore-zone molybdenite is synchronous with the age of nearby granites and granulite facies metamorphism and is considered as the best estimate for the timing of mineralisation at Molyhil. However, only one of the xenotime analysed by SHRIMP has a similar age of ~1710 Ma, the remainder forming over 1000 million years latter. These dominantly Neoproterozoic to early Palaeozoic xenotime probably formed in response to younger thermotectonic events. For example, the ~750 Ma xenotime age cluster is within error of the crystallisation age of the Mud Tank Carbonatite, located approximately 100 km SE of the Molyhil deposit. The near identical chemical features of these xenotime combined with their range in age, suggest that they formed during a number of cycles of local-scale dissolution and re-precipitation rather than the influx of distinct, successive Y- and HREE-bearing fluids.

The ability of xenotime to sometimes form at low temperatures, allows for the detection of low temperature and possibly far-field thermotectonic events to be recorded by this mineral. Indeed, the vast majority of xenotime analysed during this study, do not record the timing of mineralisation at Molyhil. Therefore, great care should be taken to the assignment of xenotime ages to specific geological events.

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U-Pb dating and Hf isotope systematics of rutile (preliminary work)

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Rutile (TiO₂) is a common metamorphic mineral which often contains measurable amounts of U, Pb and Hf. We are conducting a preliminary investigation with the ultimate aim of measuring U-Pb ages and Hf isotopic compositions of individual rutile grains in-situ. Little previous work has been done on hafnium isotopes in rutile, but Choukroun et al. (2005) reported a vast spread of ¹⁷⁶Hf/¹⁷⁷Hf values for rutile from mantle xenoliths (epsilon Hf values from -55 to +110). This large range is intriguing and suggests that an investigation into the controls on hafnium isotope ratios in rutile, and the effects of metamorphism thereupon, may be rewarding.

Initial results emphasise the suitability of rutile for the proposed study. Back Scattered Electron (BSE) imaging of 34 rutile-bearing samples from a wide variety of geological settings has shown that rutile is usually very simple structurally – compositional zoning occurs only rarely, and preservation of multiple generations of rutile growth has not been observed (Fig 1). However, needles of exolved ilmenite within rutile crystals are a common feature (Fig 1), and must be avoided during in-situ analysis. Laser Ablation ICPMS and electron microprobe analyses of rutile results for the 34 samples shows that rutile is also relatively simple chemically, consisting almost entirely of TiO₂ (usually >99%), with a limited range of elements with a similar ionic radius and, to a lesser extent, ionic charge substituting for titanium (Zack et al., 2002).

The simple structure and chemistry of rutile are favourable for the study of U-Pb and Hf isotopes in rutile. Th contents are always very low (usually below LA-ICPMS detection limits of ~0.01ppm, otherwise always <1ppm except for two samples of unusual composition), in keeping with theoretical considerations and mineral/melt partition coefficient experiments (eg Klemme et al., 2005; Brenan et al. 1994). This low Th content is advantageous for U-Pb dating because it allows for a very simple common lead correction: (virtually) all ²⁰⁸Pb present must be common lead, as little or no ²³²Th was present to form ²⁰⁸Pb through radioactive decay. Rutile also incorporates almost no Yb or Lu (predicted by mineral-melt partitioning studies, eg Klemme et al. 2005, and confirmed by our LA-ICPMS results). This is of great value for the measurement of Hf isotopes, as ¹⁷⁶Yb and ¹⁷⁶Lu cause isobaric interferences on the hafnium isotope of interest, ¹⁷⁶Hf.

Münker et al. (2001) reported a systematic error in solution MC-ICPMS measurements of hafnium isotope ratios where titanium was present with Ti/Hf>10, the exact cause of which was not well understood. We have demonstrated that this is unlikely to be a problem for measurements on our Neptune MC-ICPMS in laser ablation mode, in spite of the very high Ti/Hf ratio of all rutile. The ¹⁷⁶Hf/¹⁷⁷Hf ratios of synthetic rutiles doped with varying amounts of HfO₂ powder were measured and compared to the ¹⁷⁶Hf/¹⁷⁷Hf ratio obtained for the pure HfO₂. No systematic change in ¹⁷⁶Hf/¹⁷⁷Hf ratios was observed with changing Ti/Hf ratio, and all but one of the five mixtures agreed within error with the ¹⁷⁶Hf/¹⁷⁷Hf ratio measured for the pure HfO₂ sample (Fig 2). We are currently investigating the cause of the one discrepancy, but the lack of a systematic bias is an extremely positive result, and represents the first step towards demonstrating that ¹⁷⁶Hf/¹⁷⁷Hf ratios in rutile can be reliably measured by LA-MC-ICPMS.

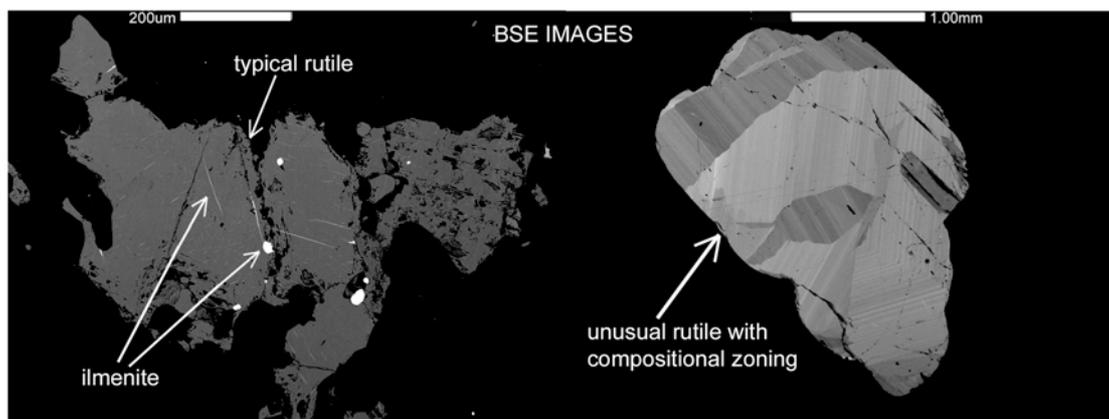


Figure 1.

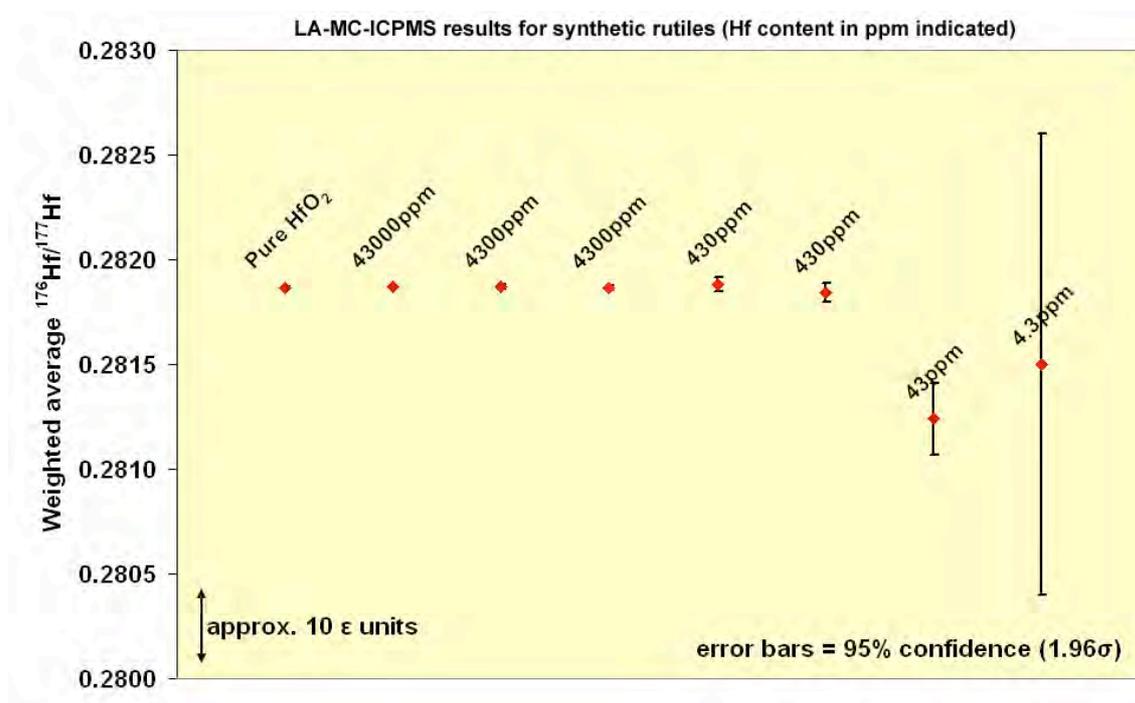


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Unravelling prograde and anatectic histories: integration of petrography, trace element geochemistry and U-Th-Pb dating of zircon and allanite

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High-pressure amphibolite facies migmatites of the Cockburn Shear Zone (CSZ), northern Musgrave Block, formed during the 580–520 Ma intraplate Petermann Orogeny. They contain a number of new trace-element-rich accessory phases compared to their unmelted counterparts. As such, they provide an excellent case study with which to extend the approach of integrating *in situ* trace element geochemistry to understand the petrological significance of accessory mineral ages.

Of the four accessory phases present in the CSZ migmatites (zircon, titanite, apatite, allanite) only zircon and allanite contained sufficient concentrations of radiogenic elements for dating. A new SHRIMP U-Pb age of 555 ± 7 Ma was obtained for metamorphic zircon rims that formed during melting within the CSZ. Allanite grains that crystallised under prograde pressure-temperature conditions display compositional growth zoning. Relatively rare earth element-poor allanite cores were overgrown by REE-rich rims and the two domains give SHRIMP Th-Pb ages of 559 ± 6 Ma and 551 ± 6 Ma, respectively. The good agreement of allanite and zircon ages provide evidence that allanite with relatively high common Pb can be successfully dated by *in situ* methods.

Whereas the major element composition of minerals (with the exception of allanite) show little zoning or are unzoned, mineral trace element compositions reflect an internal redistribution during metamorphism and partial melting related to a changing mineral assemblage and thus provide a tool to decipher the relative timing of metamorphic mineral growth. Growth of porphyroclastic garnet and hornblende and some accessory phases was primarily controlled by subsolidus hydration reactions that consumed feldspar. This is supported by the notable and consistent lack of negative Eu anomalies in all metamorphic phases, despite the presence of relict igneous K-feldspar porphyroclasts. REE compositions of zircon and late-stage allanite growth also suggest disequilibrium with garnet. Thus, the major period of garnet and hornblende growth were not coeval with partial melting.

Importantly, we were able to distinguish the dated allanite domains based on Lu, Eu and common Pb content and relate them to the major metamorphic minerals in the rock, such as garnet (a HREE-sink) and feldspar (a Eu- and Pb-sink). This provided constraints on the pressure-temperature conditions of allanite formation (Figure 1). For example, allanite cores show relative depletion in Lu (a HREE), which is generally consistent with the presence of garnet; in this case a subsolidus phase. On the other hand, allanite rims contain more Lu as well as less initial Pb; the latter is typical of allanite crystallising from a melt where it is involved in competitive partitioning of Pb and Eu with feldspar. In comparison, allanite cores are relatively Pb-rich, which is again supports a subsolidus origin and formation during the breakdown of feldspar and liberation of Eu and Pb.

The use of trace element partitioning shows that chemical equilibrium between co-existing minerals during prograde metamorphism cannot be assumed. This has implications for the calculation of P-T-time conditions on texturally complex assemblages and the construction of P-T-deformation-time paths.

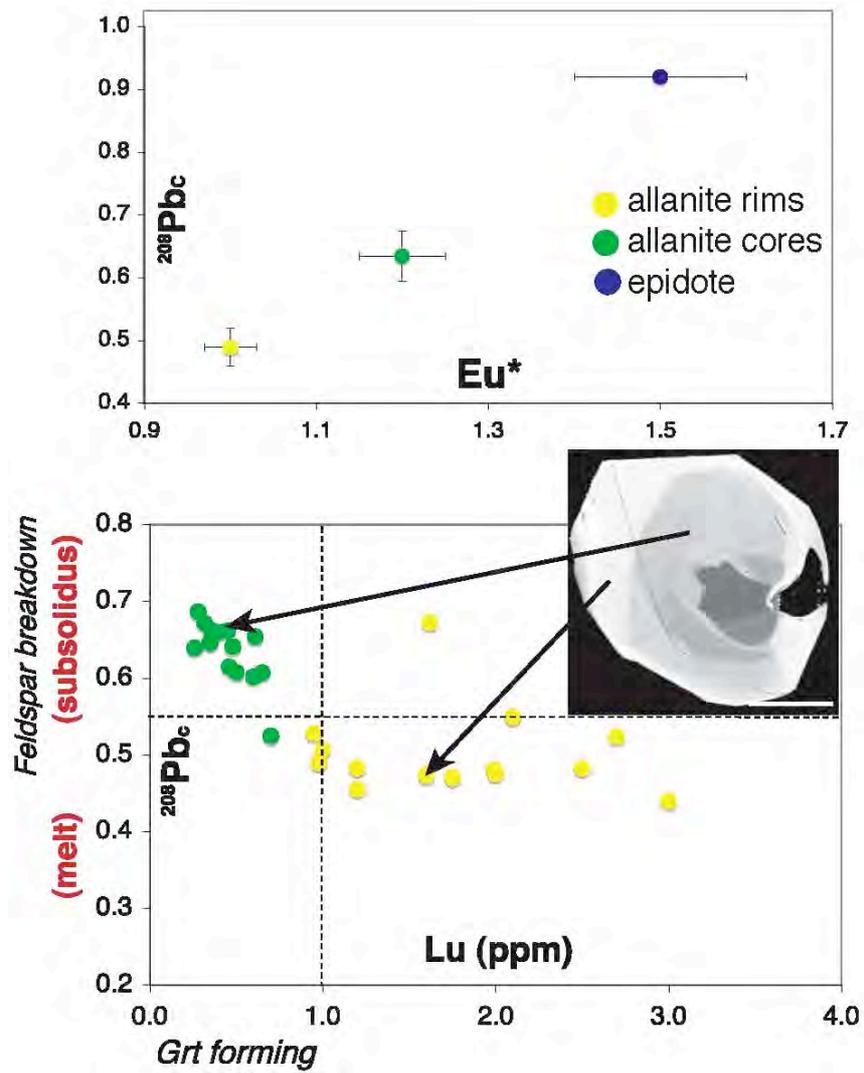


Figure 1. Distinguishing Lu, Eu and initial Pb contents of different allanite domains determined from SHRIMP and complementary LA-ICP-MS analysis.

New Insights into Crustal Petrogenesis via *in situ* O and Hf Isotopic Compositions of Archean Zircon from Southwest Greenland

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The origin of the oldest continents and how the processes that generate continental crust have changed through time continue to be key questions in Earth Science. Applying a new, multiple isotopic approach to understand the petrogenesis of granitic rocks, we have obtained coupled U/Pb, O and Hf isotopic data from Archean tonalite-trondhjemite-granodiorite (TTG) suites of Southwest Greenland. The dataset consists of >250 analyses of zircon from 11 rocks ranging in age from 3.85 Ga to 2.55 Ga.

The advantage of analyzing zircon grains is that they are relict igneous minerals and as such avoid the potential complications of secondary alteration which can affect metamorphosed bulk rock. Additionally, all the O and Hf isotopic analyses include age determinations on the same crystal domains. The samples include the most ancient tonalites of the Itsaq Gneiss Complex through to late Archean granitoids of the Qôrqt Granite Complex. All zircon grains were thoroughly characterized by cathodoluminescence (CL), secondary electron microscopy (SEM), reflected (RL) and transmitted (TL) light imaging. The U/Pb ages of the zircon were determined using SHRIMP RG; coinciding ¹⁸O/¹⁶O ratios were then measured on a freshly polished surface of the same zircon using SHRIMP II in multi-collector configuration; ¹⁷⁶Hf/¹⁷⁷Hf was subsequently measured by LA-MC-ICPMS with the RSES Neptune (Figure 1).

Zircon from the oldest, ca. 3.85 Ga, tonalites records $\delta^{18}\text{O}$ compositions within 1‰ of mantle values ($\delta^{18}\text{O}_{\text{mantle}} = 5.3 \pm 0.3$) and initial ϵ_{Hf} values largely within ± 1 epsilon unit of chondritic composition (calculated using $\lambda_{^{176}\text{Lu}} = 1.867 \times 10^{-11} \text{yr}^{-1}$). These narrow, mantle-like, O-Hf fields contrast markedly with results from studies of Phanerozoic crustal suites [1, 2], which show diverse O-Hf isotopic arrays, and with $\delta^{18}\text{O}$ generally displaced from mantle compositions towards higher values. Hf isotopic compositions of zircon from the youngest sample analysed, the 2.55 Ga Qôrqt Granite Complex (initial $\epsilon_{\text{Hf}} = -25$), are in agreement with earlier Pb isotopic studies [3] suggesting the origin of the Complex by the remelting of >3.7 Ga crust. The O isotope data from this suite, however, lie 1-2‰ below mantle compositions, again in contrast with results for Phanerozoic suites.

A striking feature of the overall dataset is the absence of high (>7‰) $\delta^{18}\text{O}$ values, highlighting the lack of recycled weathered supracrustal material in the genesis of the TTG. Of particular note is the prevalence of low $\delta^{18}\text{O}$ values, with 4 out of 11 samples, with ages from 3.7 to 2.55 Ga, having compositions 1-3‰ below mantle values. Low $\delta^{18}\text{O}$ values are a relatively rare feature in granitic suites [4] and typically result from hydrothermal alteration by surface waters, in some cases enhanced by glaciation. The presence of low $\delta^{18}\text{O}$ in these mid-crustal level Archean granitoids is unexpected and may reflect different surface conditions and hence fluid compositions during the Archean. Taken together, these new results point to differing styles of Archean versus Phanerozoic crustal growth, with supracrustal rocks playing a less significant role in early crustal genesis.

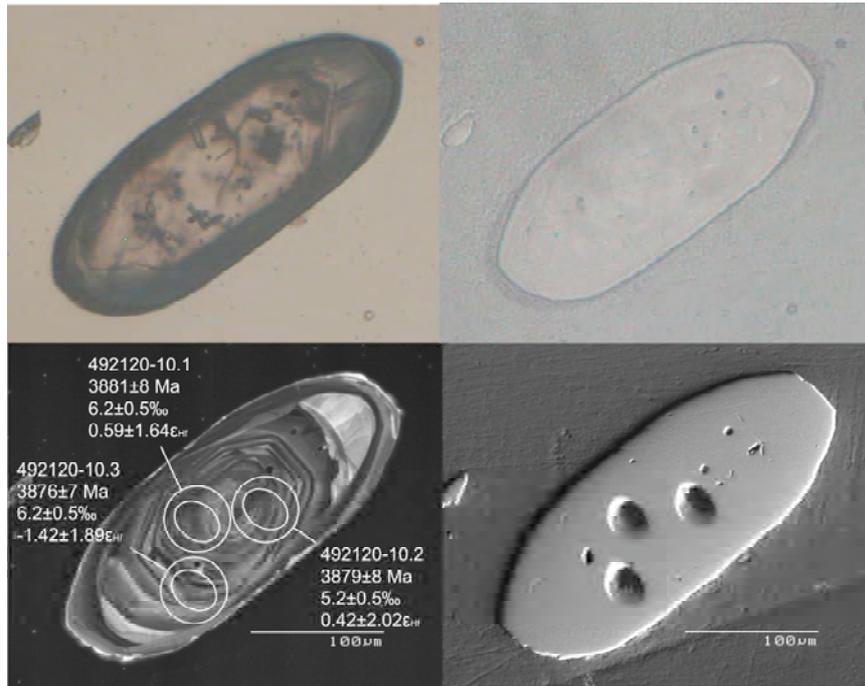


Figure 1. Clockwise from top left: TL, RL, SEM and CL images for tonalite zircon 492120-10. CL image indicates location of coinciding $^{207}\text{Pb}/^{206}\text{Pb}$ age and $\delta^{18}\text{O}$ determinations (separated by mount polishing) with $\sim 35\mu\text{m}$ diameter elliptical spots on oscillatory zoned zircon. $^{176}\text{Hf}/^{177}\text{Hf}$ analysis performed on larger $47\mu\text{m}$ diameter circular spots. SEM image following $^{18}\text{O}/^{16}\text{O}$ measurement indicates analysis was performed on pristine zircon, free of cracks or inclusions.

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Regional brecciation and alteration in the Wernecke Mountains, Canada: New constraints from He, Ne, Ar, Kr, Xe, Cl, Br and I

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The causes of regional brecciation in the Proterozoic Wernecke Mountains of Canada have implications for understanding the crustal evolution. Hydrothermal alteration associated with brecciation is characterized by variably saline fluid inclusions.

Two phase LV (liquid vapour) fluid inclusions (<26-30 wt % salt) in fluorite and barite plus most quartz samples are characterized by: greater than seawater Br/Cl values of up to $2.9 \cdot 10^{-3}$; I/Cl of up to $54 \cdot 10^{-3}$; and at four out of six localities they have elevated ^{36}Ar concentrations of 4 to >100 ppb and $^{40}\text{Ar}/^{36}\text{Ar}$ of <1000-2000. Sulphide fluid inclusions with similar $^{40}\text{Ar}/^{36}\text{Ar}$ values have near atmospheric $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{21}\text{Ne}/^{22}\text{Ne}$ values of ~ 9.8 and 0.029 , respectively; and are enriched in radiogenic $^4\text{He}^*$ with $^3\text{He}/^4\text{He}$ of <0.02 Ra (Ra = atmospheric value of 1.4×10^{-6}) and $^4\text{He}^*/\text{radiogenic } ^{40}\text{Ar}^*$ and $^4\text{He}^*/\text{nucleogenic } ^{21}\text{Ne}^*$ values of greater than the crustal production ratios. All these characteristics are typical of sedimentary formation waters.

Halite saturated LVD (liquid-vapour-daughter) fluid inclusions, with salinities of up to 44 wt % salt, are present in all of the samples but dominate in only two quartz samples. One of these samples, from the Slab mega-breccia is situated close to a horizon of meta-evaporitic scapolite and it has the lowest measured Br/Cl and I/Cl values of $0.37 \cdot 10^{-3}$ and $0.32 \cdot 10^{-6}$, respectively. The range of Br/Cl and I/Cl is compatible with the involvement of magmatic fluids in addition to sedimentary formation water. However, interaction with halite is shown to have been an important mechanism for increasing fluid salinity.

Fluid inclusions with variable salinities (LV and LVD) in a sample from the Hoover locality have the highest measured $^{40}\text{Ar}/^{36}\text{Ar}$ values of $\sim 40,000$ and variable ^{36}Ar concentrations of 5 to 0.7 ppb. Fluid inclusions inferred to have similar $^{40}\text{Ar}/^{36}\text{Ar}$ values in sulphide have crustal $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{21}\text{Ne}/^{22}\text{Ne}$ values of 6.5 and 0.35; $^3\text{He}/^4\text{He}$ of ~ 0.002 ; and $^4\text{He}^*/^{40}\text{Ar}^*$ and $^4\text{He}^*/^{21}\text{Ne}^*$ values only slightly above the crustal production ratios. Post-entrapment ingrowth of radiogenic $^{40}\text{Ar}^*$ is minor and correctable, whereas ingrowth of radiogenic $^4\text{He}^*$ is difficult to preclude. However, we demonstrate that Ne isotopes together with He do not favour ingrowth and provide robust constraints on fluid origin in these Proterozoic samples. The combined noble gas data set is most easily explained by the involvement of a second fluid with magmatic origin from U-rich basement rocks. Therefore, these data provide evidence for a hitherto poorly constrained episode of magmatism in ancestral North America.

Correlated, In-Situ Analysis of U/Pb, $\delta^{18}\text{O}$ and $\delta^{176}\text{Hf}$ in Zircon from Siluro-Devonian Granite in the Eastern Lachlan Orogen: Constraints on Juvenile Additions to the Continental Crust

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Introduction

The nature and origin of granite remains an outstanding scientific problem. Where does granite come from? Is granite derived entirely from partial melting of rocks with a long crustal residence time, or is there a significant juvenile (i.e. directly mantle derived) component? How do granites differentiate, and what is the relationship between granites with apparently linear correlations between elements on variation diagrams?

Even in some well-characterized granite terrains, there continues to be much debate on these questions. One such terrane is the eastern Lachlan Orogen. These granites have been the subjects of intense study for over 30 years, and have become a "textbook" locality for granite study (e.g., Winter, 2001) however there is little consensus in the literature as to the answers to most of the questions posed above. For example, Keay et al. (1997), Collins (1998), Healy et al. (2004), and Patino Douce (1999) have suggested that S-type granites contain appreciable quantities of directly mantle-derived material, and a number of workers, in particular Kemp et al. (2007) have suggested the same for I-type magmas. Other workers, in particular Chappell (1996) has suggested that they are derived entirely from the partial melting of crustal rocks. This problem has important implications for our understanding of crustal growth: if there is substantial input of juvenile magma into granitic magmas, then they may represent a hitherto unrecognized source of new crustal material, alternatively they simply represent a mechanism by which the crust differentiates.

Analytical Approach

Zircon is a highly refractory mineral that can remain both solid and closed to diffusion of U, Pb, O, and Hf during high-grade metamorphism, partial melting and in the presence of meteoric fluids. In addition, zircon is a common accessory mineral in granitic rocks and therefore can preserve evidence of magmatic processes with high fidelity. The approach in this study has been to take advantage of spatially resolved zircon isotopic analysis using high-resolution SIMS to measure U/Pb and $\delta^{18}\text{O}$, and LA-MC-ICP-MS for $\delta^{176}\text{Hf}$ in order to reconstruct magmatic processes and crustal evolution. Samples have been collected from S- and I- type granites and their enclaves in the Berridale, Wagga, and Kosciuszko Batholiths, where possible re-collecting from sites that have already been characterized for whole rock geochemistry as well as Sr, Nd and O isotopes.

Preliminary Results

We have determined the oxygen isotope composition of over 200 zircon grains from Siluro-Devonian granites of the Wagga, Berridale, and Kosciuszko Batholiths. All zircon analyzed for oxygen were also analyzed for U-Pb. Rocks included in the dataset are ~433 Ma S- and ~416 Ma I-type granites of varying bulk compositions, one 414 Ma gabbro and a small dataset of zircon from the 433 Ma Cooma granite, a small pluton at the metamorphic culmination of a low-P high-T metamorphic complex. Analyses of Hf isotopes in these zircon grains are in progress.

The $\delta^{18}\text{O}$ of zircon from the gabbro ($\sim 5.5\text{‰}$) is indistinguishable from that of zircon in equilibrium with the mantle and provides a reference for the oxygen isotopic composition of zircon crystallized from uncontaminated, mantle-derived magma in the eastern Lachlan Orogen.

Zircon from the Cooma granite provides an estimate of the $\delta^{18}\text{O}$ expected in zircon crystallized from a magma derived entirely by partial melting of metasedimentary rocks and early measurements indicate a value of around 9.7‰ . These values provide useful reference markers when interpreting results from granites.

A first order observation is that $\delta^{18}\text{O}$ in zircon from granites previously identified as S- or I-type on petrographic, field, or bulk-chemical grounds (Chappell and White, 2001) have distinguishable $\delta^{18}\text{O}$ enrichments. This can be plainly seen by the bimodal nature of the probability density diagram for all analyzed zircon. Zircon grains from S-type granites are fall under the high $\delta^{18}\text{O}$ peak at $\sim 9.7\text{‰}$ and zircon from I-type granites fall on under the low $\delta^{18}\text{O}$ peak at roughly 7.1‰ , although there is a large amount of scatter in the median $\delta^{18}\text{O}$ of populations of zircon from I-type granites.

Populations of zircon separated from hand-sample sized samples of granite behave differently in different rocks. S-type granites generally contain zircon that have $\delta^{18}\text{O}$ values which scatter by $\sim 2\text{‰}$. All populations, however, seem to have identical median values near $\sim 9.7\text{‰}$. Work is underway to determine whether this scatter represents variation inherited from the source, via a viscous, poorly homogenized magma or whether it is due to true open system processes like magma mixing or contamination. I-type granites typically have a main population of zircon that have identical $\delta^{18}\text{O}$ enrichments, and some have outliers that have higher $\delta^{18}\text{O}$. Preliminary work on $\delta^{18}\text{O}$ suggests that these $\delta^{18}\text{O}$ enrichments are correlated with $^{176}\text{Hf}/^{177}\text{Hf}$ suggesting that these granites contain zircon that has crystallized from magmas with very different isotopic characteristics.

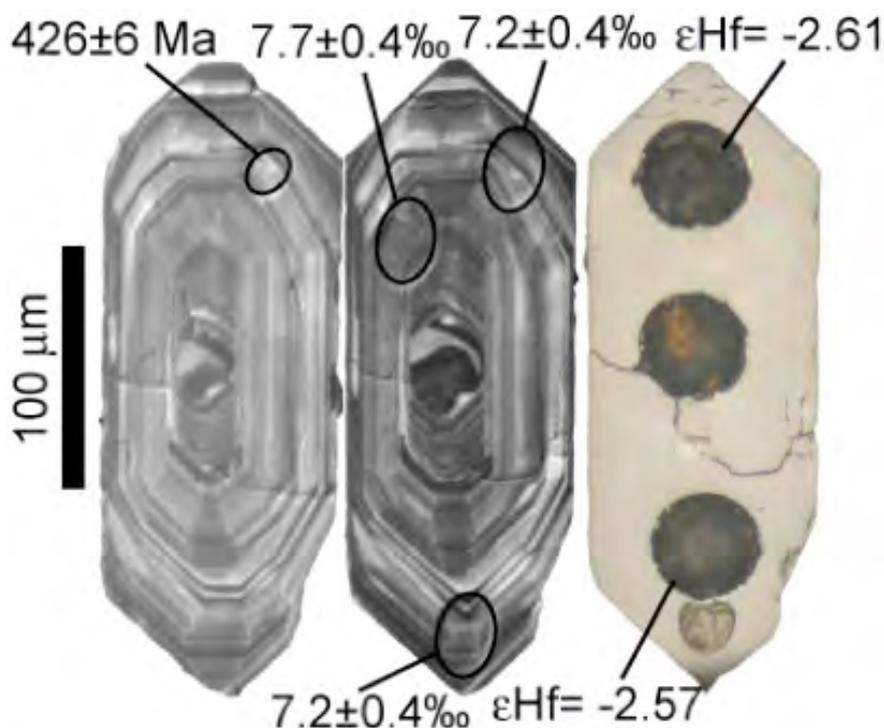


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Solar System Isotopic Heterogeneity from ^{53}Mn - ^{53}Cr

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Introduction:

One of the requirements for the application of the short-lived nuclide chronometer ^{53}Mn (half-life of 3.7 My, anchored to angrite LEW86010) and short lived nuclides in general is that samples are derived from a common reservoir with a homogeneous distribution of the parent nuclide. Ideally, this should reflect the solar system abundances as a whole, but it requires that the solar nebula was well mixed after collapse of the molecular cloud. A more likely scenario is that the solar system is heterogeneous for many isotopes, but particular subsections (such as a specific parent body) will be homogeneous and suitable for short-lived nuclide chronometric studies. Short-lived radionuclide chronometry has been successfully applied and has produced useful information, but many assumptions about initial ratios and ages are involved because insufficient samples have had two or more chronometric systems applied to them. A few samples have been found to have isotope systematics that make them discordant in different systems, showing that a completely uniform distribution of short-lived nuclides in the solar system is not the case [1, 2].

Mn and Cr isotopic heterogeneity:

A widespread and systematic chromium isotopic heterogeneity in the inner solar system was recognised by Lugmair and Shukolyukov [1] who found an apparent linear relationship between heliocentric distance and initial $^{53}\text{Cr}/^{52}\text{Cr}$ expressed in samples from Earth, Mars and those inferred to originate in the Asteroid Belt. With a few exceptions, meteorites from the Main-Belt have a common $^{53}\text{Cr}/^{52}\text{Cr}$, which suggests that $^{53}\text{Mn}/^{55}\text{Mn}$ is homogeneous within the Asteroid Belt and the chronometric interpretation of $^{53}\text{Mn}/^{55}\text{Mn}$ for samples from this region is justified. An anomalous case is that of the enstatite chondrites: Shukolyukov and Lugmair [3] showed that they have Mn/Cr ratios that are chondritic, coupled with $^{53}\text{Cr}/^{52}\text{Cr}$ ratios that are lower than those of all other meteorites believed to come from the Asteroid Belt. Chondritic Mn/Cr shows that elemental fractionation has not suppressed the evolution of $^{53}\text{Cr}/^{52}\text{Cr}$ in enstatite chondrites, so either $^{53}\text{Mn}/^{55}\text{Mn}$ or $^{53}\text{Cr}/^{52}\text{Cr}$ must be heterogeneous in the solar nebula.

Simple explanations of the radial trend could involve a stellar-derived nucleosynthetic heterogeneity in $^{53}\text{Cr}/^{52}\text{Cr}$, or heterogeneity in $^{53}\text{Mn}/^{55}\text{Mn}$, with either ^{53}Cr or ^{53}Mn increasing with heliocentric distance. Shukolyukov and Lugmair [4] noted that ^{54}Cr anomalies were not observed in meteorites other than carbonaceous chondrites, so anomalies of ^{53}Cr were probably absent as well. Recent ^{54}Cr data does show heterogeneity in the solar system for this isotope [5], but it is not correlated with radial heliocentric distance. Elemental volatility leading to a depletion in Mn (and hence ^{53}Mn) must also be considered. Mn and Cr are approximately in the middle of the volatility range, with Cr being referred to as a *common element* (50% T_c 1296 K) and Mn a *moderately volatile element* (50% T_c 1158 K) [6]. Difference in volatilities is not a favoured explanation because the bulk compositions of the planets are not well known and few constraints can be put on such models.

Comparison with ^{26}Al and Pb-Pb timescales:

Though CAIs are used as the reference point for $^{26}\text{Al}/^{27}\text{Al}$, the $^{53}\text{Mn}/^{55}\text{Mn}$ ratios obtained from CAIs are inconsistent with the rest of the ^{53}Mn timescale [e.g. 7, 8] (Figure 1) and their generally anomalous isotopic composition suggests that they should not be used as anchors for short-lived nuclide chronometric systems. CAIs have average initial $^{53}\text{Mn}/^{55}\text{Mn}$ of 4.4×10^{-5} [9] although values as high as 14.8×10^{-5} have been reported [10]. As CAIs are known to have been isotopically disturbed, these values may represent a lower limit. Using the average $^{53}\text{Mn}/^{55}\text{Mn}$ value, this equates to a CAI age that is ~ 19 Ma older than LEW86010, implying a solar system timescale that is irreconcilably long. The Pb-Pb dates for Efremovka CAIs and LEW86010 [11, 12] give a much smaller age difference of 9.4 ± 1.1 Ma, which is consistent with the ^{26}Al timescale, as well as theoretical models and astronomical observations of stellar system formation. The high initial $^{53}\text{Mn}/^{55}\text{Mn}$ may reflect an extreme early heterogeneity in the early solar system [1], which had been largely smoothed over by the time of chondrule formation.

Discrepancies between ^{26}Al and ^{53}Mn ages of some samples (D'Orbigny, Asuka 881394 and others; see [2]) are possibly expressions of solar system heterogeneity for these isotopes, or resolved differences in closure temperature. Placement of samples in the absolute timescale is also problematic, as Pb-Pb dates often have poor precision and different phases commonly return different ages. The most recent efforts at Pb-Pb dating of phases from D'Orbigny [13, 14] have yielded precise ages that are older than previously found, and make this meteorite discordant with the ^{26}Al -timescale. As such, a unique reconciliation of Pb-Pb, Al-Mg, and Mn-Cr isotope systematics is not possible with the data presently available.

Using SHRIMP to obtain $^{53}\text{Mn}/^{55}\text{Mn}$:

Sensitive High-mass Resolution Ion Micro-Probe has the potential to obtain initial $^{53}\text{Mn}/^{55}\text{Mn}$ ratios for coexisting minerals. This is especially important for chondritic meteorites which are effectively sedimentary rocks or breccias; in these cases bulk-rock samples will not necessarily meet the requirements of internal isochrons and *in situ* analysis of individual chondrules is preferred. Success will hinge on the precision of $^{53}\text{Cr}/^{52}\text{Cr}$ ratios obtained by SHRIMP, and the range of $^{55}\text{Mn}/^{52}\text{Cr}$ in coexisting mineral phases (Figure 1).

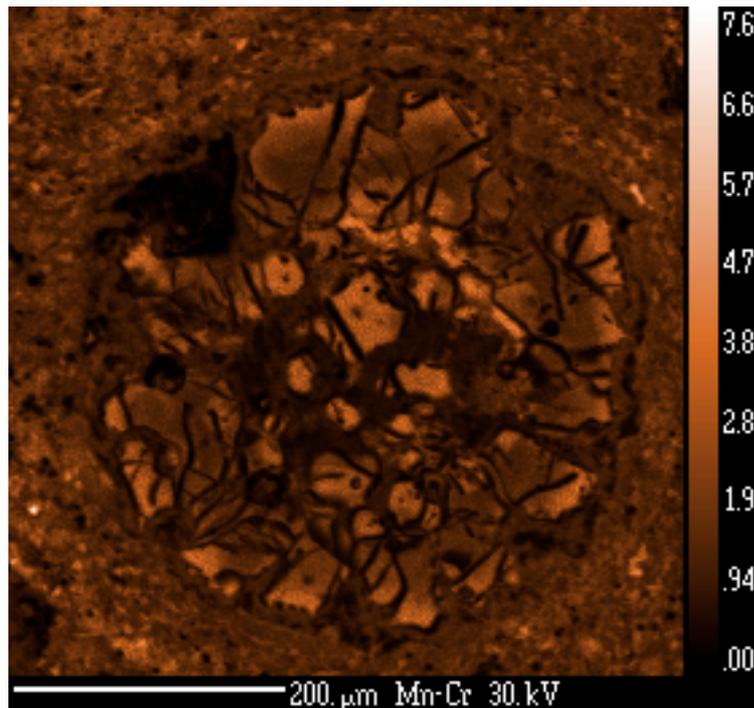


Figure 1. X-ray map of Mn/Cr ratio (calculated from electron probe raw counts) for an unequilibrated olivine chondrule from the Allende carbonaceous chondrite. Coexisting high and low Mn/Cr domains allows determination of $^{53}\text{Mn}/^{55}\text{Mn}$ at the time of isotopic closure.

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Diachronous subduction to diamond- and coesite-facies conditions in the Kokchetav massif

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The study of crustal rocks that underwent ultra-high-pressure conditions (UHP), i.e. subduction to the coesite and diamond stability fields (> 90 Km depth) offers a unique insight into the deep Earth and the tectonic processes of subduction and exhumation.

It has been proposed that the first occurrence of UHP metamorphism defines the time of onset of modern cold subduction on Earth. The Kokchetav massif in Kazakhstan contains some of the oldest known UHP rocks, which reached diamond-facies conditions indicating subduction to at least 150 km depth, at ~530 Ma. These rocks therefore provide a rare opportunity to study fundamental processes at the onset of modern plate tectonics.

SHRIMP ion microprobe dating was performed on monazite from coesite-bearing micaschists of the Kulet unit. Based on texture, trace element composition and inclusions in monazite it is concluded that the pressures peak was reached at ~520–515 Ma. Decompression is dated by the formation of monazite symplectites (Figure 1) in a second sample at 508±6 Ma. This new data provides evidence that the Kulet unit underwent UHP metamorphism 10–15 Ma later than the diamond-facies rocks in the nearby Kumdy-Kol unit (Figure 2).

This new time constrain excludes models that argue for a simultaneous evolution of coesite- and diamond-facies rocks, it suggest that subduction continued well after continental crust was involved, and that exhumation was not initiated by a single event such as slab break-off. The dynamic of this UHP massif also indicates that Cambrian tectonic was similar to that of recent orogenic belts.

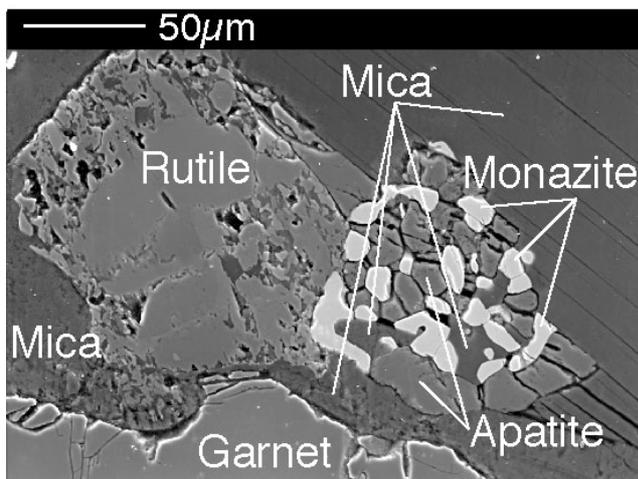


Figure 1.

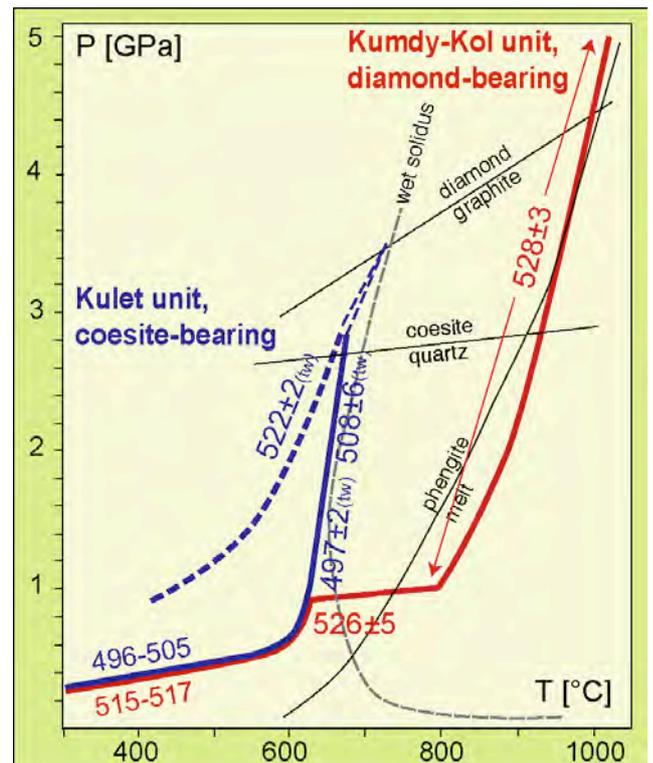


Figure 2.

Molecular Palaeontology of the Neoproterozoic–Cambrian Interval: Lipid Biomarker Geochemistry and Ancient Microbial Ecosystems

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Lipid biomarker work began in the new biogeochemistry laboratories in Jaeger 1 in 2007. Work was conducted on a selection of Neoproterozoic and Cambrian samples from Australia and throughout the world. The aim is to reconstruct the microbial ecosystems during a time that has witnessed numerous changes: "Snowball Earth" glaciations; evolution and extinction of numerous microorganisms; the first occurrence of animals; and the oxygenation of the world's oceans. Thus far, the results look very promising and has led to the discovery of lipid biomarkers that are over 1 billion years old. I am also trying to investigate rock samples from that period that originated in shallow water facies. So far, most investigations concentrated on deep water facies. I have collected rock samples from drill cores held at Geoscience Australia (Canberra). These rocks are from shallow water facies and contain numerous evaporate (salt-bearing) sequences (Figure 1).

Techniques aimed at removing potential contaminants from rock samples are under investigation. Thus far, the techniques have worked very well and helped to determine which biomarkers were likely derived from the Precambrian–Cambrian interval and which samples are contaminants (e.g. from the use of drilling fluids, fingerprints etc).

Field work was conducted at Hamlin Pool, Shark Bay Heritage Park, Western Australia (Figure 2). Microbial mat samples (smooth mats and tufted mats) were collected to study lipid biomarker diagenesis. Microbial mats at Hamelin Pool are significant in that they resemble fossilized microbial mats from the Precambrian (> 542 million years ago). Hamlin Pool mats flourish in saline conditions that preclude grazing animals, which would otherwise destroy them. Similar conditions were present in the Precambrian when animals had not yet evolved. Therefore Shark Bay mats are ideal candidates for understanding past biotas.



Figure 1. Rock sample from Geoscience Australia drill cores; brown colour = salt, grey colour = incorporated mud rock.



Figure 2. Hamlin Pool, Shark Bay Heritage Park, WA.

Systematics of noble gas, carbon and nitrogen isotope compositions in Australian diamonds from the Merlin and Argyle Mines

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Diamonds from Merlin and Argyle mines show different characteristics both on visual appearances and isotopic compositions, although the two mines are 1350 km apart from each other in opposite directions of south Darwin, Northern Territory. The Merlin diamonds (kimberlitic) are predominantly characterized by yellow colour, cube and dodecahedral form, whereas Argyle diamonds (lamproitic) are mainly octahedral in pale brown colour. Previous carbon isotopic studies on diamonds from both locations indicated the diamonds sharing $\delta^{13}\text{C}$ range from -5‰ to -16.66‰ (Lee et al 1997; Hall & Smith 1984; Jaques et al 1989). Peridotitic diamonds from Argyle mine exhibit a restricted $\delta^{13}\text{C}$ range of -4.4‰ to -9.1‰ , compared to a wider $\delta^{13}\text{C}$ from -5‰ to -16‰ for eclogitic Argyle diamonds (Jaques et al 1989). Limited noble gas studies on Argyle diamonds yielded a higher $^3\text{He}/^4\text{He}$ value $1.57 \pm 0.75 \times 10^{-4}$ and solar Ne ($^{20}\text{Ne}/^{22}\text{Ne} = 12.6 \pm 1.8$, $^{21}\text{Ne}/^{22}\text{Ne} = 0.0304 \pm 0.0048$) for colourless diamonds, and a lower $^3\text{He}/^4\text{He}$ value ($< 4.5 \times 10^{-8}$) for coloured composite diamonds (Honda et al 1987). A further systematically integrated study of noble gas, nitrogen and carbon isotopic compositions on Australian diamonds will help to understand regional time-integrated mantle history. Furthermore carbon and nitrogen isotopic compositions, combined with noble gases, in diamonds can elucidate the evolution and outgassing history of the subcontinental lithosphere.

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Relative oxidation determined by the Ce^{+4}/Ce^{+3} ratio in zircon

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The Ce^{+4}/Ce^{+3} ratio in zircon as a measure of relative oxidation was developed by Ballard et al. (2002) and utilizes the observation that Ce^{+4} partitions more readily into the zircon mineral structure than Ce^{+3} and therefore the ratio between Ce^{+4} and Ce^{+3} can be used to estimate relative oxidation for a given population of zircons. However, the premise that the difference in the ratio is primarily a function of oxidation has been questioned. Rohrlach (2002) and Core (2004) have suggested that it is principally a function of temperature and the silica and phosphorus activities of the magmas.

An investigation was therefore undertaken on the suite of rocks originally studied by Ballard et al. (2002), the El Abra-Pajonal suite of granodiorites in Northern Chile, to determine if the observed increase in Ce^{+4}/Ce^{+3} ratio values in zircon in the evolving suite, was due to oxidation or was a function of the other factors discussed by Rohrlach (2002) and Core (2004).

Results

To confirm that Ce^{+3} is partitioned into zircon via the xenotime-type substitution for all intrusions of the El Abra-Pajonal suite, the P concentrations in the zircons were plotted against the sum of the REE⁺³ and Y⁺³ concentrations (Figure 1). The 1:1 correlation indicates that the xenotime-type substitution is the dominant mechanism by which Ce^{+3} is substituting into zircon in the El Abra-Pajonal suite. Whole-rock phosphorus concentrations in the intrusions are similar (Table 1) indicating that the phosphorus activities of the magmas was not a significant factor influencing the zircon Ce^{+4}/Ce^{+3} ratio values for the El Abra-Pajonal suite.

Comparing the spread in Ce^{+4}/Ce^{+3} ratio values against corresponding Ti-in-zircon (Watson and Harrison, 2005) measured temperatures for each of the El Abra-Pajonal suite intrusions (Table 1), the observed spread for a given population of zircons is broadly correlated to temperature, such that maximum Ce^{+4}/Ce^{+3} ratio values correspond with minimum temperatures. This is expected because as intrusions cool, the entropy of the magma decreases and crystallizing zircons become less elastic (Blundy and Wood, 1994). As a consequence, Ce^{+4} is preferentially partitioned into the zircon structure due to its similar sized radius to Zr^{+4} (Shannon, 1976) and the substitution requires less energy than the coupled Ce^{+3} substitution: $[ZrSi]^{+8} - [Ce^{+3}P]^{+8}$.

However, for intrusions with zircons of similar minimum temperature (broadly correlated to the solidus temperature of the magmas) and with similar silica and phosphorous whole-rock concentrations, there are significant differences in the maximum Ce^{+4}/Ce^{+3} zircon ratio values (Table 1), which have been interpreted to be due to oxidation effects.

For example, the Central granodiorite has a maximum zircon Ce^{+4}/Ce^{+3} ratio of 607.38 and $\sigma_{Ce^{+4}/Ce^{+3}}$ ratio value (i.e. the spread in the Ce^{+4}/Ce^{+3} ratio values) of 592.51. In comparison, the thermally and chemically similar Llaretta quartz monzodiorite has a maximum zircon Ce^{+4}/Ce^{+3} ratio of 266.05 and $\sigma_{Ce^{+4}/Ce^{+3}}$ ratio value of 241.3 (Table 1).

If the zircon Ce^{+4}/Ce^{+3} ratio values were only a function of temperature and melt chemistry, then one would expect similar maximum Ce^{+4}/Ce^{+3} ratio $\sigma_{Ce^{+4}/Ce^{+3}}$ ratio values for all intrusions of the El Abra-Pajonal suite.

Therefore in suites where the whole-rock and zircon chemistry and thermal history of the intrusions is well constrained, it is possible to determine the relative oxidation state between intrusions using the Ce^{+4}/Ce^{+3} ratio in zircon method (Ballard et al., 2002).

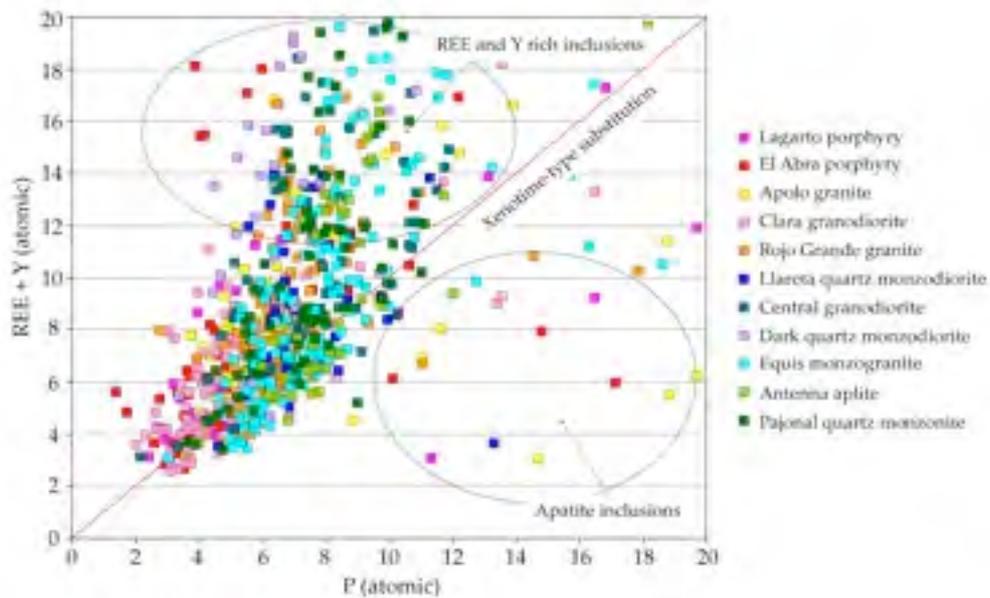


Figure 1. Evidence for the xenotime-type substitution mechanisms for the partitioning of Ce into the zircon lattice. Zircons off the 1:1 correlation line between REE + Y versus P (atomic) are inclusion rich and excluded from calculations of the Ce^{+4}/Ce^{+3} ratios for the El Abra-Pajonal suite intrusions. As the determination of the Ce^{+4} and Ce^{+3} partition coefficients are determined by the concentrations of trivalent and tetravalent cations partitioned into zircon, enrichment in these elements due to inclusions will affect the veracity of the resultant Ce^{+4}/Ce^{+3} ratios being representative of the oxidation conditions under which the zircon crystallized.

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Rate of growth of the preserved North American continental crust: evidence from Hf and O isotopes in Mississippi detrital zircons

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Detrital zircons from the Mississippi River have been analyzed for U-Th-Pb, Lu-Hf and O isotopes to constrain the rate of growth of the preserved North American continental crust. The zircon U/Pb dates, obtained by conventional Excimer laser ablation ICP-MS method, resolved six major periods of zircon crystallization: 0-0.25 Ga, 0.3-0.6 Ga, 0.95-1.25 Ga, 1.3-1.5 Ga, 1.65-1.95 Ga and 2.5-3.0 Ga. These age ranges match the ages of the recognized lithotectonic units of the North American continent in the hinterland of the Mississippi River. Ninety seven zircons, which show no age zonation and were within 7.5% of concordance, were selected from the six U/Pb age time intervals and analyzed for Hf and O isotope by laser ablation MC-ICP-MS and SHRIMP II, respectively. The $\delta^{18}\text{O}$ values of the zircons show a step increase in the maximum $\delta^{18}\text{O}$ values at the Archean-Proterozoic boundary from 7.5 ‰ in the Archean to 9.5 ‰, and rarely 13‰, in the Proterozoic and Phanerozoic. However, the average value of $\delta^{18}\text{O}$ in zircons changes little with time, suggesting that the change is as much due to an increase in diversity in the source regions of younger granitoids as to an increase in their sediment content.

ϵ_{Hf_i} values for the zircons range from 12.5 to -29.7. Zircons derived from juvenile crust, which we define as having mantle $\delta^{18}\text{O}$ (4.5 - 6.5 ‰) and lying within error of the Hf depleted mantle growth curve, are rare or absent in the Mississippi basin. The overwhelming majority of zircons crystallized from remelted pre-existing continental crust. The average time difference between primitive crust formation and remelting for each of the recognized lithotectonic time intervals, which is defined as crustal incubation time in this study, is 860 ± 360 Myr. There is also a suggestion that the crustal incubation time increases with decreasing age, which is consistent with the declining role of radioactive heat production in the lower crust with time. Average one-stage Hf model age (1.82 Ga), weighted by fraction of zircons in the river load, is in good agreement with the Nd model age (1.7 Ga) for the Mississippi River. One-stage model ages, however, are the minimum estimate for the average age of continental crust. The average, more realistic, two-stage Hf model age weighted by area, is 2.50 Ga, which is appreciably older than the one-stage model age.

Two-stage Hf model ages of zircons show two distinct periods of crust formation for the North American continent, 1.6 to 2.4 and 2.9 to 3.4 Ga. At least 45% of the preserved North American continental crust was extracted from the mantle by 2.9 Ga and 90% by 1.6 Ga, respectively. Similar two periods of growth are also recognized in Gondwana (Hawkesworth and Kemp, 2006), suggesting that these may be two major periods of global continental crustal growth. However, we stress that more data from other continents are required before the hypothesis of episodic global continental growth can be accepted with confidence.

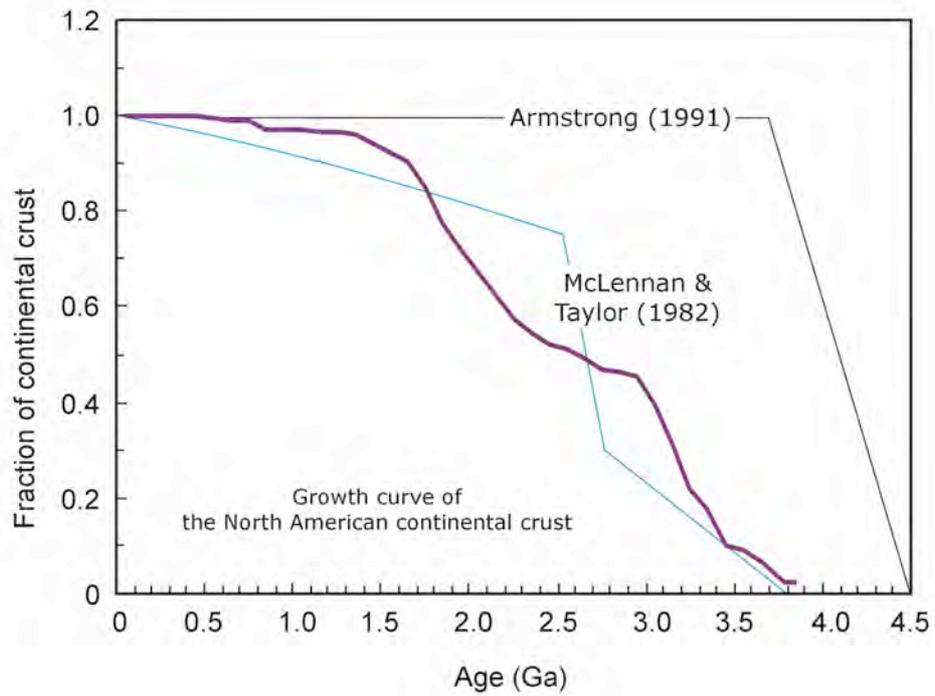


Figure 1.

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Keyhole geochronology in north-eastern Poland

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In late 2003 RSES and the Polish Geological Institute (PGI) in Warsaw signed an agreement to collaborate in a study of the basement rocks of north-eastern Poland. The collaboration, in which petrographic and geochemical studies at the PGI are combined with SHRIMP U-Pb geochronology at RSES, is resulting in a much clearer understanding of the geological evolution of the western part of the East European Craton (EUC) and its tectonic relationships to adjacent terranes.

As with all the western EUC, the basement rocks of Poland are buried beneath an extensive cover of much younger sedimentary rocks. The thickness of the cover ranges from about 500 m in the east to over 5 km in the west. The main sources of information about the broad geological structure of the underlying basement are aeromagnetic and gravity surveys, supplemented by deep seismic investigations. The only samples of the basement rocks that can be studied directly are drill cores recovered from a limited number of boreholes, mostly drilled to investigate deep geophysical anomalies. The challenge is to piece together the geological evolution of the basement using the limited view provided by these irregularly-spaced 'keyholes' (Fig. 1).

The research project is being undertaken as a series of sub-projects, each focused on a particular geophysical anomaly, rock type or region. All the sites studied lie NE of the Trans European Suture Zone, a major basement boundary that cuts approximately NW-SE through central Poland. Completed sub-projects include studies of a late Paleoproterozoic mafic igneous suite at Lomza, about 150 km NE of Warsaw (Krzemińska et al., 2005), of the 'Archean' crystalline basement of the Mazowsze granitoid massif in far NE Poland (Krzemińska et al., 2006a) and of an Early Carboniferous alkaline complex in the Pisz region about 200 km NNE of Warsaw (Krzemińska et al., 2006b).

Work is nearing completion on a belt of rocks from the Warmia area about 50 km SE of Gdańsk. Once considered to be high grade metasediments, these gneisses instead contain zircon with very simple textures and uniform ages, consistent with an igneous origin. They are coeval with the Mesoproterozoic Mazury Complex to the east, and are probably part of the same system. Work is also well advanced on some of the metagreywackes that host the igneous complexes of NE Poland. The detritus in these little-studied rocks is proving to have an unexpectedly similar range of provenance ages to that in some of the better-known metasediments of Scandinavia.

One of the surprises to come out of the project is the discovery of the large regional extent and relatively narrow age range of Late Paleoproterozoic, possibly arc-related, granitic rocks and associated metavolcanics in NE Poland (Krzemińska et al., 2007). Even the granitic gneisses of the Mazowsze massif, long considered to be of Archean age, are now known to be products of Late Paleoproterozoic magmatism. This finding has led to a major reassessment of the tectonic setting of Paleoproterozoic Poland in relation to the Archean Ukrainian Shield to the east, and the Paleoproterozoic marginal basins to the north, as igneous rocks of very similar age are widespread in the countries to the north and west that border the Baltic Sea.

The work in the Pisz region has helped to clear up some inconsistencies in earlier interpretations. The wide range of ages previously measured by Rb-Sr, K-Ar and fission track dating (265–350 Ma) does not appear to reflect differences in crystallisation age, but rather an extended post-crystallisation thermal history. Zircon ages measured at both Pisz and nearby Elk are ~345 Ma, consistent with zircon ages recently measured on alkaline rocks at Tajno, 40 km to the east.

The rocks at all three sites appear to be part of the same Early Carboniferous ultramafic-alkaline complex, rather than the gabbro at Pisz being part of a dismembered Paleoproterozoic ophiolite complex, as previously thought.

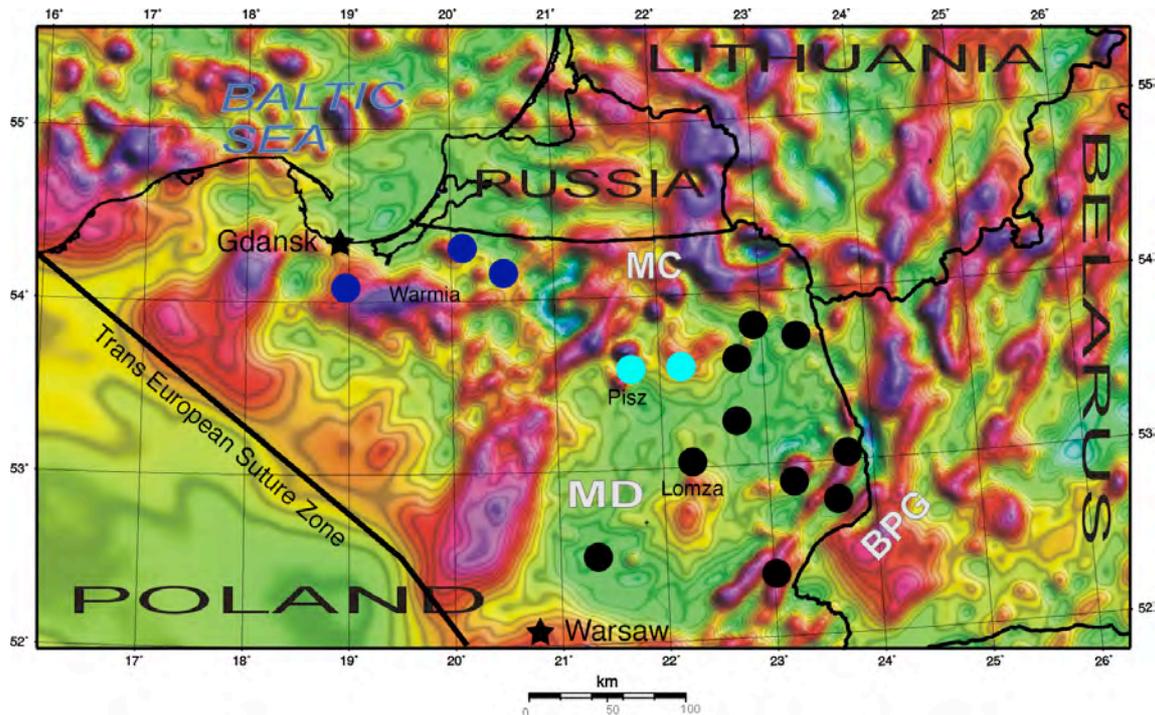


Figure 1. Magnetic anomaly map of the south Baltic region (after Wybraniec, 1999), showing the ages measured during this project on Polish basement rocks recovered from drill holes.
 Black, Late Paleoproterozoic; Dark blue, Early Mesoproterozoic; Light blue, Early Carboniferous.
 MC – Mazury Complex, MD – Mazowsze Domain, BPG – Belarus-Podlasie Granulite Belt

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Research Activities

Earth Environment

Earth Environment Introduction 2007

The Earth Environment group undertakes research on environmental and climate change with particular emphasis on the interactions between humans and the environment. The group specialises in the development of diagnostic environmental proxies within an absolute chronologic framework that spans a few tens to several hundred thousand years of Earth history. These records are used as a basis for understanding past, present and potentially future environmental and climate changes. Emphasis is placed on the reconstruction of high-resolution environmental records of both human impacts and global climate change using geochemical proxies preserved in the growth banding of foraminifer, marine sponges, fossil and modern corals, speleothems (cave deposits), layered sedimentary deposits and materials preserved in anthropologic sites of special significance.

Dr Mike Ellwood, Dr Steve Eggins, Dr Stewart Fallon, Professor Malcolm McCulloch together with Dr Martin Wille a new Post Doctoral Fellow at RSES are undertaking studies of biogenic skeletons from both modern and ancient marine sequences to determine recent as well as longer-term changes in the chemistry of the Southern Oceans. This research is being conducted in close cooperation with Professor Patrick De Deckker from the Department of Earth and Marine Sciences and is part of ANU's new marine science initiative. One of the important processes being examined is changes in the oceans 'biologic pump' which acts as a mechanism to draw-down CO₂ and hence provides an important feedback in modulating climate change. Carbonate as well as silicate secreting organisms (e.g. foraminifer, deep-sea corals and sponges) are being used as archives of ocean temperatures, acidity, nutrient fluxes and ventilation rates. The research is being undertaken using state of the art laser ablation ICPMS (including multi-collector) techniques, high precision U-series dating, accelerator mass spectrometer ¹⁴C dating, combined with boron isotopic analyses to determine changes in seawater pH. The latter is a relatively new approach pioneered at RSES with the potential to provide constraints on the extent of acidification of the oceans from uptake of anthropogenic CO₂.

Human impacts on the environment are being examined at several timescales. On modern timescales we are quantifying the extent of direct human impacts on modern coral reefs from degradation of river catchments, mangrove estuarine habitats and near shore coastal zones being conducted under the auspices of the ARC Coral Reef Centre of Excellence. Work undertaken by Dr Stacy Jupiter, Dr Guy Marion (University of Queensland) and Professor McCulloch have shown that the most severe impacts on coral reefs are due to agricultural practices such as cattle grazing, intensive sugar cane plantations and associated practices such as land clearing. Geochemical records (e.g. Ba/Ca, N isotopes) preserved in the long-lived coral skeletons, show that land-use changes in river catchments has increased sediment and nutrient supplies to many inshore reefs by up to an order of magnitude relative to pre-European 'natural' values. Work is also ongoing quantifying the extent of acidification of corals in the Great Barrier Reef due to increasing CO₂.

On Longer timescales Professor Grün's Linkage proposal on the Willandra Lakes World Heritage Area ranks is especially important for documenting Australia's unique cultural and environmental history.

This project is being undertaken jointly in a strategic alliance between the custodians and managers of the area and to build a picture of the continent's human and environmental history before this evidence is irretrievably lost. Professor Grün, Dr Maxime Aubert and PhD student Mr Renaud Joannes-Bayau have been developing and applying least destructive methods such as electron spin resonance and together with Dr Eggins using in-situ laser ablation ICPMS methods to directly date human samples of fossil teeth. This work is showing

that modern humans colonised Australia well before sites in Europe. High resolution isotopic analyses of human teeth and associated soils is also being employed by PhD student Ms Tegan Kelly to trace diets and hunting ranges as well as patterns of migration. Dr Mike Gagan and Dr Linda Ayliffe are also continuing their major research program in Indonesia examining closely the links between human evolution and climate. This involves the application of both stable isotope proxies as well as precise U-series dating to corals and speleothems and is being undertaken in collaboration via ARC projects at the Universities of Queensland and Wollongong.

Research on landscape evolution is being conducted by Professor Brad Pillans and Dr Kat. Fitzsimmons using dating methods such as paleomagnetism and optically stimulated luminescence together with Dr Tim Barrows (Dept of Nuclear Physics) who is undertaking studies using cosmogenic nuclides. This work is showing that Australia has some of the world's oldest regolith and landforms as well as providing quantitative measurements of the rates of weathering and denudation that are proving to be exceedingly slow reflecting the tectonic stability and extreme aridity of our continent.

Speleothems from Flores, Indonesia: tropical archives of climate change

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Very few precisely-dated paleorecords of climate from the tropics currently exist, despite the fact the tropics play a critical role in driving the Earth's large-scale atmospheric circulation by the export of heat and moisture to higher latitudes. Here we present some initial $d^{18}O$ results for the past 25ka from tropical speleothems from the island of Flores, Indonesia, which is a focal point for our ARC Discovery research (Gagan et al. 2006). The island of Flores, located at the southern-most extent of the Intertropical Convergence Zone (ITCZ) in the Austral summer and just within the current southern boundary of the Western Pacific Warm Pool (Sturman and Tapper 1996), is sensitive to past climate change. Tropical speleothems are ideal archives of changes in past rainfall as they can be dated precisely with the U-Th technique and their $d^{18}O$ values can be interpreted in terms of rainfall intensity as tropical rainfall $d^{18}O$ values are inversely proportional to rainfall amount (Dansgaard, 1964).

Two stalagmites from Liang Luar Cave (8°32'S, 120°27'E) were collected in July 2006 ~500m from the cave entrance. The $d^{18}O$ results of these two specimens are shown in Figure 1 together with other climate proxy records covering the past 30ka. When compared to the speleothem $d^{18}O$ records from nearby Borneo (4°N, 114°E) the Flores speleothems display a somewhat different response in rainfall $d^{18}O$ during the past 25ka, Figures 1 and 2. This is perhaps not surprising given the present day differences in climatology between the two sites. Borneo lies under the ITCZ year-round and exhibits little seasonality in rainfall (Cobb et al. 2007), while Flores has a distinct wet and dry season determined by the annual migration of the ITCZ.

Last Glacial Maximum (LGM) (19–23ka) $d^{18}O$ values of the Borneo speleothems are $1.3 \pm 0.3\text{‰}$ greater than modern values (Partin et al. 2007) while Flores speleothems are only $0.9 \pm 0.3\text{‰}$ greater than modern values during the LGM. The modern-LGM $d^{18}O$ differences of the Flores speleothems are less than what would be anticipated from global ice volume changes ($+1\text{‰}$) and $\sim 2\text{--}3.5^\circ\text{C}$ lower regional temperatures ($+0.4\text{‰}$ to $+0.7\text{‰}$). This suggests that rainfall $d^{18}O$ values were lower during the LGM at the Flores site in contrast to the neighboring Borneo site. Changes in eustatic sea levels during the LGM would have increased the continentality of Flores which probably resulted in decreased rainfall $d^{18}O$ values (Rozanski et al. 1993) at this time.

Local differences in proximity to exposed continental shelves between Flores and Borneo may explain why LGM rainfall $d^{18}O$ at Borneo was not affected to the same extent as Flores by lowered sea levels.

The response of the Flores and Borneo speleothem $d^{18}O$ records appear anticorrelated during the deglacial (17–10ka), Fig. 2. Peaks(troughs) in the Borneo record correspond with troughs(peaks) in the Flores speleothem record within error of the chronological errors (Partin et al. 2007). Furthermore most of these features appear to be synchronous with known

climate excursions during this time interval, namely that of: Heinrich Event 1 (H1); Antarctic Cold Reversal (ACR) and the Younger Dryas (YD), seen in ice core and Chinese speleothem records Fig. 1,2. Modeling results of Zhou and Delworth (2005) predict that the ITCZ migrated south in the Pacific ocean, the Walker circulation moved eastward and that the east Asian monsoon intensity weakened during H1. Negative rainfall anomalies in parts of the S/W Pacific, including Borneo, were predicted outcomes of these coupled model simulations.

Although predictions for changes in rainfall are less certain for eastern Indonesia (incl. Flores) during H1, slight increases in rainfall are suggested at the less than 95% level of confidence by Zhou and Delworth (2005). If the ITCZ did move south during H1 to be located more directly over eastern Indonesia throughout the year, then this could explain the negative $d^{18}O$ excursion seen in the Flores record (indicating higher rainfall) at the same time that Borneo was experiencing rainfall diminishment. The antiphase response in the Flores and Borneo records during the ACR (Flores: dryer, Borneo: wetter), YD (Flores: wetter, Borneo: dryer) and at ~ 11.4 - 11.8 ka (Flores: dryer, Borneo: wetter) might also be accounted for by similar oscillations in the mean position of the ITCZ.

The last major difference between the Flores and Borneo speleothem records is observed at ~ 5 ka when the Borneo record displays a decrease in rainfall $d^{18}O$ values (increased rainfall) while the Flores ^{18}O record shows no change, Fig. 1. Partin et al. (2007) attribute this ^{18}O decrease to either enhanced warm pool convection from an insolation-driven increased tropical Pacific zonal SST gradient, or changes in the position of the ITCZ. The fact that the Flores speleothem record does not show the same ^{18}O increase as the Borneo record at this time suggests that intensification of the Walker circulation is unlikely to be the principal cause, as if it were the case, similar increases in Flores rainfall $d^{18}O$ might also be expected at 5ka.

Traditionally global climate models have struggled to robustly predict past climate changes in the tropics. It is hoped that additional palaeo-rainfall $d^{18}O$ records, such as those presented here, will contribute significantly to improving the skill of future generations of GCM's.



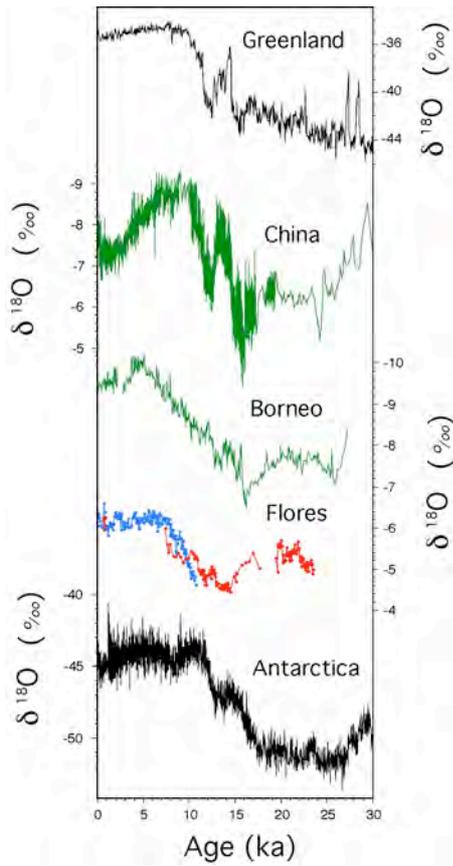


Figure 1. Speleothem $\delta^{18}\text{O}$ records from Flores ($8^{\circ}32'S$, $120^{\circ}27'E$) (LR06-B3 (blue) & LR06-C6 (red)) compared with speleothem $\delta^{18}\text{O}$ records from Borneo ($4^{\circ}N$, $114^{\circ}E$) and S/E China (Dongge: $25^{\circ}17'N$, $108^{\circ}5'E$, Hulu: $32^{\circ}30'N$, $119^{\circ}10'E$) and ice core $\delta^{18}\text{O}$ records from The North Greenland Ice core Project (NGRIP) and the European Project for Ice Coring in Antarctica (EPICA).



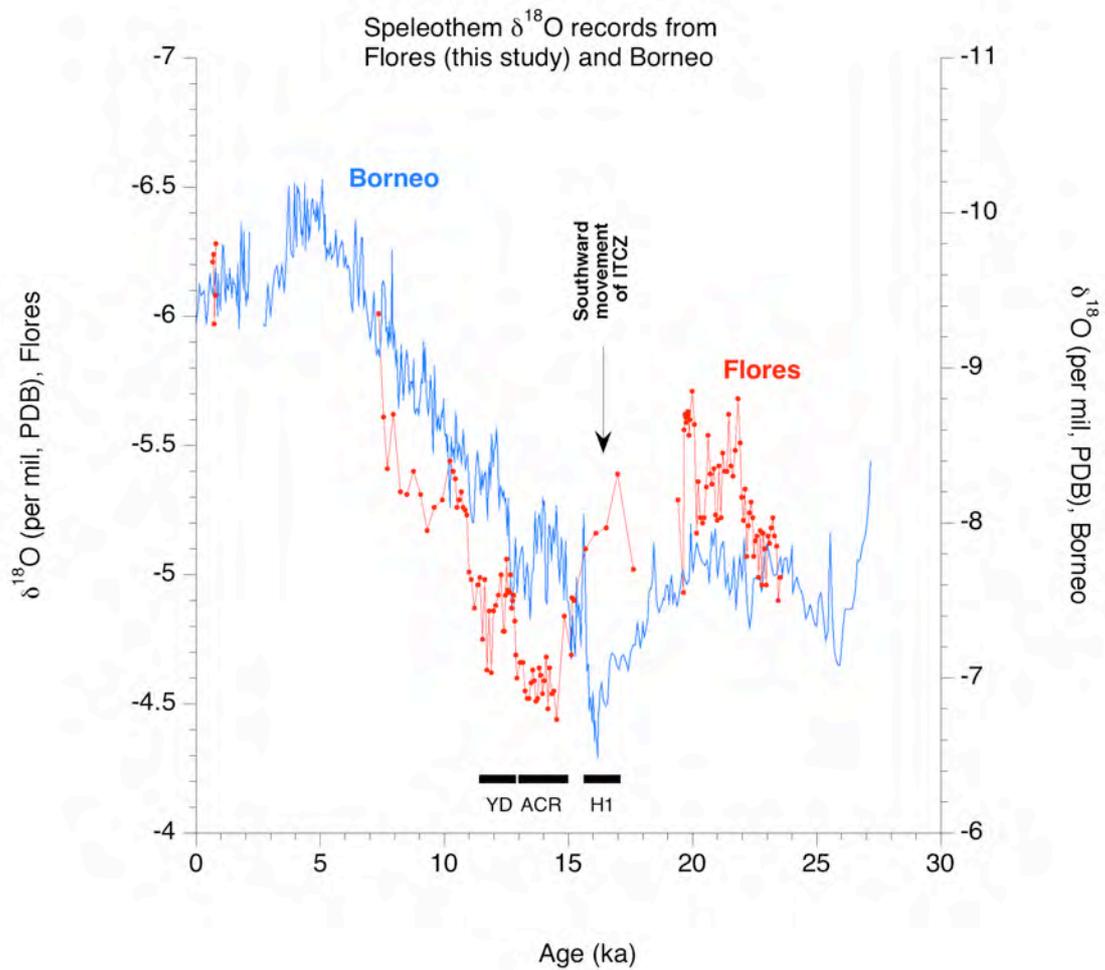


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High resolution elemental and isotopic distribution in fossil teeth: Implications for diet and migration

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New developments in laser ablation ICPMS permit the measurement of high resolution elemental and isotopic distributions in fossil teeth. For the reconstruction of diets and migrations, Sr and Ca elemental and Sr isotopic distributions were measured on sectioned teeth of a sample set from the site of Payre (Ardèche, France), which included herbivores, omnivores, carnivores and Neanderthals. In order to investigate diagenetic strontium uptake, Sr concentration and isotopic ratios were mapped in a Neanderthal tooth. The Neanderthal tooth showed by far the lowest Sr/Ca ratio of all teeth analysed followed by the carnivores and the herbivores. These observations tend to confirm earlier results based on nitrogen isotopes that had implied that Neanderthals were "super-carnivores" (Bocherens *et al.*, 1999; Richards *et al.*, 2000). On the other hand, post-depositional Sr uptake seems to play a significant role in Sr isotope distribution through the dentine and enamel. Research continues to evaluate whether a two component mixing model can be used to eliminate post mortem Sr contamination. The maps clearly demonstrate that original, perhaps variable Sr isotopic compositions of Neanderthal teeth cannot be obtained by bulk analysis whether or not associated with any leaching protocols.

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In situ oxygen isotope analysis of fossil human teeth using a secondary ion micro-probe: a new tool for palaeoecology and archaeology

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The oxygen isotopic composition ($\delta^{18}\text{O}$) in tooth enamel of freely drinking animals is closely associated to the isotopic composition of the drinking water at the time of tooth formation. While the isotopic composition of surface waters may depend on a large number of factors, in moderate climates, a strong seasonal change is observed, mainly driven by changes in temperature. As a result, compositional changes in the oxygen isotope signature in teeth give powerful insights into seasonal variability over time.

Traditionally, samples are obtained through micro-drilling. While this is adequate for the analysis of fast growing faunal teeth, any seasonal signatures in human teeth are averaged out. Following major modifications to the RSES SHRIMP II ion microprobe, it is now possible to analyse oxygen isotopic compositions on polished sections of tooth enamel on a scale of about 30 μm , allowing the detailed analysis of human teeth with a weekly resolution. A 10 kV beam of caesium ions is focused onto the tooth, thereby sputtering oxygen ions from the enamel for real time isotopic analysis by a high resolution multiple collector mass spectrometer. Each analysis only consumes about 2 ng of enamel, with a precision of about 0.2 ‰ (s.d.).

A series of experiments is currently under way to optimize measurement parameters, with a particular emphasis on the analysis of Neanderthal molars. Herbivore teeth recovered from the Neanderthal fossil sites have shown large seasonal signatures, indicating that the original oxygen isotopic compositions were relatively well preserved. So far, the apparent seasonality in a Neanderthal molar was much smaller. This may reflect a much more restricted range of diet, a much more uniform sources of drinking water during tooth formation, namely in the first five years of a Neanderthal child's life or diagenetic alteration.

Discovery of Late Pleistocene rock art in Egypt

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Intensive surveying of the Nubian sandstone cliffs immediately east of the modern village of Qurta, along the northern edge of the Kom Ombo Plain, Egypt in February-March 2007 led to the discovery of three rock art sites, designated Qurta I, II and III. These sites show petroglyphs executed in a vigorous naturalistic, 'Franco-Cantabrian, Lascaux-like' style (Fig. 1). The Qurta rock art is quite unlike any rock art known elsewhere in Egypt. It is substantially different from the ubiquitous 'classical' Predynastic rock art of the fourth millennium BC, known from hundreds of sites throughout the Nile Valley and the adjacent Eastern and Western deserts. On the basis of style, patination and weathering, these petroglyphs are definitely extremely old. Direct ages for this rock art are not yet available, but analyses are under way to explore its potential for AMS ¹⁴C dating of organics in the varnish rind and/or U-series dating.



Figure 1. Detail of a bovid at Qurta II (QII.5.1)

Holocene mega-droughts and the seasonal structure of El Niño events in the Philippines

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The Holocene climatic evolution of the Southeast Asian monsoon domain was largely controlled by opposing trends in the summer monsoon (weaker towards the present) and El Niño–Southern Oscillation (stronger towards the present). These trends have been attributed to orbitally driven changes in the seasonal cycle of insolation, which enhanced Asian monsoon rainfall and suppressed El Niños during the middle Holocene (Clement et al. 2000, Liu et al. 2000). However, new coral-based palaeoclimate reconstructions from the Philippines provide surprising evidence for abrupt shifts in climate and mega-droughts superimposed on this somewhat benign climatic picture (Gagan et al. 2006).

In this study, we examined the evolution of El Niños from 7,600 years ago to the present using annually resolved records of $^{18}\text{O}/^{16}\text{O}$ in a suite of fossil *Porites* corals from eastern Samar, Philippines. At Samar, coral $^{18}\text{O}/^{16}\text{O}$ reflects the combined effect of rainfall and sea surface temperature (SST) and pronounced positive $^{18}\text{O}/^{16}\text{O}$ anomalies relate to droughts and cooler SSTs during El Niños (Fig. 1a). The coral $^{18}\text{O}/^{16}\text{O}$ records show that long droughts (>3 years duration) were more prevalent in the middle Holocene, the longest of which lasted 14 years. These protracted droughts appear to be linked to multi-decadal climate fluctuations. The extraordinary duration of the mid-Holocene droughts may help explain why agricultural societies were not firmly established in the Philippines until after ~4,000 years ago.

To investigate the seasonal structure of the droughts in detail, we performed bi-weekly analysis of coral $^{18}\text{O}/^{16}\text{O}$ throughout the most prominent events (Fig. 1b). We compared coral $^{18}\text{O}/^{16}\text{O}$ anomalies at the start, peak and end of the four most recent El Niño events (1986/7, 1990-95, 1997/98 and 2002/03) with events recorded at 7.2 ka and 2.3 ka. Composite analysis of the droughts reveals significant changes in the onset and magnitude of the $^{18}\text{O}/^{16}\text{O}$ anomalies. Droughts associated with El Niño events in the modern coral record typically peak towards the end of the calendar year. In contrast, droughts at 7.2 ka and 2.3 ka commenced about 3-6 months earlier and ended in the middle of the calendar year within two months of the termination-time for present-day events.

In summary, the coral records show that the longest droughts occurred in the middle Holocene, yet peak anomalies on seasonal time-scales were largest in the late Holocene (at ~2.3 ka). This finding is consistent with a climate model (Clement et al. 2000) and palaeo-ENSO records (Moy et al. 2002) showing large amplitude and more frequent events in the late Holocene. Our results indicate that the magnitude, duration and seasonal structure of El Niño events have evolved substantially through the Holocene.

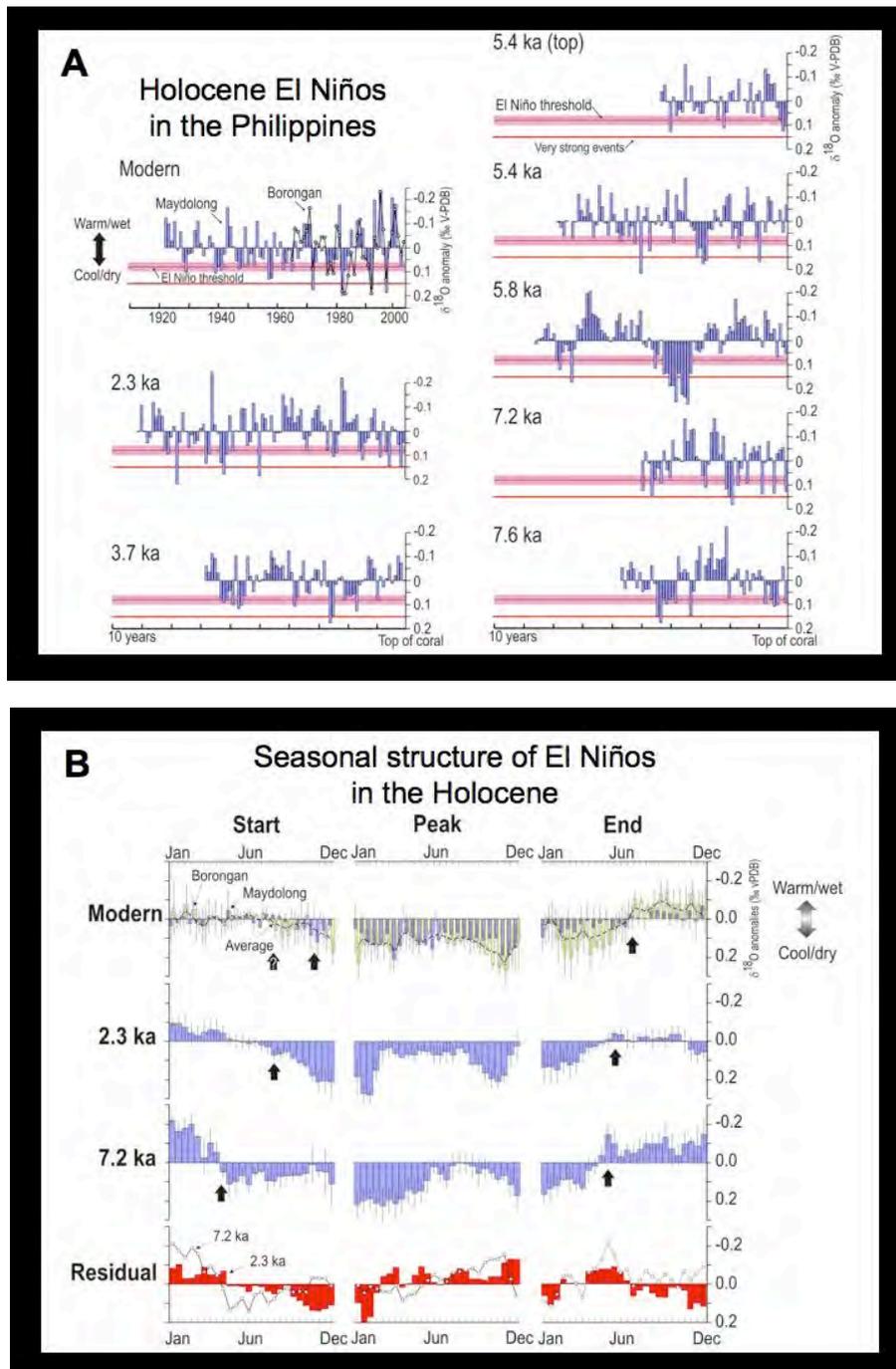


Figure 1. Holocene mega-droughts and the seasonal structure of El Niño events in the Philippines. (A) Evolution of El Niño events from 7,600 years ago (7.6 ka) to the present based on annually resolved $^{18}O/^{16}O$ anomalies in fossil corals from eastern Samar, Philippines. (B) Composite analysis of bi-weekly coral $^{18}O/^{16}O$ anomalies to reveal the seasonal structure of El Niño events at 7.2 ka, 2.3 ka, and the present.

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Speleothem records of palaeomonsoon dynamics from Flores, Indonesia

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Speleothems are cave deposits which potentially yield high resolution, independently dated proxy records of climate. At tropical sites, speleothem oxygen isotope ($\delta^{18}\text{O}$) variations are primarily dominated by rainfall amount. Fluctuations in carbon isotopes ($\delta^{13}\text{C}$) are related to the response of local vegetation and soil to climate variations. As part of an Australian Research Council *Discovery* grant, fieldwork was carried out in 2006 and 2007 within caves in Flores, Indonesia to collect speleothem material for the generation of palaeoclimate records. Collaborators from RSES, Indonesian Institute of Sciences, University of Queensland and University of Newcastle collected speleothems spanning various time periods in order to document millennial to seasonal extremes of regional monsoonal rainfall.

Preliminary uranium-series dating of the speleothem calcite indicates that the samples span a broad temporal range. Stalagmite samples collected during the 2006 field season provide records of rainfall variability from 23.5 kyr to the late Holocene. Flowstone material collected at the same time covers an overlapping period to 30 kyr and additionally from 99 kyr to 109 kyr. High resolution stable isotope and trace element analysis of this material is currently being conducted. In 2007, our team specifically targeted for collection stalagmite samples that span up to 50 kyr and flowstone material that ideally covers the past 150 kyr.

This study forms part of the stream of ARC research program Monsoon extremes, environmental shifts and catastrophic volcanic eruptions: quantifying impacts on the early human history of southern Australasia, which aims to reconstruct a continuous history of monsoon rainfall variability within the Australasian region over the last 50 kyr. Ideally, this study will clarify the connection between the Northern and Southern Hemisphere climates on millennial timescales, and the nature and source of recorded variability. Specifically, we aim to determine whether short-term, abrupt climatic changes documented in Northern Hemisphere records, such as Dansgaard-Oeschger cycles and Heinrich events, are identifiable in tropical Southern Hemisphere records. By addressing these research questions, we expect to elucidate the role of the tropics in the global climate system over the last 50 kyr.



Figure 1. Coring a flowstone in Liang Luar cave, Flores, Indonesia during 2007 (G. Smith).

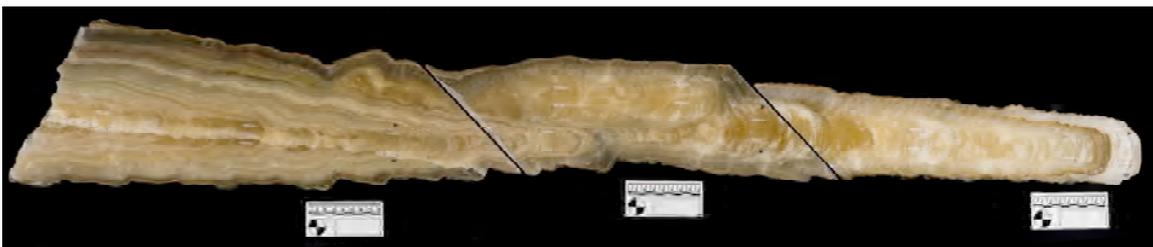


Figure 2. Stalagmite LR06-C6 from Liang Luar Cave, Flores, Indonesia, providing monsoon rainfall proxy data from 7.35–23.5 kyr (L. Ayliffe).

Gagan, M.K., Zhao, J.-x., Drysdale, R.N., Hantoro, W.S. and Schmidt, G.S. Monsoon extremes, environmental shifts and catastrophic volcanic eruptions: Quantifying impact on the early human history of southern Australasia. ARC Discovery Grant DP0663274 (2006–2008).

Boron in biogenic silica: insights into pH and pCO₂ of the Southern Ocean

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The boron isotope composition of biogenic carbonate (e.g. foraminifera, coral) has been used as a proxy for measuring seawater pH. Boron has two isotopes, ¹⁰B and ¹¹B, and their partitioning into the two species of boron that exist in seawater, boric acid (B(OH)₃) and borate (B(OH)₄⁻) strongly correlates with seawater pH. This relationship can be exploited to determine the pH of seawater at the time of carbonate precipitation.

This research looks to extend this proxy by using the boron composition of biogenic silica to measure the palaeo-pH of the Southern Ocean. The Southern Ocean is thought to play an important role in controlling atmospheric pCO₂; however the mechanism by which the ocean exerts this influence is poorly understood. An understanding of the pH, and hence the carbonate chemistry, of the Southern Ocean will provide important insights into this relationship. Using biogenic silica, namely diatoms and siliceous sponges, a palaeo-pH profile of the Southern Ocean that covers glacial-interglacial climate transitions will be used to investigate changes in Southern Ocean chemistry during these fluctuations in atmospheric pCO₂.

Work so far has focussed on developing the techniques required to measure the boron isotope composition of biogenic silica. These techniques will be used on live-collected and cultured samples in order to constrain the boron isotope pH proxy, and then applied to sediment core samples taken from the Southern Ocean.

Silica banding in the deep-sea lithistid sponge *Corallistes undulatus*: Investigating the potential influence of diet and environment on growth

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It is becoming increasingly clear that food supply and diet strongly influence the structure of deep-ocean communities and the nature of growth in the constituent organisms. We know that the export of labile phytodetritus to the ocean's interior is episodic and is influenced by climate. However, characterizing these export events and their influence on deep ocean organisms can be problematic. The use of proxy records is one way of reconstructing changes in surface ocean export and its influence on the deep-ocean community. A major hurdle is the availability of marine invertebrates that have long life spans and skeletons that archive the history of the animal's growth and diet. Marine sponges offer a unique approach to this problem as their silica spicules incorporate trace elements and carbon thus providing a potential archive of food supply related to surface ocean export.

To realize this potential, we made detailed records of trace metals and carbon isotopes to understand siliceous spicule (Figure 1) formation in the deep-sea lithistid sponge *Corallistes undulatus* Levi and Levi, 1983 (Demospongiae: Corallistidae). X-ray analysis of two longitudinal sections removed from this cup-shaped sponge revealed ~140 light and dark density band-pairs within the siliceous skeleton. In addition, four portions of silica were removed for silicon-32 (³²Si) dating in order to constrain the overall extension rate of the sponge. Although there was some variability in the ³²Si data, the overall age established using these data indicated that the sponge was between 135 and 160 yr old. This agreed well with the counts of density band-pairs, indicating that these band-pairs appear to represent an annual deposition of layers of silica in the sponge skeleton.

We also investigated the links between silica deposition and growth (food supply) were established using the radiocarbon and stable carbon isotope signatures of organic material trapped with the spicule matrix and the zinc content of the silica. A carbon budget based on these results indicated that the amount of fresh, labile surface export organic carbon reaching *C. undulatus* was not sufficient to support its growth. The radiocarbon results for organic carbon trapped in the silica spicules, deposited after the 1960s, supports this assertion; only a small atmospheric nuclear weapons 'bomb' spike was observed in the data. Taken together, the stable and radio-carbon data, and trace-metal results all indicate that the organic carbon source to *C. undulates* is likely to be a mixture of fresh, labile, surface-derived material and older, perhaps sediment-derived material, with the latter being dominant.

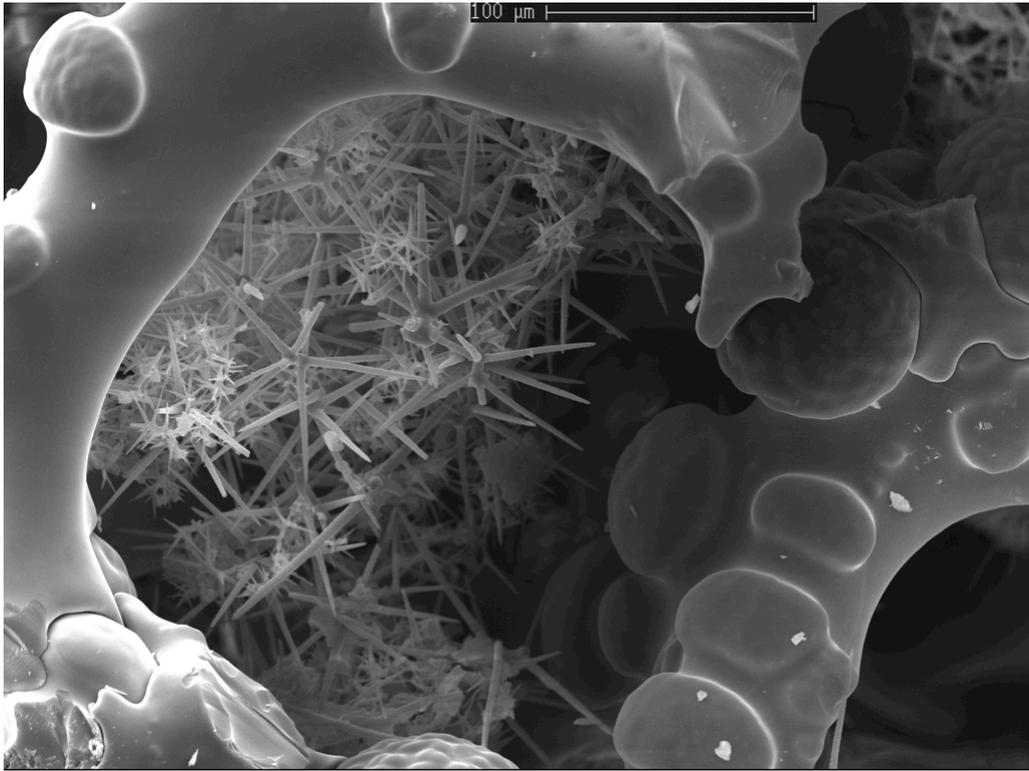


Figure 1. SEM image of the silica skeleton of the sponge *Corallistes undulatus* Levi and Levi, 1983

Determining Age and Growth Rate of Marine Sponges by Radiocarbon Dating of Carbon trapped in Silica Spicules

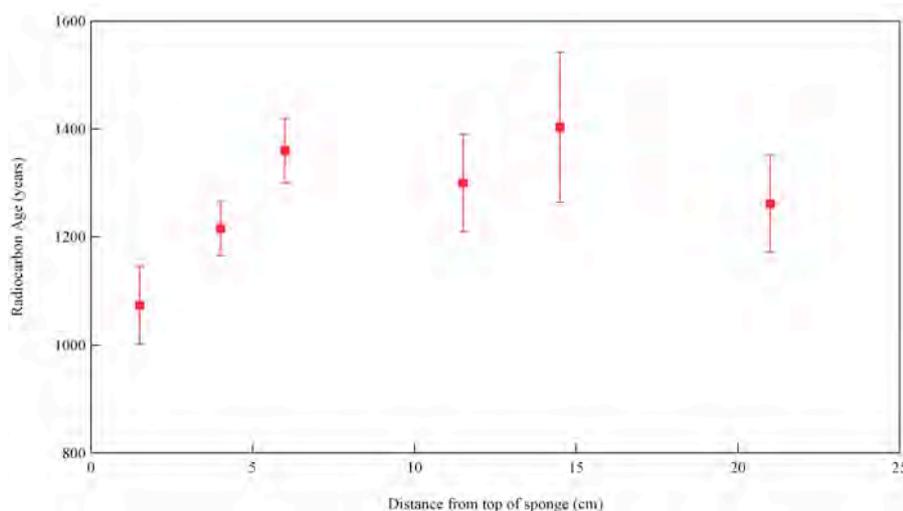
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Radiocarbon (¹⁴C), the radioactive isotope carbon can be used to determine the age of material that was once part of the biosphere. On land this is simple with the carbon-14 sourced from the atmosphere by the cosmic irradiation of Nitrogen-14. This carbon-14 is quickly oxidised to ¹⁴CO₂ and mixes into the biosphere in its proportion to ¹²CO₂ and ¹³CO₂. In the ocean there are slightly more complicating factors, the ocean takes ~10 years to come into equilibrium with the atmosphere and the residence time for a parcel of water in the deep ocean is long enough for radioactive decay. This results in the surface ocean having an apparent age of ~400 years, this is termed the reservoir age. This adds a small complication to estimating the age of a marine organism but it is correctable.

Marine sponges are filter-feeder organisms; they are ubiquitous in the world's seas. They obtain their carbon from the food they eat. Sponges are made up of an organic matrix and silica spicules. It is thought that as a sponge grows spicules are formed and a small amount of organic carbon is trapped. If we sample spicules from different areas and determine the age of the carbon in the spicules we should be able to obtain age and growth rate information. A marine sponge was collected from the Ross Sea, Antarctica. We determined that the spicules were very low in carbon content ~0.05% and that it is necessary to thoroughly clean the spicules to remove contaminant carbon. Our preliminary results suggest that as one samples further back in time along the sponge the radiocarbon age increases (Figure 1). The outer most edge of the sponge has an apparent age of 1075 years, even though it was alive when it was collected in 2005. The reason for this is that upwelling occurs in the Ross Sea, this brings water with an older age to the surface, the average radiocarbon age of surface water in Antarctica is ~950 yrs. The innermost sample (oldest) dates to ~1350 years ago, suggesting this sponge lived for ~270 years. This gives an average growth rate of 0.8 mm per year. Although the graph suggests that the growth rate may change as the sponge get older.



The history of aridity in central Australia over the last glacial cycle: Evidence from desert dunefields

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Australia is the driest inhabited continent on Earth. Aridity on the continent has intensified during the glacial cycles of the last few million years, creating stony deserts, dry salt lakes, and the extensive dunefields which preserve evidence of episodes of aridity during the more recent glacial intervals. Aridification has not been limited to Australia; drier conditions have remobilised desert dunes worldwide. Alarmingly, models of future desert dune activity suggest that human-induced climate change in the twenty-first century may enhance aeolian activity still further, resulting in even more widespread landscape instability (Thomas et al., 2005). Our work focuses on the timing of aeolian episodes in the past and their relationship to palaeoenvironmental conditions, in order to better understand mechanisms for future change.

Linear dunes occupy more than one third of the Australian continent, but the timing of their formation and their reliability as proxies for arid conditions is poorly understood. Our work has focused on the late Quaternary history of aridity of the Strzelecki and Tirari Desert dunefields, a region in the driest part of Australia. We collected 82 samples from 26 sites across the Strzelecki and Tirari Deserts in the driest part of central Australia to provide an optically stimulated luminescence (OSL) chronology for these dunefields (Fitzsimmons et al., in press). The dunes preserve up to four stratigraphic horizons, bounded by palaeosols, which represent evidence for multiple periods of reactivation punctuated by episodes of increased environmental stability. Dune activity took place in episodes around 73–66 ka, 35–32 ka, 22–18 ka and 14–10 ka. Intermittent partial mobilisation persisted at other times throughout the last 75 ka and dune activity appears to have intensified during the late Holocene.

Dune construction occurred when sediment was available for aeolian transport; in the Strzelecki and Tirari Deserts, this coincided with cold, arid conditions during marine isotope stage (MIS) 4, late MIS 3 and MIS 2, and the warm, dry climates of the late Pleistocene–Holocene transition period and late Holocene. Localised influxes of sediment on active floodplains and lake floors during the relatively more humid periods of MIS 5 also resulted in dune formation. The timing of widespread dune reactivation coincided with glaciation in southeastern Australia, along with cooler temperatures in the adjacent oceans and Antarctica. We are now also able to compare three different proxies for aridity in the Australian arid zone, using dune, salt lake and emu eggshell oxygen isotope records, in order to more precisely reconstruct past environmental conditions and mechanisms for dune reactivation.

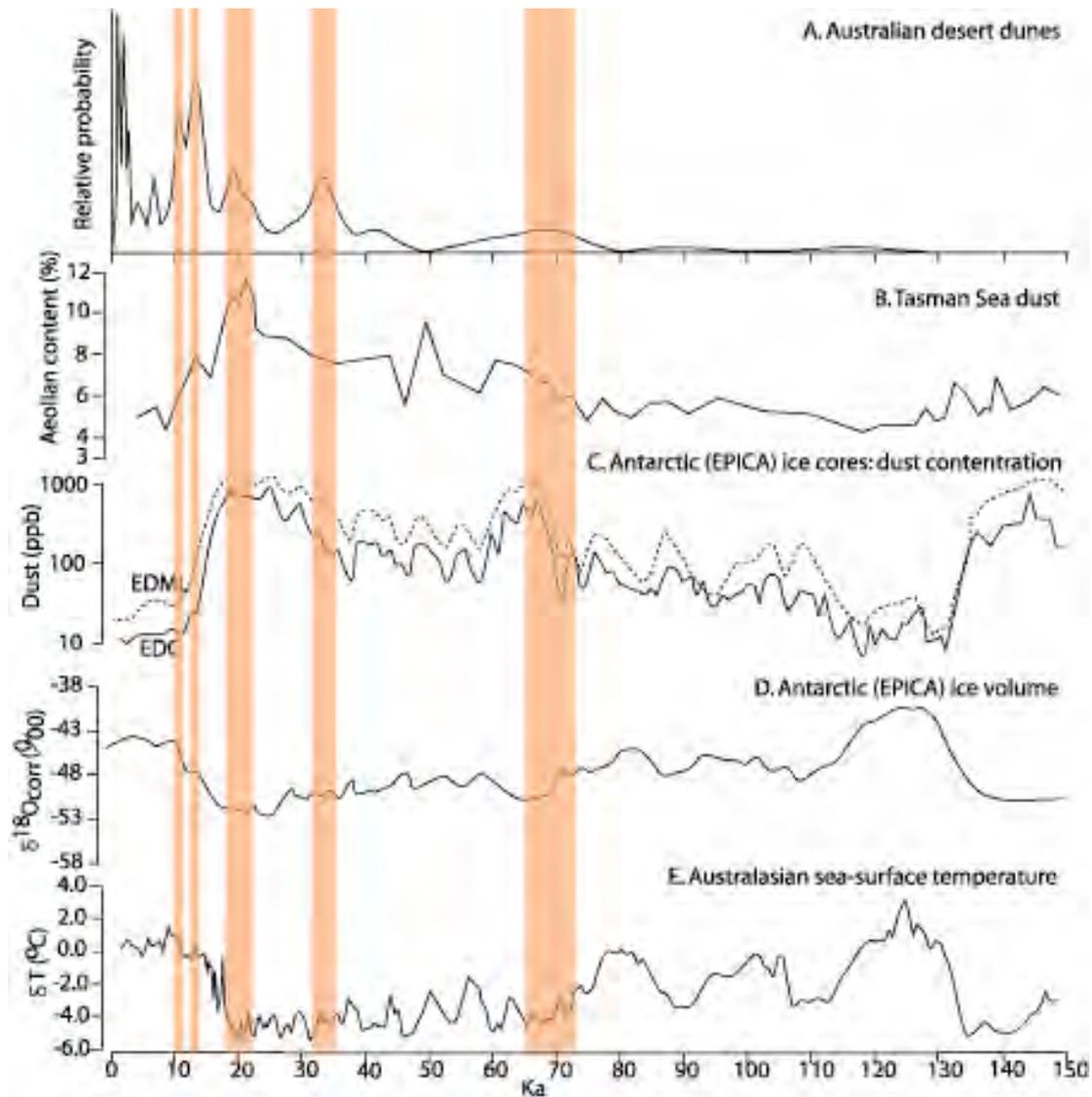


Figure 1. Comparing the Australian dune record from this study (A) with other palaeoclimatic records; (B) Aeolian concentration of dust in Tasman Sea sediments (Hesse, 1994); (C) Dust concentration in the Dronning Maud Land (EDML) and Dome C (EDC) ice cores in Antarctica (EPICA, 2006); (D) $\delta^{18}\text{O}$ (corrected) ice volume record from the EDML ice core (EPICA, 2006), and (E) Stacked sea-surface temperature record from the Australasian region (Barrows et al., 2007). Age groupings for dune activity are highlighted in orange.

Fitzsimmons, K., Rhodes, E., Magee, J., Barrows, T.T. (in press) The timing of linear dune activity in the Strzelecki and Tirari Deserts, Australia. *Quaternary Science Reviews*.

Thomas, D.S.G., et al., 2005. Remobilisation of southern African desert dune systems by twenty-first century global warming. *Nature* 435, 1218-1221.

Coral chemo-geodesy: long-term perspectives for improved prediction of great submarine earthquakes

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The nature of catastrophic earthquakes and tsunamis, such as those generated by the 2004 and 2005 earthquakes in Sumatra, is poorly understood, largely because the recurrence interval of great submarine earthquakes remains unknown. Fossil coral reefs preserved along the Sumatran subduction zone mark vertical motions during great earthquakes back to ~7,000 years ago.

Our ARC *Discovery* grant team has discovered that carbon-isotope ratios ($^{13}\text{C}/^{12}\text{C}$) in the skeletons of well-preserved massive *Porites* corals record vertical crustal deformation during submarine earthquakes (Gagan et al. 2006). The initial finding was based on analysis of a *Porites* microatoll from the Mentawai Islands, southwest Sumatra, that revealed a spectacular increase in coral $^{13}\text{C}/^{12}\text{C}$ in response to 0.7 m uplift during the magnitude ~8.4 earthquake in 1797 AD. Water column light intensity, coral symbiont photosynthesis, and skeletal $^{13}\text{C}/^{12}\text{C}$ are inextricably linked. This record showed, for the first time, that $^{13}\text{C}/^{12}\text{C}$ in coral skeletons is sensitive to the increase in light intensity when corals rise to shallower water during co-seismic uplift.

Given this encouraging result, we are developing the coral "chemo-geodesy" technique for massive (vertically growing) *Porites* corals, which are abundant in tectonically active tropical island arc settings. We now have a continuous, high-resolution time-series of coral $^{13}\text{C}/^{12}\text{C}$ showing crustal deformation before, during, and after the 1907 AD (M ~7.8) and 1935 AD (M ~7.7) earthquakes in Sumatra. In both cases, crustal rupture is preceded by an increase in seafloor submergence (lower light intensity recorded by coral) for a few years before the quakes. This apparent acceleration in crustal deformation prior to rupture is interesting because it may be a precursor to large earthquakes.

To further ground-truth the chemo-geodesy technique, we have collected coral cores from Sumatran reefs surrounded by a global positioning system (GPS) array that fortuitously measured crustal deformation during the 2004 and 2005 earthquakes. We drilled corals in areas of strong uplift (+1.5-2.8 m), and also specimens that experienced vertical displacements separated by ~3 months during the 2004/2005 "compound earthquake".

If this test is successful, we will embark on a program to produce a precisely dated, semi-continuous reconstruction of the recurrence intervals of giant submarine earthquakes along the Sumatran subduction zone over the past ~7,000 years.

In principle, such histories could be produced for any tropical island arc setting to improve our knowledge of great-earthquake cycles and tsunamis in Asia-Pacific region.

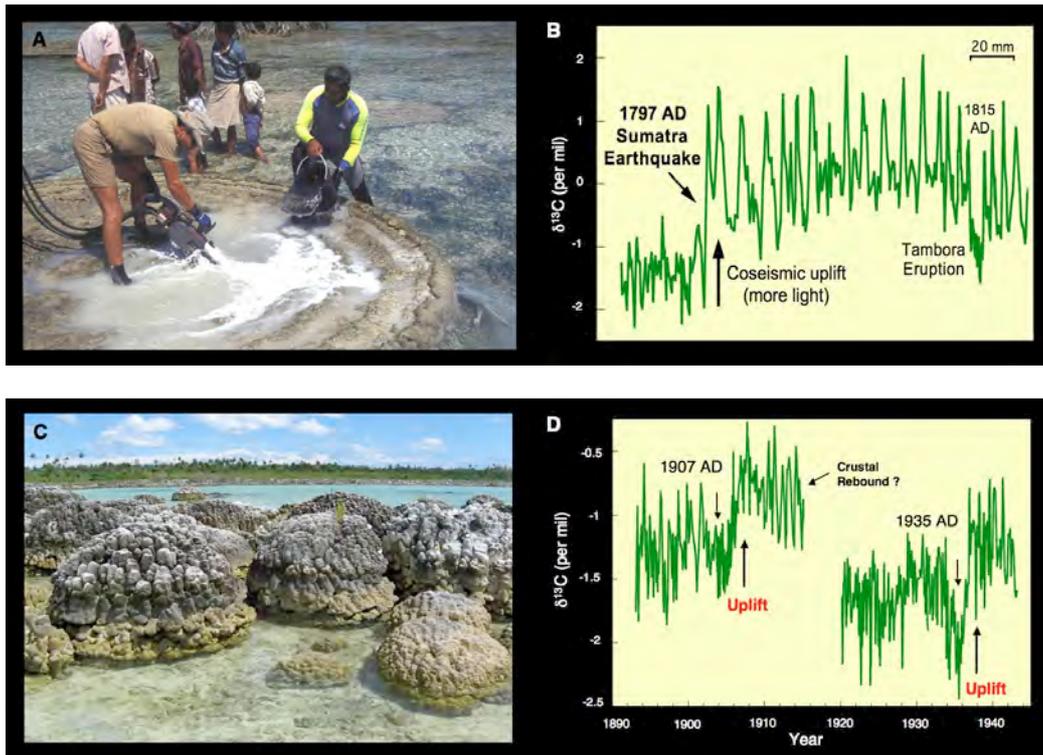


Figure 1. Coral chemo-geodesy along the Sumatran subduction zone. (A) Chain-saw slicing a giant *Porites* microatoll in the Mentawai Islands, Sumatra. (B) Profile of skeletal $^{13}\text{C}/^{12}\text{C}$ in a *Porites* microatoll showing abrupt increase in $^{13}\text{C}/^{12}\text{C}$ marking ~ 0.7 m coseismic uplift during the M 8.4 earthquake in February 1797 AD. (C) Emergence (+2.8 m) of massive *Porites* corals on the island of Nias during the M 8.7 March 2005 earthquake. (D) Profile of skeletal $^{13}\text{C}/^{12}\text{C}$ in a massive *Porites* coral showing crustal deformation before (submergence), during (abrupt emergence), and after (crustal rebound) the 1907 AD (M 7.8) and 1935 AD (M 7.7) earthquakes in Sumatra.

Gagan, M.K., Hantoro, W.S., Natawidjaja, D.H., Lough, J.M., Meyers, G.A., Liu, Z., Sieh, K., ARC Discovery Grant DP0663227 (2006–2010): The Indian Ocean Dipole, Australasian drought, and the great-earthquake cycle: Long-term perspectives for improved prediction.

High resolution analysis of uranium and thorium concentration as well as U-series isotope distributions in a Neanderthal tooth from Payre using laser ablation ICP-MS

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A Neanderthal tooth from the site of Payre was selected to evaluate and advance *in situ* analyses, including U-series, Sr, Ca and O isotopes. First results on SHRIMP oxygen isotope analysis (with spot sizes of 35 μ m diameter, 2 μ m deep, allowing weekly to bi-weekly resolutions in human molars) and Sr elemental distributions on this tooth using laser ablation were reported by Grün et al. (2006), maps of Sr isotopes by Aubert et al. (2007). Here, we present the first high resolution U and Th concentration and U-series isotope maps of a human fossil.

In a first exploration of the U-distribution, 21 parallel laser scans were measured, covering a cross section of occlusal and lingual enamel and the adjacent dentine (Area 1, Figure 1). The tracks had a width of 85 μ m, with a spacing of 100 μ m and consisted of 1100 individual measurements. Figure 2 shows maps of the U and Th elemental distributions. In the enamel Th is predominantly enriched right at the surface (Figure 2C) where it is associated with detrital coatings (Figure 1). In the 3-D presentation, this thin veneer occurs as separate isolated cones, which is the result of rastering caused by the track width and interpolation strategies of the software. Uranium diffusion into the enamel did not follow a simple D-A model (Pike et al 2002), which would have produced $_$ -shaped U distributions. The lowest concentrations are found near the occlusal surface where U-concentrations drop to less than 10 ppb, indicating little or no U-uptake. Elsewhere uranium has migrated into the enamel in a variety of modes. Firstly, U is concentrated along visible cracks, one is clearly visible starting from the cusp of the dentine reaching to the surface (just above "I" in Figures 2A and B).

At least three different lineaments with enriched U-concentration are visible, all running at shallow angles to the surface and dentine/enamel boundary. The most obvious feature in the enamel is a relatively large domain of greatly increased U-concentrations of up to 1500 ppb (around Cycle 500 in Tracks 9 to 14, Figure 2B). Uranium migrated from the dentine into the enamel along two pathways (perhaps tubules that pass from the dentine through into the enamel) leading to a U-enrichment in an area, which reaches about 600 μ m into the enamel and has a width of about 800 μ m. A series of smaller linear diffusion paths lead further into the enamel. This domain of high U can clearly not be explained by monotonic diffusion into a homogeneous layer, but more likely is due to a mineralogical change in this area. The uranium concentrations in dentine ranged from about 25,000 ppb to 45,000 ppb. There is a general gradient from the centre of the dentine (Cycles 500-800, Tracks 1 to 5) towards the enamel. It is obvious that U-mapping is essential to understanding the mode of U-migration.

Figure 3A shows an SEM photograph of the approximate dentine region of Area 2. Figure 3B shows the Th distribution in Area 2. Th was adsorbed at the outside of the dentine and shows no sign of diffusion into the dental tissue. Inside the dentine, U/Th ratios were well above 10,000. U-series ratios and age estimates were calculated from the U maxima at the surfaces of the dentine (Figures 3C to E). At the outside surface, elemental U/Th concentrations ratios were as low as 350, at the inside surface well in excess of 1000 implying that none of the U-series age calculations were affected by the presence of detrital ²³⁰Th, particularly those of Track 6.

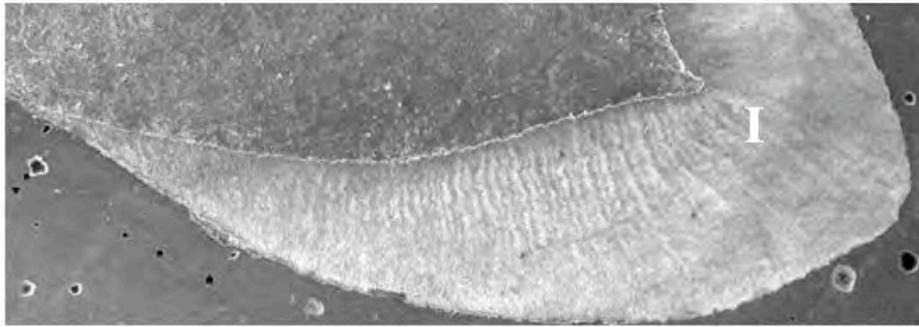
The $^{234}\text{U}/^{238}\text{U}$ ratios (Figure 3D) varied within a small band width, the average value being 1.202 ± 0.023 . In contrast, $^{230}\text{Th}/^{234}\text{U}$ ratios (Figure 3E) varied greatly along and between the tracks. The same applies, of course, to the calculated apparent U-series age estimates (Figure 3F). Depending on the relationships between U-concentration and apparent U-series ages, we can distinguish four regions (I-IV, Figure 3C). In Region I, at and near the inner surface of the dentine, the highest U-concentrations are associated with the higher apparent U-series ages. This is generally expected from the predictions of the D-A model.

The oldest ages occur at the inner surface (Cycles 240 to 260) and are steadily increasing from Track 1 to Track 6. Region II shows some distinct U maxima and minima, and these are inversely associated with U-series ages. In the central Region III, the U-concentrations are lowest, but the apparent U-series ages are significantly higher than in the surrounding Regions II and IV. Region IV shows a similar pattern as Region II. The apparent U-series ages near the outer surface (Cycles 40 to 80, Region IV) are significantly lower than on the opposite side (Region I). On the SEM image (Figure 3A), Region I closely correlates to the darker rim around the pulp cavity (see Figure 1), which consists of secondary dentine and/or weathered primary dentine. Region II seems to be dominated by tubules, while Regions III and IV are undistinguishable in the SEM characteristics with non-directional patterns, perhaps caused by an overprint of secondary dentine or other secondary minerals.

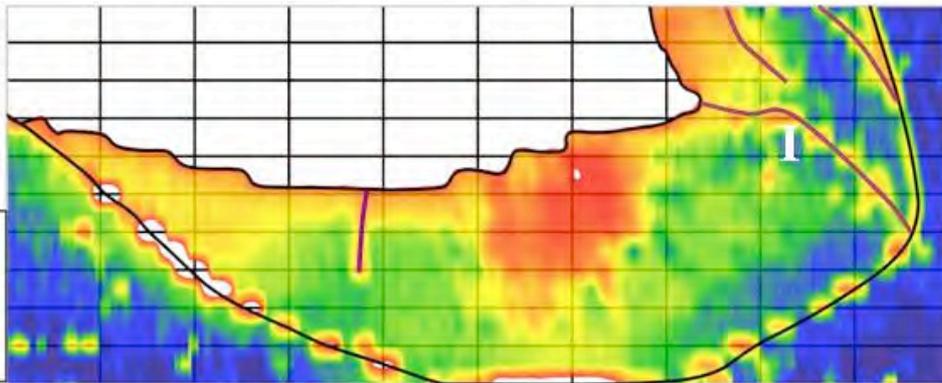
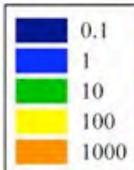
Near the inner surface, there is no sign of U-leaching, so that the apparent U-series ages in Region I, around 200 ka, can be regarded as minimum age estimates for the tooth. This is in good agreement with independent age estimates for this tooth of 175 to 230 ka.



Figure 1. Photos of the Neanderthal tooth from Payre. Area 1 was scanned for U and Th elemental concentrations, Area 2 for U and Th elemental concentrations and U-series isotopes. The arrows indicate the directions of the laser tracks.

A**B**

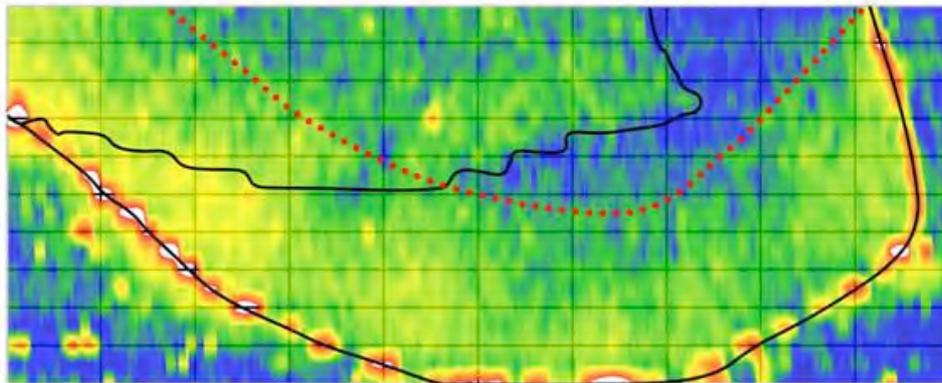
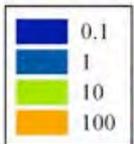
U
(ppb)



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1100 1000 900 800 700 600 500 400 300 200 100
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Figure 2. 3A: SEM image of Area 1; B: U-distribution. The solid lines indicate the enamel boundaries and lineaments of increased U-concentration. C: Th-distribution. The dotted line limits and area of higher Th concentration, which is unrelated to the enamel/dentine boundary

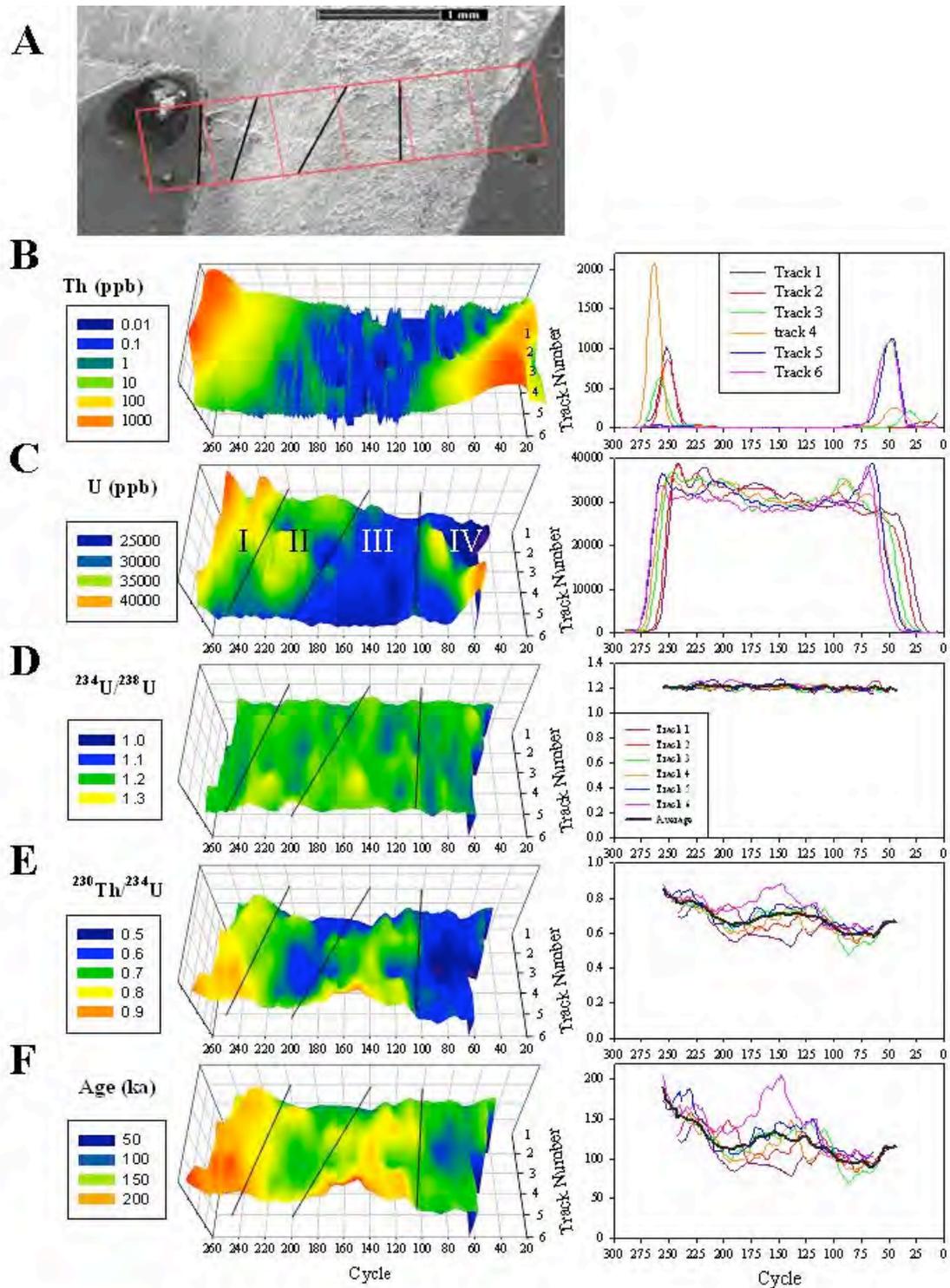


Figure 3. Elemental, isotopic and age distributions in Area 2. A: SEM of the dentine in Area 1, but about 50 μ m below in depth. The large red square is for orientation, subdivided into 50 cycle sections. Black lines indicate the boundaries of Regions I to IV (see Figure C). B: Th distribution, Regions I to IV indicate areas of different relationships between U-concentrations and U-series age calculations. C: U distribution, Regions I to IV indicate areas of different relationships between U-concentrations and U-series age calculations. D: $^{234}\text{U}/^{238}\text{U}$ ratios. E: $^{230}\text{Th}/^{234}\text{U}$ ratios. F: U-series age estimates.

Aubert M, Grün R, Eggins S, Moncel MH (2007) High resolution elemental and isotopic distribution in fossil teeth: Implications for diet and migration. XVII INQUA Congress, 28 July - 3 August 2007, Cairns, Australia, Abstract 0880, *Quaternary International* **167-168**: 17-18.

Grün R, Aubert M, Eggins S, Williams I Moncel MH (2006) High-resolution *in situ* analysis of O and Sr isotopes in fossil human teeth. Poster at 150 years of Neanderthal discoveries. Early Europeans - continuity & discontinuity. 21-26 July 2006, Bonn, Germany. Abstract, *Terra Nostra* **2006/2**: 115.

Pike AWG, Hedges REM Van Calsteren P (2002) U-series dating of bone using the diffusion-adsorption model. *Geochimica et Cosmochimica Acta* **66**: 4273-4286.

Direct dating of fossil human remains

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Renaud Joannes-Boyau is an international PhD student at RSES from France. He started his PhD "*direct dating of fossil human remains*" in October 2006, under the supervision of Professor Rainer Grün. His research focuses at the moment on decomposing the ESR spectra observed in fragments of tooth enamel crystal from the CO_2^- defect. Studies on tooth enamel fragments have shown that the ESR spectra are significantly more complex than previously assumed (Figure 1, Grün et al. in press). The ESR signal of the CO_2^- radical in hydroxyapatite has been used for the assessment of the past radiation dose, which in turn is converted into numerical age estimates, once the dose rate parameters are assessed. ESR dating studies are conventionally carried out on powdered samples, and it has repeatedly been demonstrated that the ESR spectra recorded from fossil samples are qualitatively similar to those generated by laboratory irradiation.

However, when attempting non-destructive ESR analysis, which is essential when working on fossil human remains, measurements are carried out repeatedly on tooth enamel fragments. Because of the anisotropic nature of hydroxyapatite, the ESR spectra show strong angular dependencies. In contrast to powders, the ESR spectra of fossil samples are significantly different to those generated by laboratory irradiation. Because of unstable components, it was initially suspected that all ESR age estimations could be underestimated (Joannes-Boyau et al. 2007).

At the present point, the study focuses on the enamel structure to understand where the different components are located within the crystal. The enamel structure is exceptionally complex. Our studies have so far revealed a composite organisation of crystal clusters, in prismatic and inter-prismatic configurations, both having different ESR responses. At the same time, research has been performed to understand the incorporation of uranium into the different tissues of the tooth. To clarify the assimilation of uranium in the teeth, especially in enamel, a cross section of an entire tooth has been analysed using laser ablation ICP-MS (for details see annual report of Grün et al.).

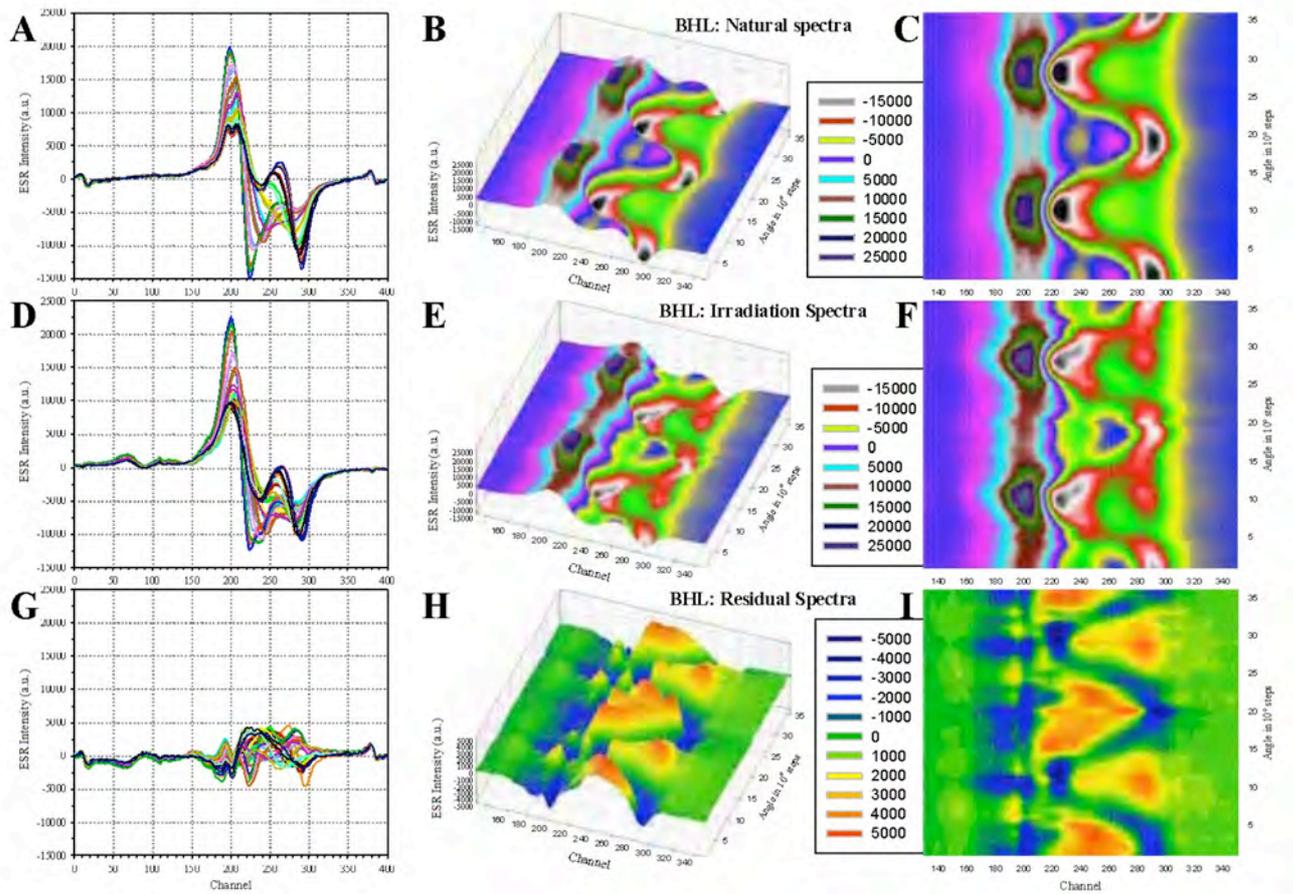


Figure 1: The main difference between powder and fragments while working on tooth enamel is the strong angular dependency of the CO_2 -radicals. The BHL configuration corresponds to a rotation around the occlusal surface of the tooth. The irradiated spectra (laboratory) and natural spectra present some significant differences.

Grün R, Joannes-Boyau R, Stringer, C (in press) Two types of CO_2 -radicals threaten the fundamentals of ESR dating of tooth enamel. *Quaternary Geochronology*.

Joannes-Boyau R, Grün R, Stringer C (2007) Two radicals threaten the fundamentals of ESR dating. XVII INQUA Congress, 28 July - 3 August 2007, Cairns, Australia, Abstract 151, *Quaternary International* 167-168: 195.

Linkages between coral assemblages and coral-based proxies of terrestrial exposure along a cross-shelf gradient of the Great Barrier Reef

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Field studies from recent decades suggest that coral assemblages from sites within proximity to land are shifting in response to both local and diffuse sources of terrestrial pollution. While coastal and nearshore communities have been identified to be at high risk from agricultural runoff in the Mackay section of the Great Barrier Reef, few baseline studies have been performed in this region to assess current coral assemblages and how they may be affected by terrestrial exposure.

We scored transects for benthic cover composition at seven reef locations along a gradient of distance offshore from the Pioneer River mouth. We categorized community structure into major benthic cover types (live hard coral, soft coral, fleshy macroalgae, substratum), dominant coral families, and growth morphology Acroporid corals, the most abundant group. Multivariate analysis of transect data showed that the nearshore reef assemblages at Keswick and St. Bees Islands (~33 km offshore) were categorically different from the other nearshore and midshelf sites due to the high cover of fleshy macroalgae overgrowing dead reef matrix.

Multiple tracers (luminescence intensity, $\delta^{15}\text{N}$, barium to calcium ratios) measured from coral core records collected from long-lived *Porites* colonies showed a gradient of disturbance from terrestrial runoff across the inner-shelf sites. While values of Ba/Ca and $\delta^{15}\text{N}$ were strongly correlated with terrestrial runoff at Keswick and St. Bees, there was no significant influence of river discharge at the next island offshore (Scawfell at ~50 km). The enriched $\delta^{15}\text{N}$ during major flood years in Keswick Island corals suggest that coral reef communities are receiving pulses of anthropogenic nutrients (mostly fertiliser-derived nitrogen) sourced from the Pioneer catchment. We therefore suggest that the current community composition at reef sites within 35 km of the Mackay coast is likely to be strongly influenced by repeated influx of sediments and nutrients delivered from flood plumes, which likely affect coral recovery and enable the persistence of late-successional algal stands.

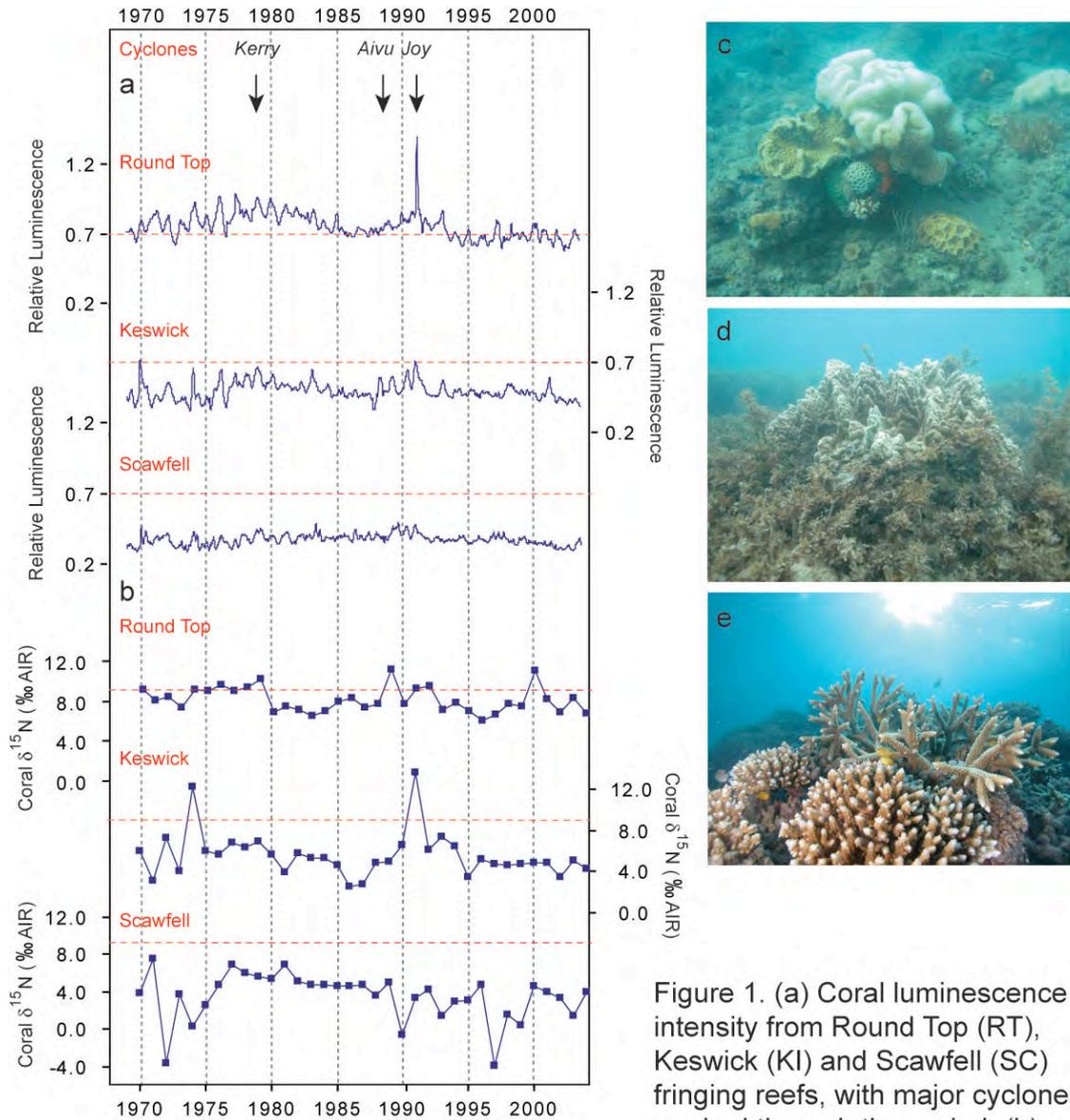


Figure 1. (a) Coral luminescence intensity from Round Top (RT), Keswick (KI) and Scawfell (SC) fringing reefs, with major cyclones marked through the period. (b) Annual coral skeletal $\delta^{15}\text{N}$ from a 3-core composite at RT and single cores from KI and SC. Data courtesy of G. Marion. (c-e) Representative habitat conditions at RT (c), KI (d) and SC (e).

Strontium isotope tracing in animal teeth at the Neanderthal site of Les Pradelles, Charante, France.

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Strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) can be utilised in reconstructing the migration and mobility of ancient animal and human populations. The Sr isotope ratios of geological materials are a function of the age and composition of the material (Capo et al. 1998) and therefore vary across rock units. The bio-available Sr isotopes in rocks and soils are passed on to local plants and into the food chain (Beard & Johnson 2000). Sr isotopes in tooth enamel reflect the isotopes consumed by an animal during the period of tooth formation (Bentley 2006). In most animals, this period is early childhood, though rodents, with ever-growing incisors, are an exception (Rinaldi & Cole 2004). Strontium isotopes in fossil tooth enamel can be compared to a geological, bio-available strontium isotope map, to determine whether teeth are from local or migrant individuals.

This study was carried out on the Upper Pleistocene site of Les Pradelles (Marillac-le-Franc, Charente, France), which has yielded numerous faunal remains including an important collection of Neanderthal pieces (*Homo neanderthalensis*) (Beauval et al. 2002). The surrounding area consists of two main rock regions, the limestones of the Dordogne and the metamorphic and granitoid rocks of the Massif Central, which yield differing average strontium isotope ratios (see below).

Soil and plant samples were collected from 40 locations across both rock regions. Soil samples were sieved and leached to ensure only biologically available strontium would be measured. Plant samples were dried, ashed and dissolved. All samples had total Sr concentration measured via solution ICP-MS before Sr separation was undertaken via ion exchange chromatography. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured via ICP-MS analysis. The fossil faunal samples from the site consisted of 23 teeth from seven species including both herbivores and carnivores. Sr isotopes in the tooth enamel were measured via laser ablation ICP-MS, resulting in high resolution records along the growth axis of the enamel.

Despite some variation in $^{87}\text{Sr}/^{86}\text{Sr}$ within each rock region, the two main regions can be successfully differentiated on the basis of bio-available Sr isotopes of soils and plants and a Sr isotope map of the area is produced (fig 1). The Sr isotope ratios in animal teeth do not vary significantly along the growth of the tooth enamel (fig 2), potentially indicating a lack of migration across the rock provinces while the teeth were forming. However, the lack of seasonality may alternatively be explained by reservoir effects and complexities in tooth mineralisation. Animals with small feeding ranges, such as marmots, are successfully linked to particular rock regions according to Sr isotope ratio, whereas intermediate $^{87}\text{Sr}/^{86}\text{Sr}$ values in migrating animals, such as reindeer, suggest an averaging of values from both units (fig 3). The wolf sample provides a high ratio, tracing it to the granitoid region, although it would have eaten migratory animals. This suggests the animal migrated to this region in later life, spending its childhood in an area away from the influence of the limestone values.

Hence, although seasonal migration was not detectable in the tooth enamel Sr isotope ratios, lifetime migration may be determined. This study forms the basis for an ongoing study into Neanderthal migration.

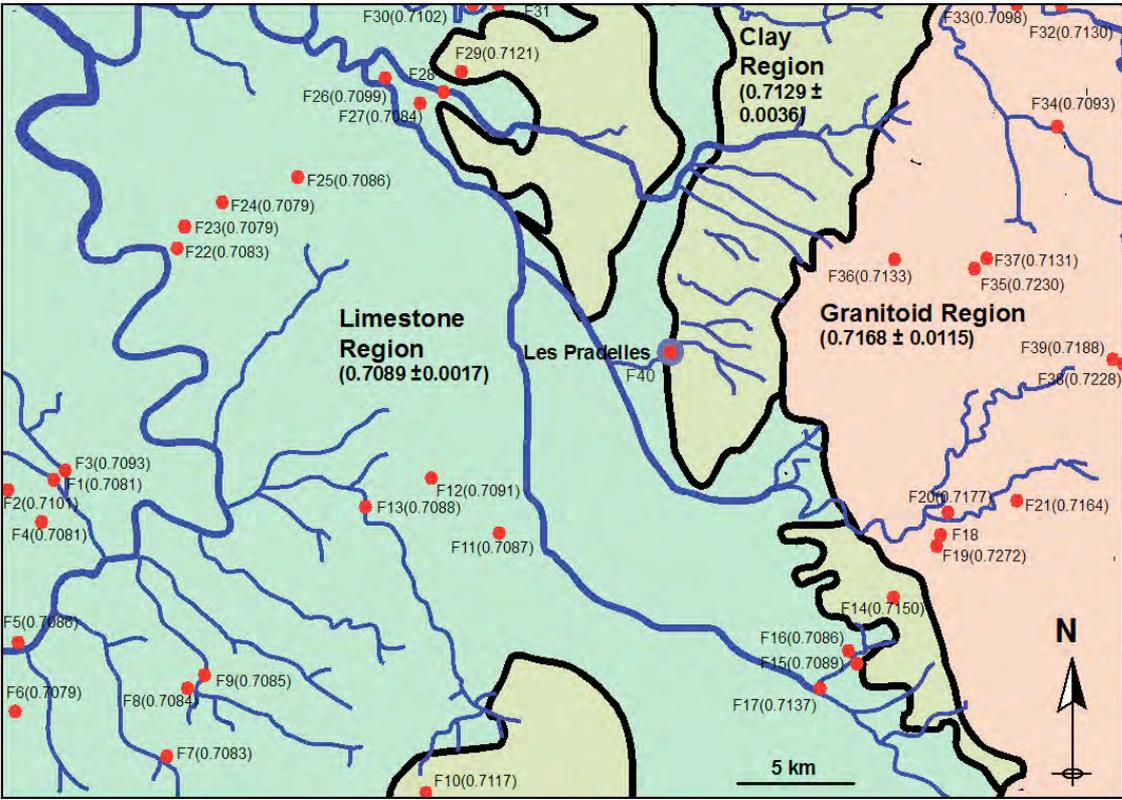


Figure 1

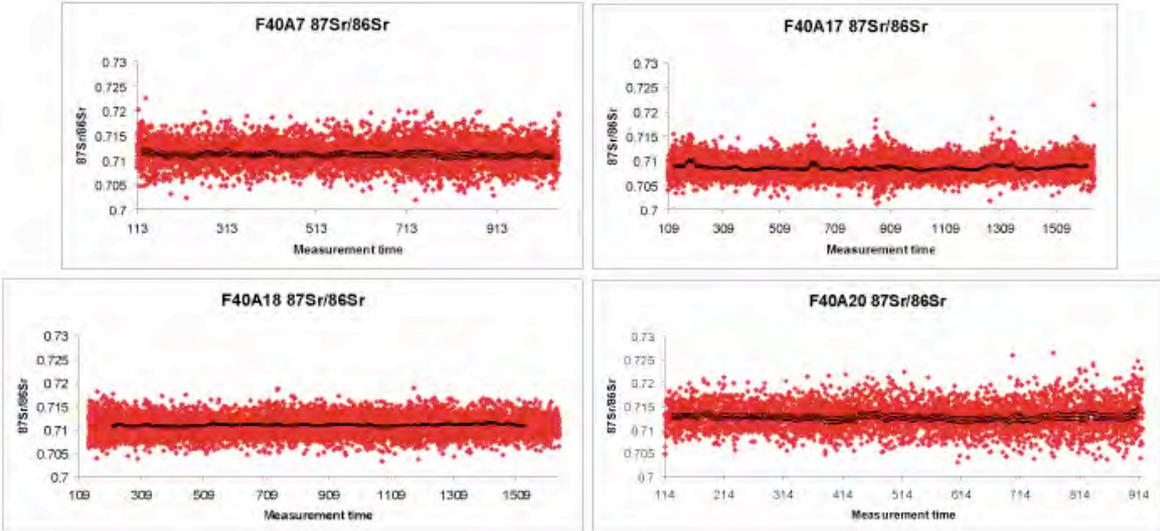


Figure 2

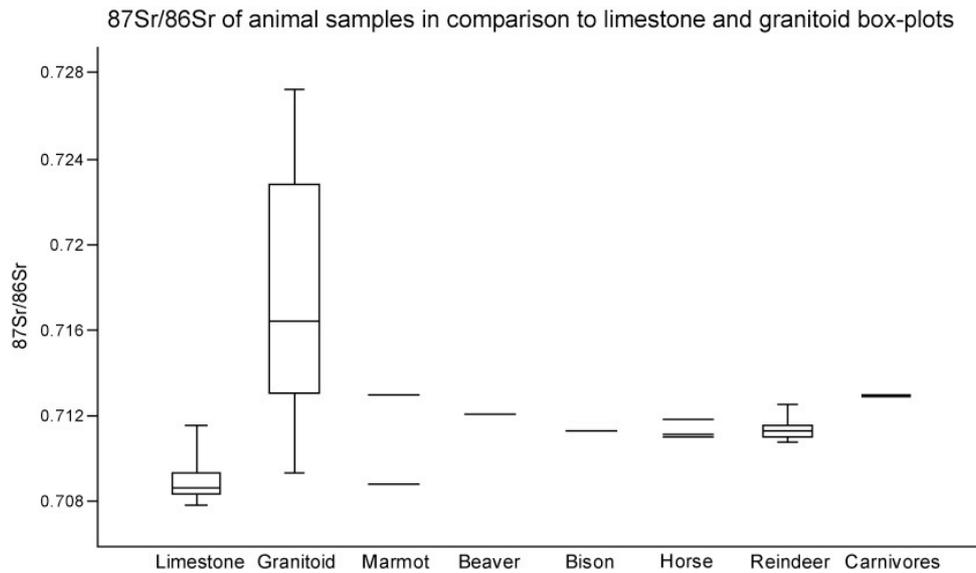


Figure 3

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Coral Reefs and Global Change

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Although coral reefs inhabit only about one percent of the world's continental shelf area, they represent a disproportionately important and essential marine resource as well as being of immense ecological value. Coral reefs are however sensitive to the threats from global climate change as well as direct human impacts from degradation of their local marine environment, both of which are now occurring at unprecedented rates. Higher levels of atmospheric CO₂ from fossil fuel burning, is not only causing global warming, but also increasing the acidity of the world's oceans. The effects of increased ocean acidity on marine ecosystems are however still only very poorly understood as previous episodes of global warming, such as occurred during the Last Interglacial ~125,000 years ago, were accompanied by lower (~300 ppm) rather than the significantly higher levels of CO₂ predicted for the near future (i.e. ~400 to 500 ppm by 2100). Increasing acidity of the world's oceans and the resultant decrease in the carbonate saturation state of seawater thus has the potential to cause substantial and still largely uncertain impacts on coral reef and marine ecosystems generally. Recent changes in seawater pH due to CO₂ uptake by seawater are now being investigated at RSES using boron isotopic variations in coral skeletons. These provides a long-term record of changes in seawater pH since industrialising and are demonstrating significant shifts in seawater pH of >0.2 pH units especially during the last several decades.

In order to better understand how corals have adapted to past episodes of global warming we are continuing our studies of Last Interglacial reefs such as those that are preserved along the Western Australian coastline. These reefs which grew when ocean temperatures were several degrees warmer than today, similar to those predicted for our Greenhouse Earth by 2100, and show that in the absence of mankind's footprint, corals given time, can adapt to the effects of warming. This is evident from the prolific coral growth observed in high latitude reefs of the southern-most portion of south-west Western Australia. The timescales for adaptation under Last Interglacial (normal) pH conditions are however still poorly constrained and maybe of the order of hundreds to thousands of years. Whether corals can adapt or acclimatise to the combined effects of global warming and lower seawater pH however remains at best highly problematic and ultimately depends on the future level that atmospheric pCO₂ stabilises. The most immediate and severe impacts on coral reefs are still nevertheless those that arise from direct human activities. Locally, landuse changes in river catchments, wetlands and estuaries is leading to increased supplies of sediment and nutrients to many inshore coral reefs. In some cases these, together with pressures from other activities such as trawling and overfishing are now resulting in an evolutionary trajectory that may ultimately result in an abrupt phase shift from a coral to macro-algae dominated ecosystem. It is thus clear that the long-term sustainability of coral reefs is not only dependent on the still poorly understood effects of global climate change and increased ocean acidity, but also on maintaining the health and hence the resilience of reef systems by minimising direct/local human impacts.

Long-term landscape evolution of the Yilgarn Craton, Western Australia

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The antiquity of Australian landscapes has long been postulated. Almost 100 years ago Jutson (1914, p. 92) observed that "*the land surface of Western Australia is one of the oldest land surfaces on the globe, and that it has not been below the sea for many geological ages*". In doing so, Jutson cited the complete lack of younger marine strata overlying the Precambrian shield (Yilgarn and Pilbara Cratons), other than in coastal areas, as "strong negative evidence" for his conclusion. Jutson's reasoning was that if the sea had covered a significant proportion of the shield, then it was highly improbable that some remnants of marine strata were not preserved at inland locations. Indeed, Jutson's broad conclusion is entirely consistent with modern paleogeographical reconstructions (e.g. BMR Palaeogeographic Group 1990) indicating that parts of the Australian continent, including the Yilgarn Craton, have been subaerially exposed for hundreds of millions of years.

Recent advances in dating regolith on the Yilgarn Craton provide ample evidence of ancient regolith and landforms, some with paleomagnetic weathering ages extending back to the late Carboniferous (e.g. at Meekatharra and Laverton - Pillans 2007). However, long-term denudation rate estimates for the Yilgarn Craton based on cosmogenic nuclides are in the range 1-3 m/Ma on 10^5 - 10^6 year timescales (Chappell 2003), while denudation rates on 10^7 - 10^8 year timescales, based on sediment budgets (Killick 1998) and apatite fission-track thermochronology (Kohn *et al.* 2002; Weber *et al.* 2005), are generally higher. Therefore the persistence of pre-Tertiary regolith and landforms at or near the surface is unlikely, and their survival is more likely as the result of burial and exhumation. On the other hand, relict Tertiary regolith and landforms are widespread surface and near-surface features across the Yilgarn Craton.

Based on apatite fission-track thermochronology, Weber *et al.* (2005) derived a model for the denudation history of the northern Yilgarn Craton. The essential elements of their model are surface exposure and weathering during the Late Carboniferous, followed by rapid burial by a ~3 km cover of Permian sediments, and then slow exhumation until re-exposure in the Late Cretaceous. Such a model is consistent with the preservation of Permo-Carboniferous regolith and landforms. The thick Permian cover also explains the lack of Archean-age detrital zircons in Late Paleozoic and younger sediments of the adjacent Perth Basin (Sircombe and Freeman 1999).



Figure 1. Paleomagnetic dating of deeply oxidised regolith at Meekatharra has yielded Late Carboniferous weathering ages.

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Two distinct processes of U-series isotopic diagenesis in a single fossil *Porites* coral and model correction age

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We made multiple measurements of U-series isotopes in skeletal sub-samples within a single *Porites* coral to explore the diagenetic history of U-series isotopes in fossil corals from the raised reefs of Sumba, Indonesia (Gagan et al. 2006). Detailed analysis of two recognizable diagenetic stages and corresponding changes in U-series isotopic composition has revealed two distinct processes of U-series isotope diagenesis in this single coral. Both styles of diagenesis are different from those suggested before (e.g.: GALLUP et al., 1994; SCHOLZ et al., 2004; THOMPSON et al., 2003; VILLEMANT and FEUILLET, 2003).

The earlier-stage process demonstrates the addition of allochthonous dissolved ²³⁴U and ²³⁸U together with detrital non-radiogenic ²³⁰Th, while the later-stage shows that loss of ²³⁴U and ²³⁸U occurred along with the introduction of detrital ²³⁰Th. Locally, radiogenic ²³⁰Th appears to have played an important role in maintaining a constant ²³⁴U/²³⁰U as allochthonous U was added, while detrital ²³⁰Th was critical to maintain a fixed ²³⁴U/²³⁰U when percolating meteoric water dissolved coral skeletal U. The results strongly suggest that a mechanism like diffusion or osmosis controls the addition or loss of dissolved U and detrital Th into or out of the coral by way of a solute concentration gradient. Model correction ages could be determined for both diagenetic processes and they yield essentially the same age of 133.6 ka.

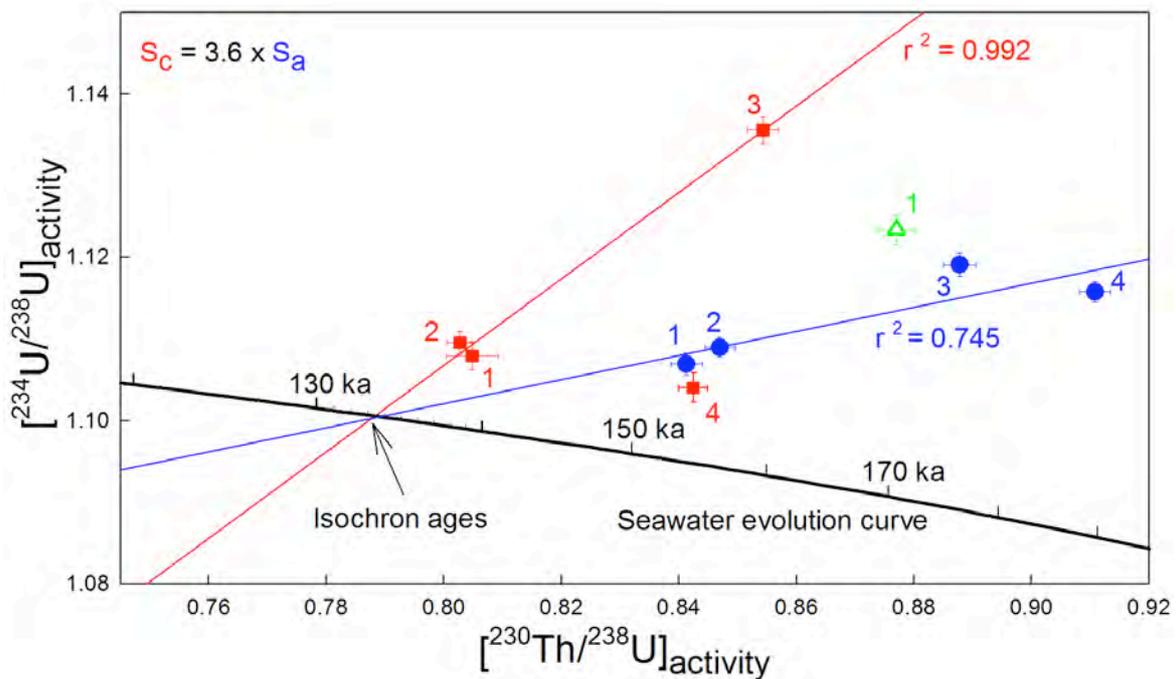


Figure 1. Diagenetic alteration of U-series isotopes in fossil coral MV03-A-2 from the island of Sumba, Indonesia. Analysis of two groups of sub-samples (red and blue) from different cores through the coral demonstrate that two distinct diagenetic processes have altered the ²³⁴U/²³⁸U and ²³⁰Th/²³⁸U activities.

The red line is the linear regression for 3 sub-samples from core "c" while the blue line is the regression for all 4 sub-samples from core "a". The different slopes for the two data sets ($S_c = 3.6 \cdot S_a$) are indicative of two distinct diagenetic pathways. Independent "isochron" ages were determined by intersecting the regression lines with the seawater evolution curve. The results show that both sample groups yield essentially the same model age of 133-134 ka. Error bars for individual data points are 2s.

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Uncertainties in seawater thermometry deriving from intra- and inter-test Mg/Ca variability in *Globigerinoides ruber*

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Laser ablation ICPMS microanalysis of fossil and live *Globigerinoides ruber* from the eastern Indian Ocean reveals large variations of Mg/Ca composition both within and between individual tests from core-top or plankton pump samples. Although the extent of inter- and intra-test compositional variability exceeds that attributable to calcification temperature, the pooled mean Mg/Ca molar values obtained for core-top samples between the equator and >30 °S form a strong exponential correlation with mean annual sea-surface temperature (Mg/Ca mmol/mol = $0.52 \cdot \exp(0.076 \cdot \text{SST}^\circ\text{C})$; $r^2=0.99$) (fig.1). The inter-test Mg/Ca variability within these deep-sea core-top samples is a source of significant uncertainty in Mg/Ca seawater temperature estimates, and is notable for being site specific. Our results indicate that widely assumed uncertainties in Mg/Ca thermometry may be underestimated. We show that statistical power analysis can be used to evaluate the number of tests needed to achieve a target level of uncertainty on a sample by sample case (fig.2). A varying bias also arises from the presence and varying mix two morphotypes (*G. ruber ruber* and *G. ruber pyramidalis*) which have different mean Mg/Ca values. Estimated calcification temperature differences between these morphotypes range up to 5°C and are notable for correlating with the seasonal range in seawater temperature at different sites. (Article accepted, Journal of Paleoceanography, 2007)

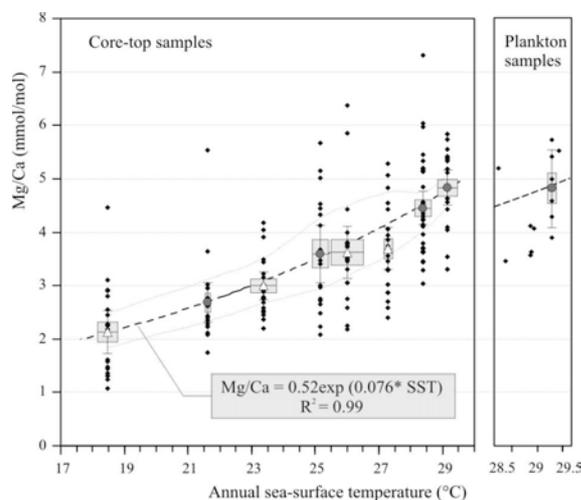


Fig. 1 Plots of annual SST at each core-top site versus the measured Mg/Ca composition of individual tests (black diamonds) and the sample mean Mg/Ca composition for each core top (grey circles – core-tops younger than 3 kyr; grey triangles older than 3 Kyr.). The standard errors of the sample mean Mg/Ca and the SST values for each core-top sample are represented by the height and width of the boxes. Error bars indicate the 95% confidence interval for each sample mean Mg/Ca composition, and the thin dotted line outlines the envelope of predicted Mg/Ca values based on the seasonal SST range at each site (taken from World Ocean Atlas 2001 [Conkright et al., 2002]).

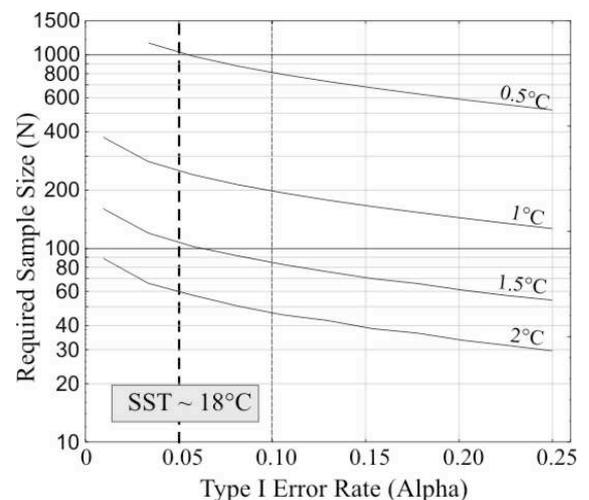


Fig.2 Calculated sample size (number of tests) required to achieve a target temperature uncertainty using Mg/Ca thermometry of *G.ruber* based on power analysis. The figure shows results for SST = 18°C based on the typical intra- and inter-test Mg/Ca sample variance. Calculations have been performed for four different target levels of SST uncertainty (0.5°C, 1°C, 1.5°C and 2°C)

Ge-Si ratio in siliceous organisms: A proxy for oceanic circulation?

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This research project will utilise both the Si isotope signature and the germanium (Ge) to Si concentration ratio (Ge/Si) of diatom frustules and sponge spicules to reconstruct historical Si concentrations in surface and deep ocean waters, thereby allowing concentration depth profiles to be recreated. In addition, a radically new model for interpreting isotope and elemental fractionation within siliceous organisms will be utilised. Further, new Si isotope and Ge/Si records will be generated to link changes in the Si cycle to the biological pump and the extent to which carbon is sequestered away from the atmosphere-equilibrated surface waters to the ocean's interior.

This research aims to lay the groundwork to understand the oceanic cycling of Si during the past, with a particular focus on the Southern Ocean, using a multi-proxy and multi-organism approach. The main objectives of this research are to: (1) examine Si isotope and Ge/Si fractionation of diatoms and sponges grown under controlled conditions to understand processes that lead to fractionation; (2) relate culture results for isotope and elemental fractionation within diatoms and sponges to the Si isotope and Ge/Si distribution patterns in the modern ocean; (3) measure the Si isotope and Ge/Si signatures of fossil organisms, with the aim of reconstructing the distribution of Si in the ocean during the last ice age.

Method development and construction of experimental culture facilities for this project began earlier this year. The main objectives of this research are currently being investigated with a particular emphasis on the development of sponge culture. A few experimental sponge culture studies (figure 1) have been successful and chemical analysis of the experiments is currently underway.

A research cruise is planned from Hobart to Antarctica on the Aurora Australis (Figure 2) at the end of 2007. On this cruise biological and water samples from the Southern Ocean will be collected and analysed for distribution patterns germanium and Si isotopes in the Southern ocean.



Figure 1. Experimental sponge culture experiment.



Figure 2. Aurora Australis

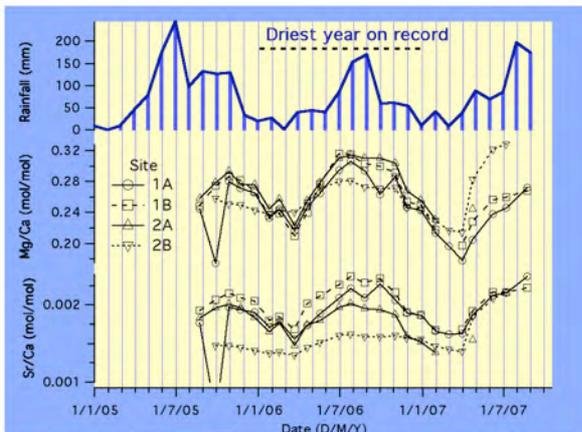
Decoding past rainfall trends from southwest Australian speleothems

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Southwest Western Australia experienced a reduction in rainfall of around 10-20% that has persisted since about 1970. This rainfall reduction has had significant consequences for dam levels and water-dependent ecosystems in the region. Dr Treble is the chief investigator on a project to reconstruct the frequency, duration and intensity of past multi-decadal dry periods in the southwest Western Australian speleothem record for the past 1000 years. Research during 2007 in Earth Environment by Dr Treble focused on constraining the climatic controls on cave drip water chemistry in the southwest of Western Australia. Understanding the relationship between surface climate and cave hydrology/geochemistry are fundamental for unraveling past climatic information preserved in cave speleothems.

A key process in understanding the relationship between surface climate and the stalagmite geochemical trends is monitoring the real-time encoding of inter and intra-annual climate variations in the cave environment. This was done by monitoring changes in the drip water hydrology and geochemistry, as well as soil moisture and rainfall events. Interpretation of a 2.5 year long dataset has revealed that speleothem growth takes place primarily during the winter seasons driven by the partial pressure of cave CO₂ which in turn is related to the hydrology of the overlying rock. Distinct annual cycles in cave drip water Mg/Ca and Sr/Ca are directly related to the amount and duration of winter rainfall entering the cave each year.



The existence of these annual cycles provides an important chronological tool as well as valuable seasonal information. Importantly, this research demonstrated that the cave drip water chemistry responded to the winter rainfall deficit in 2005 which was the driest year on record for this region.

This research was partly aided by an Exchange Fellowship granted to Dr Treble by the British Council. Dr Treble travelled to the University of Birmingham in the UK to collaborate with Prof Ian Fairchild on this research topic. Journal articles reporting the results of this study are currently in preparation.

Deep water upwelling and its implication for the Precambrian Cambrian boundary. Evidences from Molybdenum isotopes in black shales

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The environmental circumstances which have caused a decline in abundance and diversity of the soft-bodied Ediacara fauna at the end of the Precambrian followed by the "Cambrian explosion", is still a question of debate. It has been proposed that an increase in atmospheric oxygen concentration during the late Neoproterozoic period, and a subsequent change in ocean redox conditions could have played a key role in the evolution of eukaryotic organisms. The molybdenum isotope record is a good tool to investigate global paleoredox conditions and redox changes of the ocean.

We present Mo isotope signatures in black shales from two sample sets (Ara Group, Oman, and Yangtze Platform, China) which were deposited at and shortly after the Precambrian-Cambrian (PC-C) boundary. At first view, the overall Mo isotopic signature of the early Cambrian black shales from Oman and China is similar to that found in mid-Proterozoic sediments [1] and might support the idea of a stratified ocean with anoxic bottom water through most of the Proterozoic.

On closer inspection, however, a transient Mo signal following immediately after the PC-C boundary in both sample sets indicates a short global non-steady state situation. Combined with extreme Mo enrichment, found in the Chinese sulfide marker bed at the PC-C boundary, which cannot be explained by Mo scavenging mechanisms known from the modern oceans, upwelling of euxinic bottom water masses provides a reasonable explanation for this Mo signal. This scenario not only explains the Mo isotopic signal, it can also be responsible for the sudden extinction of the Ediacaran fauna.

[1] Arnold G., Anbar A., Barling J., and Lyons T. (2004). Molybdenum isotope evidence for widespread anoxia in mid-proterozoic oceans.

Research Activities
Earth Materials & Processes

Earth Materials and Processes 2007 Introduction

The former Earth Materials area has been renamed Earth Materials and Processes to reflect better the diversity of the science we do. The area comprises groups in Experimental Petrology, Rock Physics, Thermochronology, and Structure & Tectonics. The research of these groups centres around laboratory based measurements under controlled conditions, simulating those occurring in nature, but these activities are complimented by field based observations, often in collaboration with scientists from other institutions, nationally and internationally. Through such investigations we are developing understanding of the structure and chemical composition of planetary interiors, and the processes by which they evolve. Our interests start at the very beginning of solar system history with how the Earth and other rocky planets accrete, and encompasses core formation, mantle convection, volcanism, metamorphism, global tectonics and the formation of ore deposits.

Areas of current research activity include:

- The making of terrestrial planets. Chemical constraints on the accretion of the Earth and similar planets from the solar nebula, and the processes of core formation; mineralogical and chemical properties of the deep mantle and their influence on global tectonics.
- The nature of the Earth's upper mantle. Experimental studies and thermodynamic modelling of the phase equilibria relevant to upper mantle melting and ultra-high-pressure metamorphism associated with crustal thickening and subduction; experimental and microstructural studies of phenomena associated with lattice defects and grain boundaries including incorporation of water into nominally anhydrous minerals and microscopic mechanisms of seismic wave attenuation; experimental studies and modelling of grain-scale melt distribution and its implications for melt transport, rheology and seismic properties.
- Coupling between fluid flow and fault mechanics in the continental crust. Experimental studies of the role of fault healing and sealing processes in controlling the time dependence of fault strength and permeability at high temperatures and pressures; complementary field-based and modelling studies exploring fluid-driven growth of shear networks with applications to understanding the development of lode gold systems, especially in the Western Australian goldfields.
- Oxidation state and coordination of metal ions at high temperatures. Studies of crystals, melts and hydrothermal solutions by X-ray absorption spectroscopy, using synchrotron radiation. Studies of silicate glasses and melts to very high temperatures under controlled redox conditions. Analysis of hydrothermal solutions trapped in synthetic fluid inclusions is providing important basic information on metal complexes at high temperatures.

Experimental Petrology introduction

The Experimental Petrology Group uses a laboratory-based experimental approach combined with field observations to study the Earth, its origin, evolution and mineral wealth. The group operates a wide range of experimental apparatuses for generating the high temperatures and pressures that are needed to reproduce the natural conditions within the Earth.

The equipment includes: high temperature furnaces capable of reaching 1800°C, several of which are equipped for precise control of oxygen and sulfur fugacities by gas mixing; eleven solid-media piston-cylinder devices for generating pressures to 6 GPa and temperatures in excess of 2000°C, a multi-anvil apparatus, which can presently achieve pressures of 27 GPa; and a well-equipped hydrothermal laboratory. These high-temperature, high-pressure apparatuses are complemented by an array of microbeam analytical techniques, including a Cameca SX100 electron microprobe; laser-ablation ICP-MS, which is now being used regularly to analyse trace-elements in experimental run products; a STOE STADIP powder X-ray diffractometer; and FTIR spectroscopy for the determination of H₂O, CO₂ and other volatile species in minerals and glasses. To complement this latter facility, the group acquired a Agilent 6850 Gas Chromatograph, which has been combined with a capsule-piercing device to enable the extraction and analysis of small quantities of C-O-H fluids from high-pressure experimental run products.

As well as the conventional 1/2 inch and 5/8 inch apparatus for use to 4 GPa, the group's piston-cylinder laboratory also runs a high-pressure device that is now operating regularly at 6.5 GPa; the laboratory also has two large-capacity piston-cylinder devices that take 30 mm and 50 to 65 mm diameter pressure assemblies respectively, enabling pressure to be controlled extremely accurately, and which are capable of synthesising relatively large volumes of high pressure phases for detailed mineralogical studies. A novel diamond composite hard material, developed in these apparatuses and now under commercial production, offers promise as an anvil material to extend the pressure range of the multi-anvil apparatus above 26 GPa, thereby allowing detailed experimental exploration of the pressure-temperature regime of the Earth's lower mantle. To further this research the multi-anvil apparatus has now been refurbished and provided with full computer control of pressure and temperature.

In recent years the group has become increasingly involved in developing methods to characterise geologic materials by X-ray absorption spectroscopy (XANES) and related techniques that use synchrotron radiation. Research in this area is presently concentrating on oxidation states in silicate melts, including in-situ measurements at temperatures to 1500°C, and speciation in ore-forming hydrothermal solutions.

Members of the group continue to investigate conditions and processes in the Earth's upper mantle (Professors David Green and Hugh O'Neill, Dr Robert Rapp), and metamorphism in the continental crust (Drs Joerg Hermann), as well as the physical chemistry of ore-forming solutions (Drs John Mavrogenes, Katy Evans).

Clarification of the Influence of Water on Mantle Wedge Melting

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Water is a significant component in primitive island arc magmas and its ubiquitous presence is attributed to release of water from dehydration reactions in subducted oceanic crust and lithosphere. Water released from the subducted slab is inferred to be transferred as aqueous vapour or water-rich melt into the overlying peridotite of the mantle wedge. Because of the inverted temperature gradient inferred for the mantle wedge immediately above the subducted slab, access of aqueous vapour or water-rich melt will initiate melting close to the water-saturated peridotite solidus. The location of a region of water-saturated mantle melting, if it exists, can be predicted if we know the P,T dependence of the water-saturated peridotite solidus and can model the temperature distribution in a particular subduction setting. A number of experimental studies in the 1970's defined the P,T conditions for the water-saturated solidus of lherzolite. The solidus decreases rapidly from ~1100°C at atmospheric pressure to 0.5 GPa, 1000°C, and continues to decrease slightly to a minimum of 970°C at 1.5 to 2 GPa. At higher pressure, the water-saturated solidus increases in temperature (i.e. positive $\delta T/\delta P$), so that it is above 1100°C at 4 GPa.

A new experimental study by Grove et al (2006)* suggests major revision of this earlier work such that these authors' interpretation of their observations placed the water-saturated lherzolite solidus at ~1000°C at 0.5 GPa but their solidus continues with a negative $\delta T/\delta P$ to at least 3.5 GPa, 800°C. Thus, in comparison with earlier work summarised above, Grove et al (2006) conclude that melting at depths around 100km within the mantle wedge begins at >200°C below the previously determined conditions.

Additional major differences in the new work are the presence of chlorite as a subsolidus and above-solidus phase from 2 GPa to 3.2 GPa and the restriction of amphibole (pargasite) to pressures <2 GPa., compared with 3GPa found in earlier work. These differences in observation and interpretation of peridotite melting have large effects for geophysical, geodynamic and petrological modelling of convergent margin processes and characteristics and there is a need for reconciliation of the new and earlier results.

We have therefore repeated selected experiments of Grove et al (2006) and extended their investigation particularly by varying the water content of the experimental charges from the very high value (14.5 wt%) used by Grove et al (2006). We have carried out experiments which clarify the roles of aqueous fluid (including solid phases quenched from fluid), water-rich silicate melt and amphibole (pargasite) stability. We reproduce the observations of Grove et al. (2006) with 14.5% H₂O but demonstrate that glass observed in the experimental charges below 1000°C is quenched from a water-rich fluid phase, and not from a silicate melt. By varying the water content of the charge we are able to differentiate between fluid-saturated silicate melt and the coexisting water-rich fluid-phase for water contents in the peridotite between 0.073% and 14.5% H₂O. Pargasite is stable to 3GPa at 1000°C with low water contents (2.9%, 1.45%, 0.145% and 0.073% H₂O) and at this P,T, has a modal abundance of 3% of the peridotite. Pargasite is destabilised at higher water contents of 14.5% and 7.25% as sodium and potassium enter the fluid rather than the silicate minerals. Compositions of clinopyroxene and pargasite correlate with water content. At 2.5GPa coexisting melt and fluid have ~25% and ~80% by wt of H₂O respectively. We demonstrate that the fluid-saturated solidus of the lherzolite model mantle composition is at 1000°C<T<1025°C at 2.5 GPa and 1200°C<T<1225°C at 4 GPa.. The near-solidus melt at 2.5 GPa. is a very silica-undersaturated olivine nephelinite.

We also used olivine single crystal discs and either olivine aggregates or carbon sphere aggregates as melt and fluid traps forming interstitial films or inclusions within olivine. For several experiments with high water contents, the capsule was pierced under high vacuum at room temperature and the vapour released was analysed by gas chromatography.

The study confirms that early work establishing the fluid-saturated solidus of fertile lherzolite+ H₂O (model mantle compositions) at ~1025°C at 2.5 GPa and has a positive $\delta T/\delta P$ at higher pressure, is correct. Similarly, pargasite is stable at and below the lherzolite+ H₂O solidus up to pressures of 3 GPa. Chlorite is not stable at subsolidus or near-solidus conditions in lherzolite unless high water/rock ratios remove the Na₂O+K₂O components required for pargasite or phlogopite stability. Our new experiments demonstrate that melting of lherzolite+ H₂O at pressures to at least 4 GPa does not show supercritical behaviour but above the fluid-saturated solidus at high pressures has water-rich (~30% H₂O) silicate melt and alkalis+silica-rich aqueous fluid (~80% H₂O) in sufficiently water-rich compositions. In realistic geological settings, including the mantle wedge above a subducted slab, we should expect lherzolite+H₂O to experience either fluid-undersaturated melting (i.e. the solidus of pargasite lherzolite or phlogopite lherzolite) or fluid-saturated melting with all fluid components entering the melt at, or very close to, the solidus.

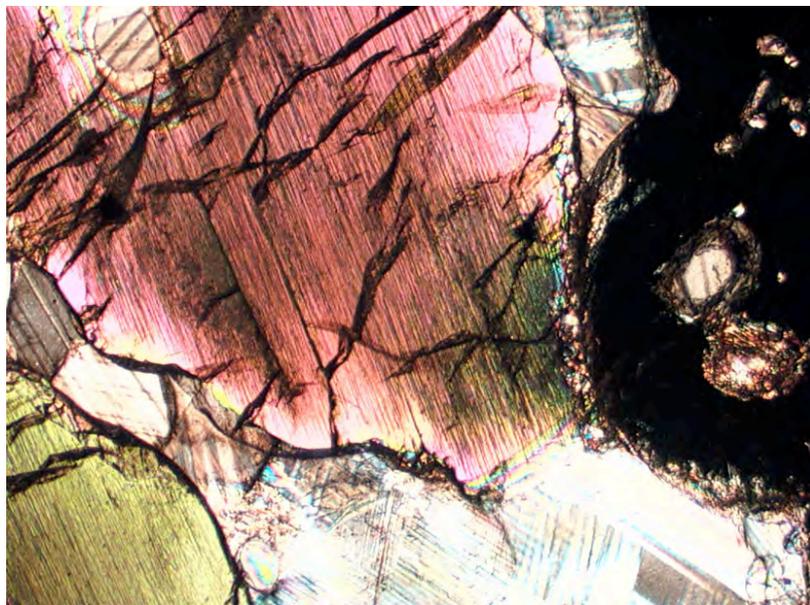


Figure 1

Grove, T.L., N. Chatterjee, S.W. Parman, and E. Medard, (2006) The Influence of H₂O on Mantle Wedge Melting. *Earth and Planetary Science Letters*, v.249, 74-89

The effect of CO₂ on the speciation of RbBr in solution at temperatures to 650 degrees C and pressures to 0.65 Gpa

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Carbon dioxide- and salt-bearing solutions are common in geological environments. The presence of CO₂ affects mineral solubilities, fluid miscibility, and viscosity/wetting properties, and is expected to affect salt speciation. EXAFS measurements of RbBr-H₂O-CO₂ fluids contained in corundum-hosted synthetic fluid inclusions (SFLINCs) have been used to investigate the effect of CO₂ on salt speciation at temperatures to 650°C and pressures to around 0.65 GPa.

Surprisingly, results for Rb in CO₂-free and CO₂-bearing solutions are effectively identical. This is attributed to exclusion of CO₂ from the vicinity of the solvated cation, and is consistent with significant variation in fluid properties in the vicinity of solvated cations. This result has implications for thermodynamic modelling of CO₂-bearing fluids as it suggests that bulk fluid properties may be inappropriate for calculation of solute parameters. Results for Br in CO₂-free solutions are different to those from CO₂-bearing solutions. The contrast between the results for cations and anions is consistent with the characteristics of ion-water bonding; the geometry of anion-water complexes permit greater continuity between the bulk solvent and solvated waters than is possible for cation-water complexes.

Otherwise, the results are consistent with those of previous work. Increases in pressure and temperature cause an apparent decrease in the number of waters of solvation for Rb of up to 67 %, and a contraction in bond lengths of around 4 %. Results for Br also show apparent solute dehydration. However, forward modelling indicates that solute dehydration might be difficult to distinguish from ion-pairing.

Advances in conceptual models based on the results presented here are pertinent to CO₂-bearing solutions in a range of geological environments that include granulite, ore-forming and magmatic environments.

A preliminary investigation of chlorine XANES in silicate melts

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The nature of chlorine speciation in silicate melts affects volatile exsolution history, rheological, and thermodynamic properties of the melt, but is poorly known. XANES (X-ray Absorption Near Edge Structure) spectra, taken from 26 natural and synthetic samples, have been used to constrain Cl-speciation in silicate melts, and to test the hypothesis that Cl in silicate melts is hosted by a combination of salt-like cation-Cl complexes.

The results are consistent with the existence of a CaCl_2 species that has reduced short-range order compared to the CaCl_2 salt. However, there is no evidence to support the existence of an equivalent MgCl_2 species. This is surprising, given the similar positive effects that Mg and Ca exert on the solubility of Cl in silicate melts. It is concluded that Cl in silicate melts cannot be represented by a combination of salt-like cation-Cl species, and that some combination of mixed cation-Cl species, polymeric cation-Cl species, lone Cl species, and Cl incorporated into network-forming polymers must be invoked to explain observed spectral features. Further investigations using XANES, alternative spectroscopic techniques, and forward modelling approaches are required to distinguish between these possibilities. NaCl-like features exhibited by the natural samples are attributed to NaCl present in the sample that is not hosted by the melt.

Accessory phase control on the trace element signature of subduction zone fluids

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In order to understand the general trace element signature of arc lavas, phase and melting relations in metapelites at sub-arc depth are of first order importance. We performed an experimental studies on trace element doped, hydrous (2–7 wt.% H₂O), synthetic pelite and granite in the range 20–45 kbar and 600–1050°C, i.e conditions relevant for the slab at sub-arc depth. In the metapelite, a hydrous melt that quenches to a glass is present at conditions above 700°C, 25 kbar; 750°C, 35 kbar and 800°C, 45 kbar. At lower temperatures, a solute-rich aqueous fluid is present, which is not quenchable. In the experiments, this fluid has been captured in diamond traps, and the quench material as well as the glass have been analysed with LA-ICP-MS.

One surprising feature in the run products is the presence of accessory phases at subsolidus and at suprasolidus conditions, even at large melt proportions of 50%. Rutile, apatite and zircon have been found over the entire investigated P-T range (Figure 1). Allanite is present at 2.5 GPa up to 800°C, and at 3.5 and 4.5 up to 750°C. At higher temperatures, monazite is stable up to 1000°C. This has profound bearings on the trace element characteristics of the fluid phase. In a residue consisting of garnet, clinopyroxene, phengite and coesite, all trace elements in the fluid phase are governed by partitioning behaviour. In contrast, in the presence of accessory phases, several trace elements are buffered (Ti by rutile, P by apatite, Zr by zircon, LREE by monazite/allanite).

This means that the concentration in the fluid phase is independent of the amount of the phase in the residue (as long as it is present) and independent of the amount of partial melting. Figure 2 displays the variation of such buffered elements as a function of pressure, temperature and nature of the fluid phase. The concentration of these elements in hydrous melts is well constrained and principally changes as a function of temperature and to much lesser extent as a function of pressure. The concentrations of trace elements in the aqueous fluid are much harder to determine but show consistently lower values. It appears that there is a sudden decrease in the concentration of buffered elements at the transition from hydrous melts to aqueous fluids. The most distinct feature of arc rocks is the addition of a subduction component containing LILE (K) and LREE (Ce).

If we consider that in most cases, the subduction component constitutes less than 20% of a primitive arc magma and use for example primitive arc lavas of the Marianas having 5000–8000 ppm K and a subduction contribution of 3–15 ppm of Ce, the minimum concentration in the fluid phase released from the subduction zone must be 25'000–40'000 ppm K and 15–75 ppm Ce. It is directly evident that this is only possible if the fluid phase is a hydrous melt and top slab temperatures are higher than 750°C.

Zircon is able to fractionate geochemical twins such as Zr and Hf (Figure 3). Hf decrease in the melt is less pronounced than Zr with decreasing temperature and thus hydrous melts at 750–800°C leaving the slab have a Zr/Hf significantly lower than the primitive mantle value. Therefore addition of hydrous melts to the mantle wedge would be an efficient way to add a subducted sediment Hf-isotope component to arc lavas.

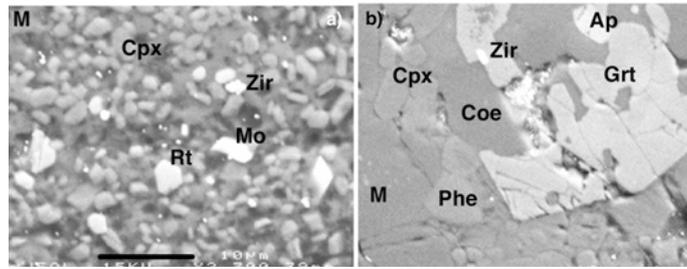


Figure 1. Experimental run products. a) 750°C, 3.5 GPa: Accessory phases rutile (Rt), monazite, (Mo) and zircon (Zir) are stable with hydrous melt (M). b) Accessory apatite (Ap) and zircon are present in a run at 1000°C, 4.5 GPa. Other abbreviations: Grt = Garnet, Phe = Phengite, Cpx = Clinopyroxene, Coe = Coesite.

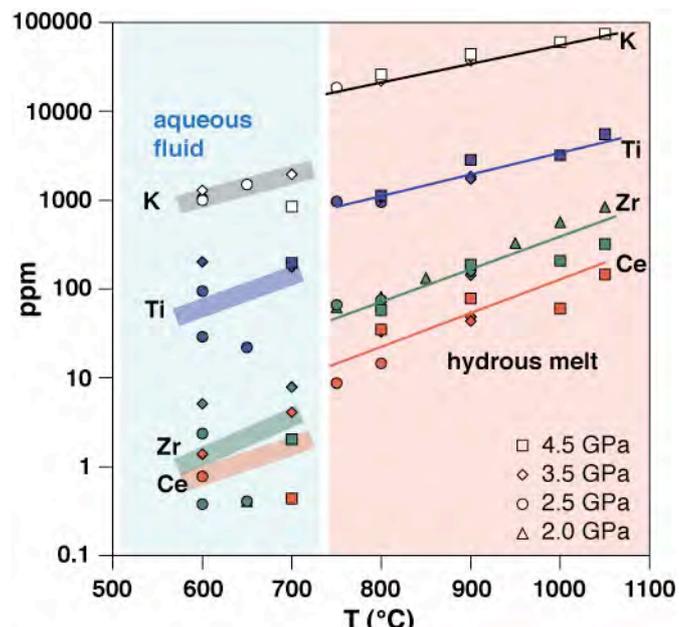


Figure 2. Experimentally determined concentration of trace elements in the fluid phase that are buffered by phengite (K), rutile (Ti), zircon (Zr) and allanite or monazite (Ce). The concentration decreases strongly as a function of temperature and the nature of the fluid phase (aqueous fluid vs. hydrous melt).

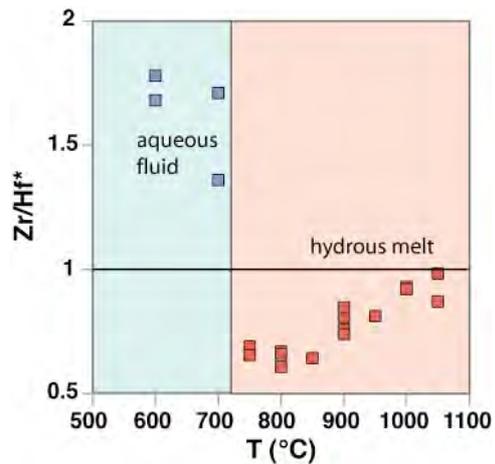


Figure 3. Residual zircon is able to fractionate the geochemical twins Zr and Hf. Zr/Hf* refers to the ratio of Zr/Hf in the analyzed fluid phase normalized to the Zr/Hf of the starting material.

The limitations of using unpolarized absorbance spectroscopy on anisotropic minerals

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To complete the project outlined in last year's Annual Report, we have carried out a parallel experimental and theoretical study of the behaviour of IR light, and assessed implications for its wide use in characterising atomic vibrations and water content in thin sections or small samples of minerals.

Starting from Maxwell's equations, we developed a theory indicating that angular variation of linear polarized transmittance in weakly absorbing anisotropic minerals can be described by the relationship:

$$T(\theta) = T_{\max} \cos^2 \theta + T_{\min} \sin^2 \theta \quad (1)$$

where θ specifies the orientation of the direction of polarisation. We label this equation '**T theory**' and note that its derivation requires several approximations. The first is that the mineral is not 'strongly absorbing'. The second approximation means that Eq. 1 will be accurate when light propagates exactly along an optic axis and an excellent approximation when the light direction is sufficiently inclined to the optic axes, but deteriorates somewhat in accuracy when the light direction lies in a small region immediately surrounding the optic axes.

Eq. 1 may be well approximated if, in a given section, the linear polarized maximum absorbance (A_{pol}^{\max}) is relatively small, or the ratio of the linear polarized minimum and

maximum absorbances (A_{pol}^{\max} , A_{pol}^{\min}) is close to unity, by:

$$A(\theta) = A_{pol}^{\max} \cos^2 \theta + A_{pol}^{\min} \sin^2 \theta \quad (2)$$

We label this equation as the '**A theory**'. It holds for linear polarized absorbance of a single absorbance peak as well as for integrated polarized absorbance of overlapping peaks.

In contrast to Eq. 1, Eq. 2 can be easily integrated over all angles to predict unpolarized absorbance, resulting in a simple relationship between unpolarized (either linear or integrated) absorbance and polarized maximum and minimum absorbance in any given section:

$$A_{unpol} = \frac{1}{2} (A_{pol}^{\max} + A_{pol}^{\min}) \quad (3)$$

We tested both the nearly exact 'T theory' and the approximate 'A theory' against systematic polarized and unpolarized measurements of minerals with a variety of principal linear absorbance values (Fig. 1). Firstly, we present data from sections of minerals (topaz and calcite) that have sufficiently strong net absorbance characteristics that there is predicted to be a clear difference between the 'A theory' and the 'T theory', as demarked in Fig. 1. We confirm that in these cases the 'T theory' fits the data well, but the 'A theory' does not (topaz, Fig. 2). We then measured samples with absorbance characteristics such that the 'A theory' was expected to be a good approximation (calcite cleavage parallel section, Fig. 3), and demonstrate empirically that unpolarized IR can be used to recover quantitative absorbances from a population of randomly oriented mineral grains.

In this later case the unpolarized average absorbance is exactly one third of the total polarized absorbance (either linear or integrated).

The important consequences of our parallel studies are that quantitative IR absorbance can be measured (a) using unpolarised IR, (b) on non-oriented samples, so crystal size is not limiting, and (c) on anisotropic materials with crystal symmetry lower than orthorhombic.

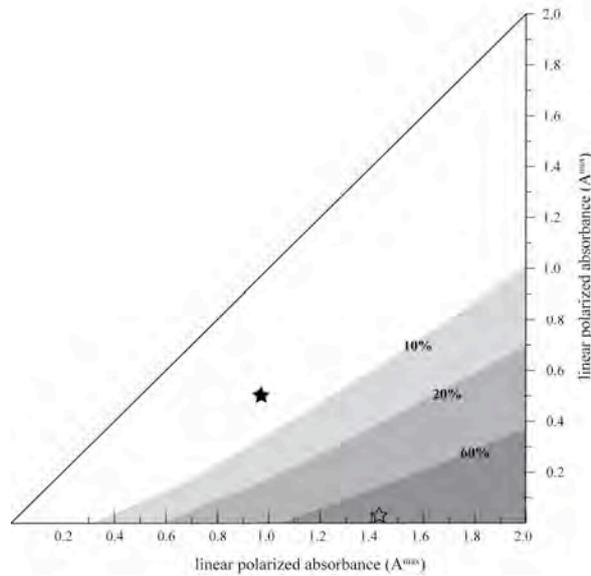


Figure 1 The error from using the approximate 'A theory' (Eq. 2) compared to the nearly exact 'T theory' (from numerical integration of Eq. 1) for calculating unpolarized absorbance, as a function of linear polarized absorptions A_{pol}^A and A_{pol}^T . Actual values of A_{pol}^A and A_{pol}^T for samples used in this study are plotted as follows: open star – topaz, 1.66 mm thick basal section (001) for the absorbance peak at 2320 cm^{-1} ; filled stars – seven calcite sections cut parallel to the cleavage (10 1 1) of thickness 198 to 1958 μm .

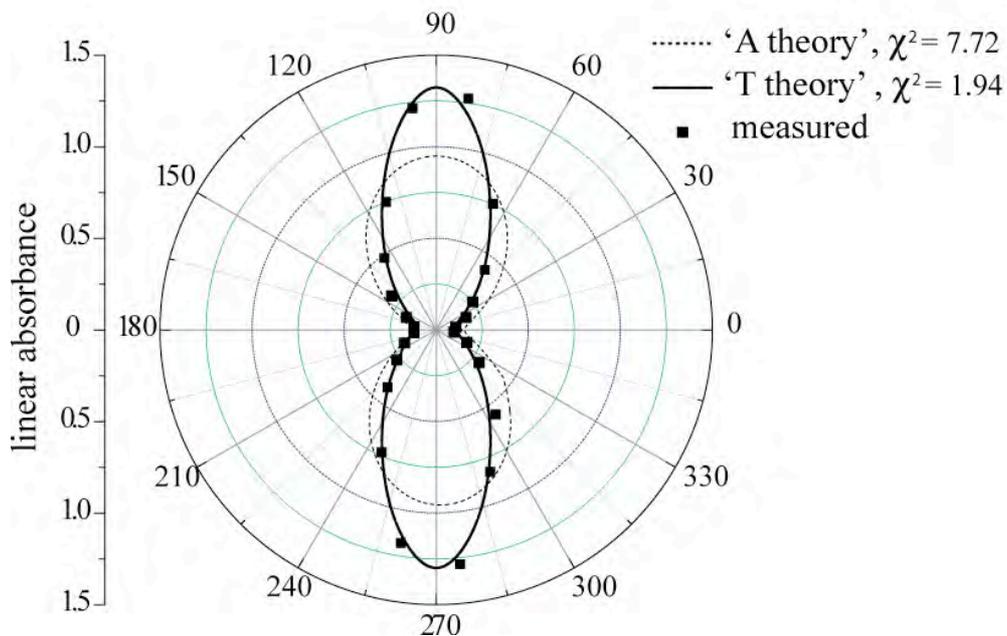


Figure 2 The linear absorbance at 2320 cm^{-1} in a 1.66 mm thick basal section of topaz (001). Angular variation of the linear polarized absorbance, with the solid curve and the dashed curve fitted to the 'T theory' (Eq. 1) and the 'A theory' (Eq. 2), respectively, assuming an uncertainty of 3% in each datum.

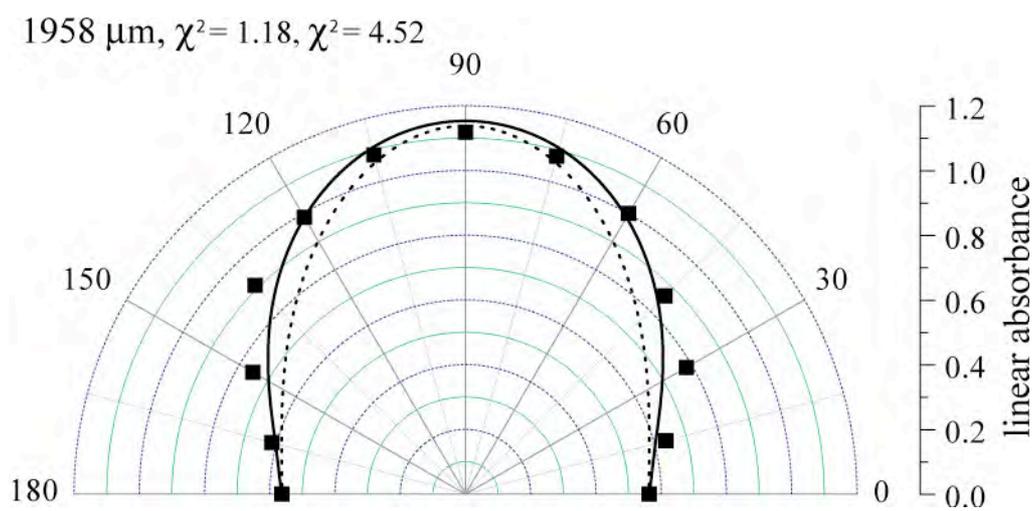


Figure 3 Angular variation of linear absorbance for the peak at 3943 cm^{-1} in a 1958 μm thick calcite section, cut parallel to the cleavage (10 1 1). The solid curves and the dashed curves are least-squares fits to the 'T theory' (Eq. 1) and the 'A theory' (Eq. 2), respectively, assuming an uncertainty of 3% in each datum.

Vanadium partitioning and mantle oxidation state

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Vanadium exists in multiple valences in natural basaltic melts (V^{2+} , V^{3+} , V^{4+} and V^{5+}), and because most crystalline phases prefer to incorporate V^{3+} rather than V^{4+} and V^{5+} , its crystal/silicate-melt partitioning tends to decrease with increasing oxygen fugacity (fO_2). Such dependence has been experimentally demonstrated and used to estimate the fO_2 of mantle and mantle-derived rocks. Recent modelling of V and V/Sc systematics in basalts has led to the view that the relative fO_2 of the upper mantle is constant, both through time and among the sources of different types of basaltic magmas (i.e. MORB, OIB and IAB).

This is contrary to the notion given by other oxygen barometric methods, mostly based on the distribution of Fe^{2+} and Fe^{3+} on peridotites and basalts, which indicate an upper mantle heterogeneous in relative fO_2 . To explore further the potential of V to estimate the relative fO_2 of mantle peridotites and basalts, a set of high-pressure and high-temperature experiments was carried out using 1-atm vertical tube furnaces (at 1300°C) and piston-cylinder apparatus (1275–1450°C and 1.5–3.2 GPa) under controlled oxygen fugacity conditions. Contrary to previous studies, the range of oxygen fugacity obtained in our experiments is large enough (10^4 to 10^{-20} bars) to constrain the behaviour of all four potential oxidation states of vanadium in natural systems.

Five starting compositions were used, producing silicate melt in equilibrium with all major phases of the upper mantle (olivine, orthopyroxene, clinopyroxene, spinel and garnet). The experimental products were analysed by laser-ablation ICP-MS to determine V partition coefficients, which plot for all phases as approximately sigmoid-shaped curves in log D-log fO_2 space. Details of the shape of the curve are controlled by the relative preference of each crystalline phase for a specific valence of V. Contrary to previous studies, our results do not suggest a systematic increase in $D_V^{cpx/opyx}$ with decreasing fO_2 .

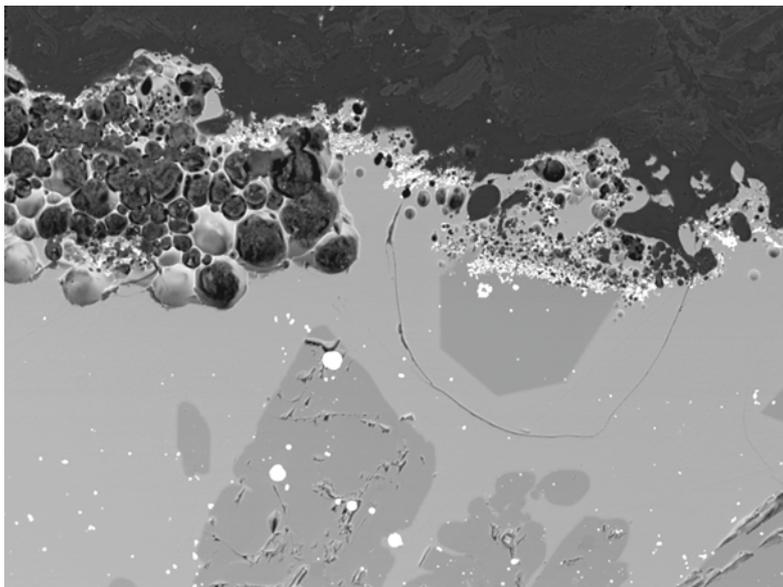


Figure 1. Example of an experimental charge run at very reducing conditions ($fO_2 \sim 10^{-18}$ bars), where the oxygen fugacity is set by the CO-Ar-graphite equilibrium via gas mixing. Dark area on top is the graphite container, dark grey are silicate crystals, light grey is the silicate melt, and white patches are metal phases. Scale: ~ 300 microns across.

Collisional erosion and the non-chondritic composition of the terrestrial planets

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The compositional variations among the chondrites inform us about cosmochemical fractionation processes during condensation and aggregation of solid matter from the solar nebula. These fractionations include: 1) variable Mg-Si-RLE ratios (RLE: Refractory Lithophile Element); 2) depletions in elements more volatile than Mg; 3) a cosmochemical metal/silicate fractionation; and 4) variations in oxidation state.

Moon-to-Mars-sized planetary bodies, formed by rapid accretion in local feeding zones within 106 years, may exhibit some of these chemical variations. However, the next stage of planetary accretion is the growth of the terrestrial planets from ~102 embryos sourced across wide heliocentric distances, involving energetic collisions, in which material may be lost from a growing planet as well as gained. While this may result in averaging out of the "chondritic" fractionations, it introduces two non-chondritic chemical fractionation processes: post-nebular volatilisation and preferential collisional erosion.

In the latter, geochemically enriched crust formed previously is preferentially lost. That post-nebular volatilisation was widespread is demonstrated by the non-chondritic Mn/Na ratio in all the small, differentiated, rocky bodies for which we have samples, including the Moon and Mars. The Bulk Silicate Earth (BSE) has chondritic Mn/Na, but shows several other compositional features in its pattern of depletion of volatile elements suggestive of non-chondritic fractionation. The whole Earth Fe/Mg ratio is 2.2 ± 0.1 , significantly greater than the solar ratio of 1.9 ± 0.1 , implying net collisional erosion of ~ 10% silicate relative to metal during Earth's accretion. If this collisional erosion preferentially removed differentiated crust, the assumption of chondritic ratios among all RLEs in the BSE would not be valid, with the BSE depleted in elements according to their geochemical incompatibility.

In the extreme case, the BSE Earth would only have half the chondritic abundances of the highly incompatible heat-producing elements Th, U and K. Such an Earth model resolves several geochemical paradoxes: the depleted mantle occupies the whole mantle, is completely outgassed in 40Ar , and produces the observed 4He flux through the ocean basins. But the lower radiogenic heat production exacerbates the discrepancy with heat loss.

The dependence of upper mantle melting temperatures on composition: A parameterization for peridotite based on the Gibbs phase rule

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The temperature at which material of the Earth's upper mantle melts and produces basaltic magma places important constraints on the thermal structure of the Earth and patterns of mantle convection. This temperature depends on the chemical composition of the mantle material. Experimental studies have determined the solidus (the beginning of melting) as a function of pressure for various bulk compositions, but without a systematic assessment of how the solidus depends on compositional variables, the significance of the reported differences in solidus temperatures is ambiguous, leading to controversy regarding the relative influence of temperature anomalies as opposed to compositional heterogeneity on variations in the initial depth of melting and melt productivity.

This problem is exacerbated by the experimental difficulties in determining both the extent of melting and the compositions of partial melts at low melt fractions. Here we introduce a parameterization of the equilibrium melting temperature for upper mantle spinel lherzolite as a function of pressure and composition, which can be combined with mineral/melt partition coefficients to calculate the solidus temperature precisely, and the increase in melt fraction with temperature above the solidus. The parameterization takes as its starting point partial melting in the system CaO-MgO-Al₂O₃-SiO₂ (CMAS), and then quantifies the effect of other components individually, where these additional components are FeO, Cr₂O₃, Na₂O, K₂O, P₂O₅, TiO₂ and the volatile components H₂O and CO₂.

By testing the parameterization against the entire experimental database for melting of spinel lherzolite, we demonstrate that higher-order terms between these additional components are negligible at relevant concentrations, except for a term describing the interaction of H₂O and CO₂. The parameterization enables experimental studies of different compositions to be tested for mutual consistency, and permits the compositions of initial and low melt fraction partial melts to be estimated. The parameterization may be integrated readily into physical models for melt generation, and provides a benchmark for testing more comprehensive models based on mineral and melt thermodynamic properties.

The solidus temperature of the system CMAS-Na₂O-FeO was parameterized from the comprehensive experimental data from 0 to 4.0 GPa. For the spinel-lherzolite facies we obtain

$$T_{(\text{CMAS-Na-Fe})} = 1319 + 174 (P-1.1) - 22.7 (P-1.1)^2 - 0.86 \text{Fe}_{\text{melt}}^{\#} - 6.1 c_{\text{Na}_2\text{O}}^{\text{melt}}$$

where P is in GPa and T in °C. The depression of the solidus due to additions of other minor components is:

$$T = T_{(\text{CMAS-Na-Fe})} - 5.8 [c_{\text{K}_2\text{O}}^{\text{melt}}] - 1.0 [c_{\text{TiO}_2}^{\text{melt}}] - 2.0 [c_{\text{P}_2\text{O}_5}^{\text{melt}}] + 3.25 \text{Cr}_{\text{sp}}^{\#} - 0.08 (\text{Cr}_{\text{sp}}^{\#})^2 + 0.000672 (\text{Cr}_{\text{sp}}^{\#})^3 - 46.4 c_{\text{H}_2\text{O}}^{\text{melt}} - 4.3 c_{\text{CO}_2}^{\text{melt}} + 14.7 c_{\text{H}_2\text{O}}^{\text{melt}} c_{\text{CO}_2}^{\text{melt}}$$

Interactions between felsic melts and peridotites in sub-arc conditions: Comparison between experimental results and natural samples

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In subduction zones, lavas from volcanic arcs usually show a clear slab signature. Within the subducted slab, several recent studies have shown that the interaction of a hydrous fluid, that derives from dehydration of hydrous phases in the lower portion of the slab, with sediments on top of the slab produces a felsic melt enriched in varying amounts of Na and K and incompatible trace elements. However, it remains still unknown how these melts are able to migrate within the mantle wedge to induce partial melting.

We have performed piston cylinder experiments to study the amount and the kind of interactions, which could happen between slab-derived melts and the mantle wedge. Two types of assemblages were chosen to investigate this question. The first assemblage consists of a fine-grained mix of 75% of San Carlos olivine with 25% of granitic glass (Fig.1a) whereas the other set consists of a layer of coarse-grained olivine (100µm) overlain by the granitic glass (Fig.1b). These experiments were run at 35kbar with a range of temperatures from 950°C to 1050°C equivalent to sub-arc mantle temperature.

The mixed experimental charge was designed to represent porous flow in the mantle. The added granitic melt reacted completely with the olivine to form a peridotite containing garnet, orthopyroxene, phlogopite and a residual aqueous fluid that has been trapped in graphite spheres. (Fig.1a). The layered capsule aimed to imitate a channel flow through the mantle. Results were somewhat different as the reaction between olivine and granite is confined to a small layer of garnet orthopyroxenite at the contact of both phases (Fig.1b). Only accessory phlogopite was found in those layered experiments showing that most of K, Na, H₂O remains in the granite. This observation suggests that the garnet-orthopyroxene zone acts as a shield between the mantle and a felsic dyke.

In New Caledonia, the main Massif du Sud ophiolite is interpreted to derive from a supra-subduction zone and shows many dykes of various compositions. A family of dykes was particularly noticed in the field by their analogy with the experimental results. These dykes are generally of dioritic to trondhjemitic composition and show a clear reaction zone with the surrounding harzburgite. This continuous metasomatic zone is characterized by a centimeter to decimeter thick orthopyroxenite (Fig.2). Such walls of orthopyroxenes are easily explained by a silica enrichment in the peridotite following the reaction $(\text{Mg,Fe})_2\text{SiO}_4 + \text{SiO}_2 \Rightarrow (\text{Mg,Fe})_2\text{Si}_2\text{O}_6$. The absence of garnet in regards to the experimental results is due to a lower pressure which only allows the formation of spinel-group minerals.

Field observations and experimental results have shown that felsic melts can be transported over long distance without important and complete interactions with the surrounding peridotite once pyroxenite walls are formed. This finding has important consequences on the way how incompatible elements are transported from the slab to the locus of partial melting in the mantle wedge.

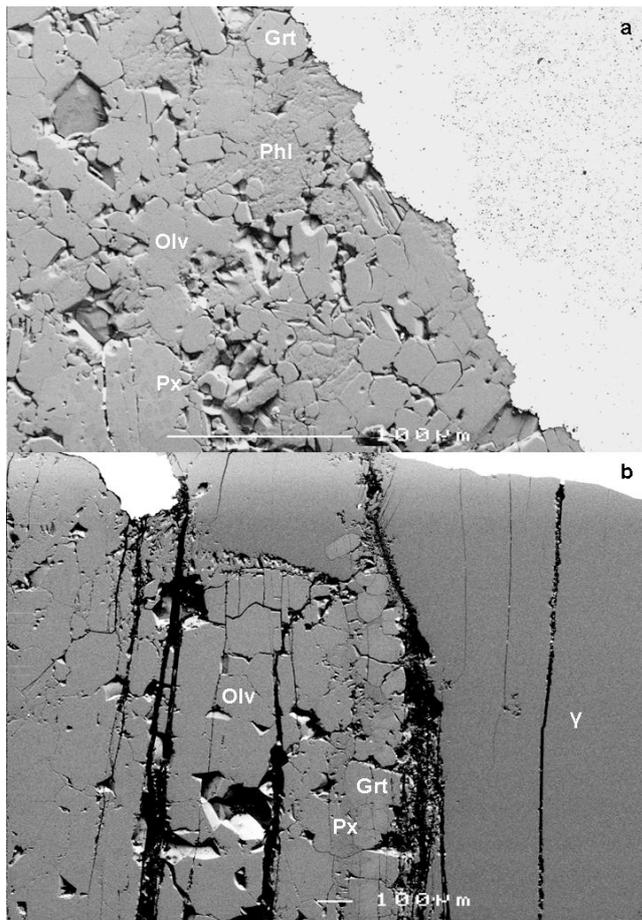


Figure 1. Experimental run products a) 1050°C, 35kbar, mixed experimental charge. Recrystallized olivine with pyroxene and garnet embedded in phlogopite. b) 1050°C, 35kbar, layered experimental charge. Contact zone between olivine and glass with idiomorphic garnet and orthopyroxenes. Olv : Olivine, Px : Orthopyroxene, Grt : Garnet, Phl : Phlogopite, _ : Granitic glass.

Figure 2. Fine-grained leucogabbro dyke with coarse gabbro margins in harzburgite. The dyke-peridotite contact is characterized by orthopyroxenite walls. Rivière Blanche, Massif du Sud, New Caledonia



Subduction recycling of continental sediments and the origin of geochemically enriched reservoirs in the deep mantle

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Isotopic and trace element geochemical studies of ocean island basalts (OIBs) have for many years been used to infer the presence of long-lived (~1-2 Ga old) compositional heterogeneities in the deep mantle related to recycling of crustal lithologies and marine and terrigenous sediments via subduction (e.g., Hofmann, 1997; Willbold and Stracke, 2006). In particular, models for the EM-1 type ("enriched mantle") OIB reservoir have invoked the presence of subducted, continental-derived sediment in the lower mantle or at the core-mantle boundary to explain high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, low $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios, and extreme enrichments in incompatible elements (e.g., K, Pb, Rb, Ba, Sr, La, Ce, etc.) observed in OIB lavas from, for example, the Pitcairn Island group in the South Pacific.

More recently, ultrapotassic, mantle-derived lavas (lamproites) from Gausberg, Antarctica have been interpreted as the product of melting of deeply recycled (subducted) Archean-age metasediments in the mantle transition zone at ~400-700 km depth (Murphy et al., 2002). We have carried out a series of high-pressure laboratory experiments in the multi-anvil apparatus in which continent-derived sediments were subjected to pressure (16-24 GPa) and temperature (1300-1800°C) conditions equivalent to those of the mantle transition zone. The high-pressure mineral assemblages produced in our experiments contain ~15-30 wt% K-hollandite (KAlSi_3O_8 , a high pressure polymorph of K-feldspar), in addition to stishovite (a high-pressure polymorph of quartz), garnet, an Al-silicate phase (kyanite or phase egg), and a Fe-Ti spinel (corundum). Analyses of K-hollandite with the ion microprobe at Woods Hole reveal that this phase controls a significant proportion of the whole-rock budget of the incompatible trace elements (e.g., Rb, Ba, Sr, K, Pb, La, Ce and Th).

Comparisons between the abundances and selected ratios of these elements in K-hollandite with those in EM-1 type ocean-island basalts from Pitcairn Island and related seamounts, and with the Gausberg lamproites, strongly implicate the presence of deeply recycled, continent-derived sediments in the source region for these lavas. Our results suggest that the incompatible element signature of EM-1 OIB reservoirs in general and of the Gausberg lamproites in particular can be attributed to recycling of K-hollandite-bearing continental sediments to transition zone depths, and perhaps even deeper into the lower mantle.

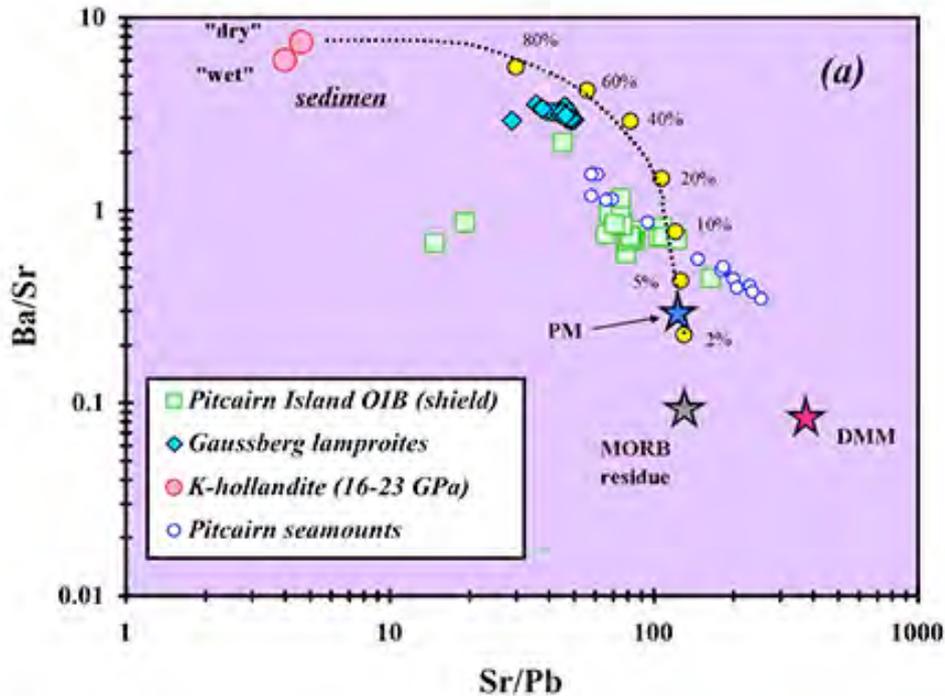


Figure 1. Ratios of incompatible element pairs (Ba/Sr versus Sr/Pb) in K-hollandite bearing sediments from high-pressure experiments compared with those for Gaussberg lamproites and Pitcairn Island, with mixing curves calculated for various proportions of subducted metasediment and subequal amounts of MORB residue (grey star), depleted MORB mantle (DMM; pink star) and primitive mantle (PM; blue star) reservoirs. Between 5 and 10% sediment is implied for the mantle source for EM-I OIB from Pitcairn, and much higher proportions (40-50%) for the Gaussberg lamproite source.

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Chlorine Partitioning: The Behavior of Cl in the Presence of Sulfide – Silicate Melts and Aqueous Fluid

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Can sulfide melts exsolve halogen rich fluids? Several ore deposits around the world (eg. Broken Hill, Stillwater, Sudbury and Bushveld) have occurrences of halogen-rich minerals in association with the ore. To help better understand these occurrences, piston cylinder experiments were performed to investigate the partitioning behavior of Cl between coexisting haplogranite and Pb-Fe-Zn-sulfide melts at 0.5 GPa pressure and 810°C temperature.

In water undersaturated experiments where a Cl doped haplogranite glass was used as the silicate starting material, the Cl was found to partition strongly into the sulfide melt. Here Cl may be acting as a flux within the sulfide melt resulting in lowering its eutectic temperature. Not only is Cl dissolved in the sulfide melt, but as the sulfides crystallize the residual sulfide melt progressively enriches in Cl. In water saturated experiments where Cl was doped into the sulfides, Cl was noticeably absent from both quenched sulfide melt and silicate glass, suggesting strong partitioning into the coexisting aqueous fluid. The results indicate that the partitioning preference of Cl, when in equilibrium with sulfide-silicate melts and aqueous fluid, decreases in the order aqueous fluid – sulfide melt – silicate melt.

These experimental results can be applied to understand the cooling of sulphur- and chlorine-bearing magmatic systems. Initially, Cl will partition into a sulfide melt that coexists with a hydrous silicate melt. Once an aqueous fluid exsolves from the silicate melt – due to decompression or crystallization at the solidus – Cl will partition into the newly formed fluid causing the sulfides to freeze and crystallize rapidly. The escaping Cl-rich fluid might lead to extensive halogen alteration in the country rocks of the intrusion. The concepts investigated in this study may have significant implications for understanding the evolution of magmas giving rise to copper porphyry deposits and aid in our understanding of halogen-alteration and halogen-rich minerals in major sulfide deposits.

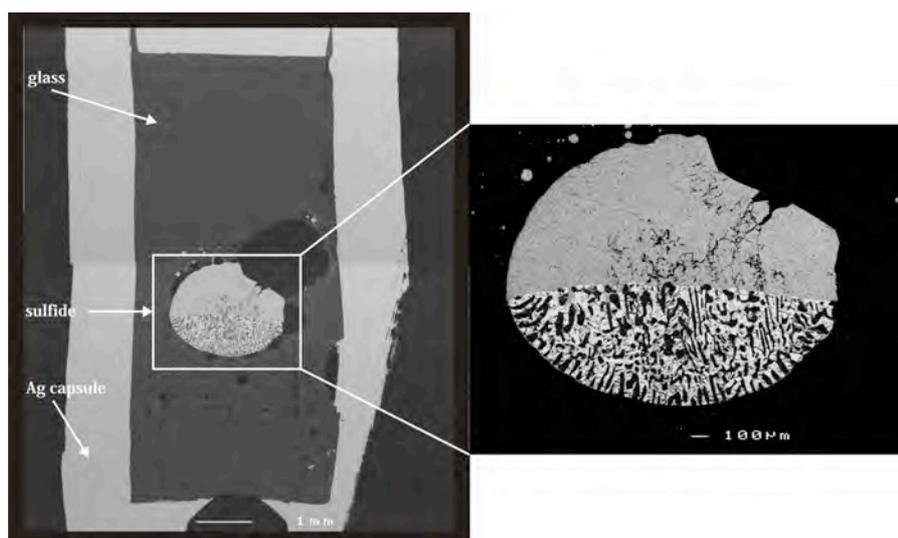


Figure 1. Back-scattered electron images of a water saturated sulfide-silicate partitioning experiment. Image on left is view of entire capsule, showing rounded sulfide bleb in the centre of quenched glass. The large black void seen on upper right of sulfide bleb and surrounding the sulfide bleb are remnants of excess water pockets. Inset is a detailed view of the sulfide bleb showing inhomogeneous sulfide quench texture. In this experiment, neither sulfide nor silicate showed detectable Cl values.

Ti site occupancy and distribution in zircon: implications for thermometry

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Application of the Ti-in-zircon thermometer (Watson et al, 2006; Watson and Harrison, 2005; Ferry and Watson, 2007) requires an understanding of which site Ti occupies within the zircon structure, the influence of chemical variables on Ti-saturation and other physiochemical parameters that may influence Ti-distribution within a given zircon grain. For the purpose of this research, Ti-site occupancy in zircon was determined via experiments run under varying phase assemblages and Ti K_α XANES spectra of synthetic zircons from these experimental suites. The study of zircons crystallized under different TiO₂-ZrO₂-SiO₂ phase assemblages can also be used to critically evaluate the difficulties and concerns surrounding the nucleation and crystallization of buffering-phases within experimental systems. The research highlights of the last year include 20+ flux-type experiments (e.g., Hanchar et al, 2001) that successfully synthesized zircon under different phase assemblages. Normalized and reduced XANES spectra of zircon and standard Ti-bearing samples, as measured at the APS in Chicago, have demonstrated that Ti likely sits on the zircon Si-tetrahedral site.

In addition to site occupancy, this study has focused on the distribution of Ti within natural and experimentally produced zircon populations. Some synthetic zircons seen in this experimental program have shown notable Ti sector zoning in the absence of any correlative SEM-CL zoning. In addition to experimental systems, natural zircons studied in this program have shown that Ti-distribution can show antithetic or non-correlative distribution with regard to SEM-CL signal. This is not unexpected, so long as factors controlling Ti-saturation and saturation of CL-activating elements are decoupled during the growth of zircon, and if Ti occupies a different site to elements responsible to CL-signal.

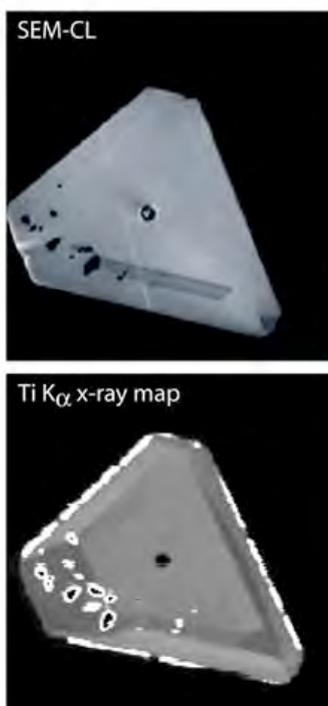


Figure 1. SEM-CL and Ti x-ray map for a 500_μm synthetic zircon (1300°C/1atm). Many experimental grains show little correlation across the two analytical techniques, indicating that Ti-distribution and SEM-CL signal can be decoupled. Caution should be used then, where targeting specific domains within a natural zircon on the basis of CL variation.

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Hanchar J, Finch R, Hoskin P, Watson B, Cherniak J, and Mariano J (2001) Rare earth elements in synthetic zircon: Part 1. Synthesis, and rare earth element and phosphorous doping. *American Mineralogist* 86 667-680.

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Watson B, Wark D, and Thomas J (2006) Crystallization thermometers of zircon and rutile. *Contributions to Mineralogy and Petrology* 151 413-433.

Fault weakening and slow earthquakes as a consequence of fault gouge strengthening in hydrothermal regimes – insights from laboratory experiments

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A laboratory study was conducted to investigate how solution transfer processes influence the mechanical behaviour of simulated quartz fault wear products at high temperature, hydrothermal conditions. Experiments were performed under nominally dry conditions, as well as in the presence of an aqueous pore fluid, at elevated temperatures (500 to 927°C), and at 100MPa effective confining pressure. The mechanical data and detailed microstructural analysis indicate that the kinetics of solution transfer processes exert a fundamental control on the time-dependence of the mechanical behaviour of fault wear products. At nominally dry conditions, the gouges deform by cataclastic creep with distributed shear.

The strength and microstructural evolution are relatively temperature insensitive. At moderately chemically reactive, hydrothermal conditions (T=500°C, coarse grain size, fast deformation rate), the gouge sliding resistance is slightly lower than at dry conditions, most likely due to the operation of chemically-enhanced fracture growth and dissolution of ultra-fine particles and surfaces of coarser particles, assisting cataclastic flow. At highly chemically reactive, hydrothermal conditions (T=600°C, small grain size, slow deformation rate), substantial gouge compaction and low, distributed shear strains, are accommodated largely by dissolution-precipitation creep processes. Increase in average grain contact areas during compaction by dissolution-precipitation creep is associated with strain hardening. However, at axial displacements of 0.5 to 1.0mm, a peak strength is reached (Figure 1), followed by up to 50% stress drop over several minutes. Slow stress drop is associated with slip localisation at the gouge-hostrock interface. Subsequent frictional sliding on this interface occurs at friction coefficients as low as 0.4.

The experimental results indicate that the presence of reactive pore fluids can lead to rapid strengthening of wear products during interseismic intervals. Earthquake recurrence in faults containing reactive pore fluids will thus be influenced by the relative rate of recovery of shear strength and the rate of tectonic loading. The low resistance to frictional sliding after slip localisation is interpreted to reflect a role of dissolution processes play in overcoming frictional barriers during slow slip. It is speculated that fluid-assisted shear strength recovery, and the potential effects of fluids in controlling slow stress drop during slip localisation, may be pertinent to understanding the role of fluids in generating slow earthquakes in parts of subduction systems and in the continental seismogenic regime.

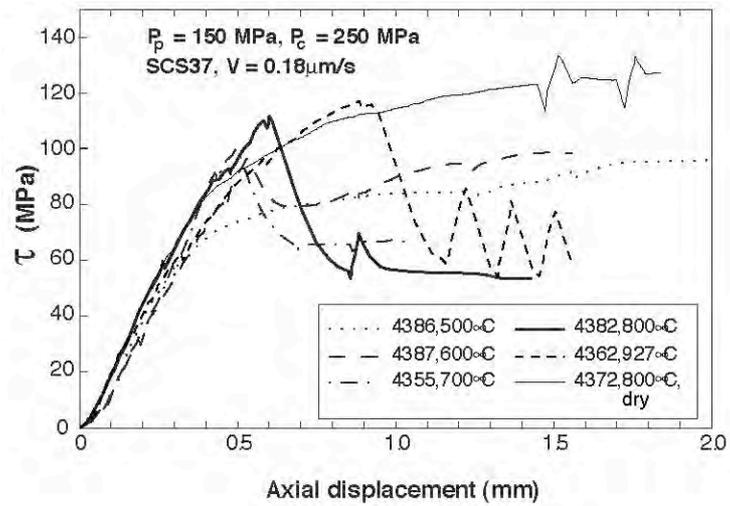


Figure 1. Shear stress versus axial displacement for quartz gouges deformed at high pressure hydrothermal conditions and at temperatures in the range 500°C to 927°C. The nominal displacement rate was $0.18 \mu\text{m s}^{-1}$. Experiment 4372 was conducted without pore water, but at the same effective confining pressure conditions as the other experiments.

High-temperature viscoelasticity and seismic wave attenuation: materials, methods and micromechanical modelling

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At sufficiently high temperatures in the Earth's interior, the mechanical behavior changes from elastic to viscoelastic with profound implications for mantle rheology and also seismic wave speeds and attenuation. Such viscoelastic behaviour results from the stress-induced migration of vacancies and dislocations (extended defects reflecting prior or current deformation). As part of an ongoing study of high-temperature viscoelasticity, focused on olivine-rich upper-mantle materials, we have made substantial progress this year on several fronts:

Testing of novel materials: It has recently been demonstrated that high-purity synthetic Fo_{90} olivine ($\text{Mg}_{0.9}\text{Fe}_{0.1}\text{SiO}_4$) prepared from a sol-gel-derived precursor is much stronger than its natural counterpart [1]. A possible role for grain-boundary chemistry in explaining these differences has been explored this year by modifying the sol-gel procedure to incorporate ~1% Ca which is preferentially accommodated in the grain boundaries of the polycrystalline material. Deformation experiments suggest that the Fo_{90} :Ca specimens are not significantly weaker than the pure Fo_{90} material. Small concentrations of water, accommodated within nominally anhydrous minerals like olivine, may enhance the concentration and/or mobility of the defects responsible for high-temperature viscoelastic relaxation. In order to study such effects in fine-grained polycrystalline olivine, it is necessary to suppress grain growth that is typically dramatically enhanced by the presence of water. We have explored the feasibility of restricting grain growth by changing the stoichiometry of the sol-gel precursor to yield ~50% of the additional silicate phase orthopyroxene. Comparison of the microstructures (Fig. 1 '6465' and '6626' respectively) for pure olivine and olivine-orthopyroxene mixtures, hot-pressed with added water, clearly demonstrates the effectiveness of the added orthopyroxene in inhibiting grain growth.

Improved experimental methods: The experimental procedure used in our laboratory for the study of high-temperature viscoelastic relaxation in geological materials involves low-amplitude forced torsional oscillation of a specimen assembly in which a cylindrical specimen is sandwiched between ceramic torsion rods (Fig. 2). Direct contact and chemical reaction between the specimen and the torsion rods is prevented by metal foils that also serve to relax thermal stress concentrations at the interface and to impose appropriate redox conditions. This year, we have newly quantified a contribution to the overall torsional compliance of the specimen assembly from the interfaces between the metal foil and alumina torsion rod at each end of the specimen. We have demonstrated that this (previously neglected) extraneous contribution to the apparent compliance of the specimen can be removed by subtraction of the torsional compliance of a foil-bearing reference assembly similarly containing two alumina-foil interfaces. This new strategy provides more accurate determination of the shear modulus and associated strain-energy dissipation $1/Q$.

Correction of previously published data for fine-to-medium grained polycrystalline olivine for the interfacial compliance suggests somewhat milder frequency and temperature dependence of $1/Q$ than previously reported and substantially stronger grain-size sensitivity.

Micromechanical modelling: Experimental data for high-temperature viscoelastic relaxation in fine-grained ceramic and geological materials have proved difficult to reconcile with the classic models of grain-boundary sliding [2]. Collaboration with Stephen Morris at the University of California, Berkeley, has resulted in a more comprehensive analysis of grain-boundary sliding in which both viscous sliding and diffusional transport of matter along the boundary have been incorporated for the first time. An analytical (perturbation) solution, valid in the limit of vanishing boundary slope, indicates that $1/Q \sim 1/\omega$ at sufficiently low frequency ω as expected for viscous rheology (diffusional creep). At much higher frequency, the $1/Q$ peak of (anelastic) elastically accommodated sliding is predicted with a peak height varying inversely with the boundary slope – suggesting that elastically accommodated sliding might be suppressed in this model for boundaries of finite slope. At intermediate frequencies, $1/Q \sim 1/|\ln \omega|$ – a milder frequency dependence than previously predicted. The new model, now being extended through numerical simulations of the behaviour of arrays of elastic crystals undergoing diffusively assisted grain-boundary sliding, should ultimately provide a more robust framework for the interpretation of experimental data for fine-grained materials.

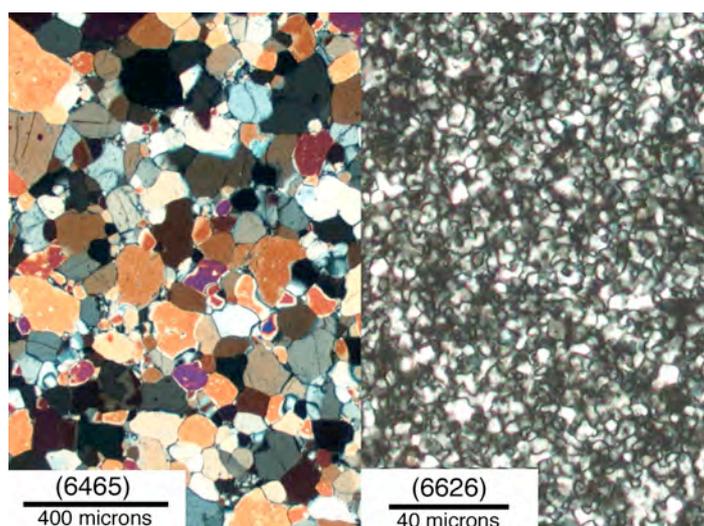


Figure 1

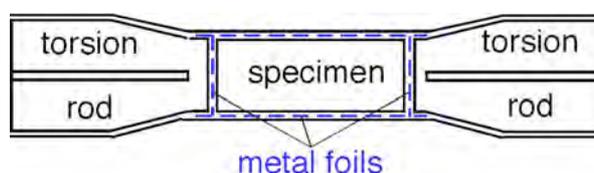


Figure 2

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Exploration potential of stress transfer modelling in fault-related mineral deposits

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This project applies the principles of the triggering mechanisms and triggering effects of active fault systems to understand gold mineralisation in ancient fault systems. Earthquakes generate small elastic stress changes, which in turn trigger other earthquakes and many thousands of aftershocks. Each aftershock is a fault slip event that enhances the permeability of the crust and high-frequencies of aftershocks tend to occur on faults with the same dimensions as those faults that host gold mineralisation in Australian gold camps. Previously, we have shown that at crustal depths of 10–20 km, orogenic-type gold deposits occur where co-seismic stress changes around a fault are likely to have triggered clusters of aftershocks (Micklethwaite and Cox, 2004, 2006; Micklethwaite, 2007). Therefore Stress Transfer Modelling helps us understand the dynamics of ancient fault systems and acts as a valuable predictive tool for the exploration industry.

Stress Transfer Modelling is now being extended to gold mineralised fault systems that developed in near-surface crustal environments (1–6 km) during episodes of normal faulting and high geothermal gradients, such as epithermal gold deposits and Carlin-type gold deposits. Active faulting in volcano-tectonic environments provides a modern day analogue for epithermal fault systems (e.g. Taupo Zone, New Zealand; Coso geothermal field, USA). Using a combination of detailed field work, contemporary observations of geothermal fields, plus stress transfer modelling, we have found there is a complex interaction between faulting, intrusive activity, and potential mineralisation. Fault slip events and permeability enhancement can be triggered by dyke intrusions, or other fault slip events, and these triggering mechanisms control fault growth and fault spacing. Importantly, dyke intrusion transiently changes local stress states, with a profound influence on fault kinematics, and the location permeability enhancement and mineralisation (figure 1).

In addition, collaboration with Dr Heather Sheldon (CSIRO, Perth, Western Australia) is enabling us to use Damage Mechanics Theory to understand why small stress changes generated by fault-slip events exert such a strong control on resulting aftershocks, fluid flow and ultimately fault-related mineralisation (Sheldon and Micklethwaite, 2007).

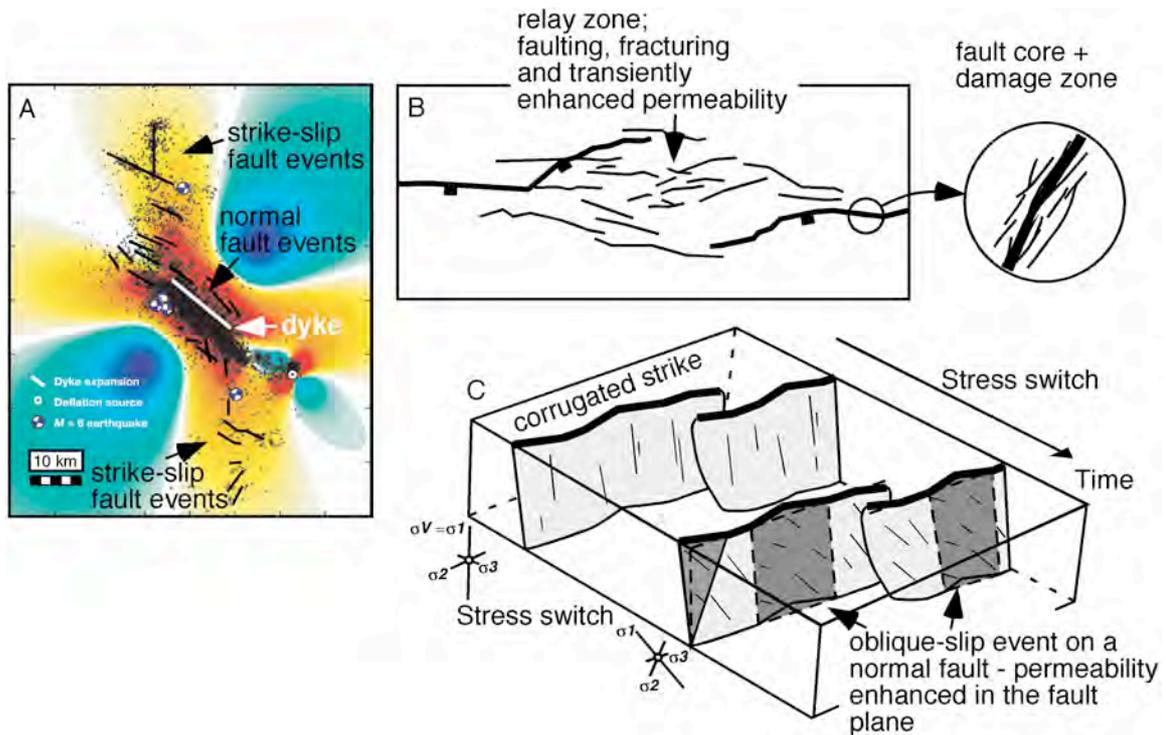


Figure 1. (A) 10000's of earthquakes (represented by black dots) were triggered by the intrusion of a dyke (white line) off the coast of Japan (Toda et al., 2002). The interconnected earthquake swarms represent massive permeability enhancement and Stress Transfer Modelling is able to predict their distribution by calculating the positive stresses (red) generated by intrusion of the dyke. Normal earthquakes were triggered on the flanks of the dyke and strike-slip earthquakes were triggered in the tails. If the dyke intrudes in a slightly different position, some of the normal faults can be reactivated as strike-slip faults. (B) Normal fault systems have complex linkages and fault shapes. Fluids can flow along-strike through fault jogs, but they can also flow upwards through fracture-related permeability in relay zones, and to a limited extent through damage zones associated with their fault cores. (C) Normal faults develop corrugated strikes. In mineralised regions the intrusion of a dyke can change the stress state on a fault from one decade to the next, leading to dramatic changes in fault-plane permeability when there is a slip event. This directly affects where mineralization will be focused.

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Micklethwaite S. and Cox, S.F. (2004) Fault-segment rupture, aftershock zone fluid flow and mineralization. *Geology*, 32, 866-870.
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Cycles of lithospheric thickening and thinning along convergent plate margins: a case study from the European Alps

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Recent studies (Beltrando et al., 2007; Beltrando et al., in press) have shown that the European Alps, in the 44–30 Ma period, underwent at least two deformation mode switches from shortening to extension and vice versa. This complex deformation history resulted in multiple burial–exhumation cycles of the different tectonic units (Figures 1, 2 and 3).

An enlargement of perspective to the evolution of the Africa–Europe plate margin in the 44–30 Ma interval shows that the burial–exhumation and shortening–extension cycles observed in the axial zone of the mountain belt are probably the result of regional scale episodes of lithospheric thickening and thinning (Figure 4). Such short-lived episodes, each lasting <5 Ma, resulted in the formation of specific tectonic associations.

Lithospheric thickening is responsible for the tectonic burial of rock units down to ultra-high-pressure depths. Thickening is achieved through thrusting and upright folding, which are also responsible for the creation of topographic relief. These periods are characterized by little or no magmatism along the plate margin.

Lithospheric thinning, instead, is responsible for the rapid exhumation of rocks from ultra-high-pressure depths. Vertical thinning is achieved through the activity of extensional shear zones and the formation of recumbent folds. Extensional deformation, which is also recorded in the peripheral basins, culminates in the topographic collapse of the mountain belt. Lithospheric thinning results in rapid vertical advection of mantle material, producing decompressional melts of mafic composition. Their interaction with crustal rocks may be responsible for the creation of acidic melts, leading to bimodal magmatism. The general perturbation of the isotherms is also responsible for re-heating of portions of the orogen, leading to Barrovian metamorphism on a regional scale.

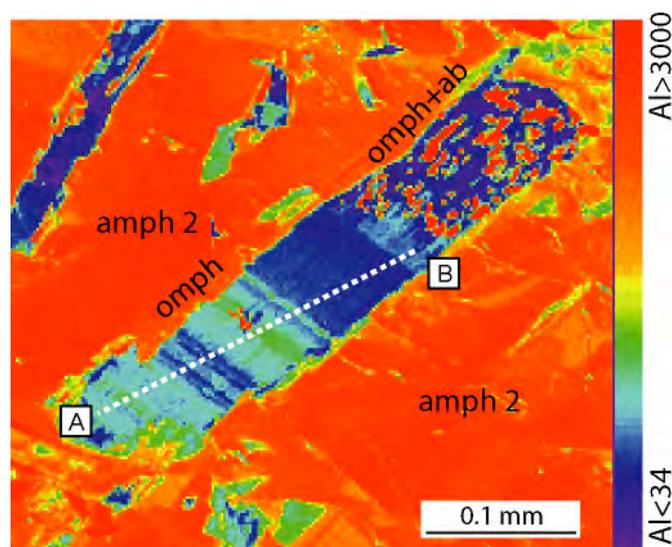


Figure 1.

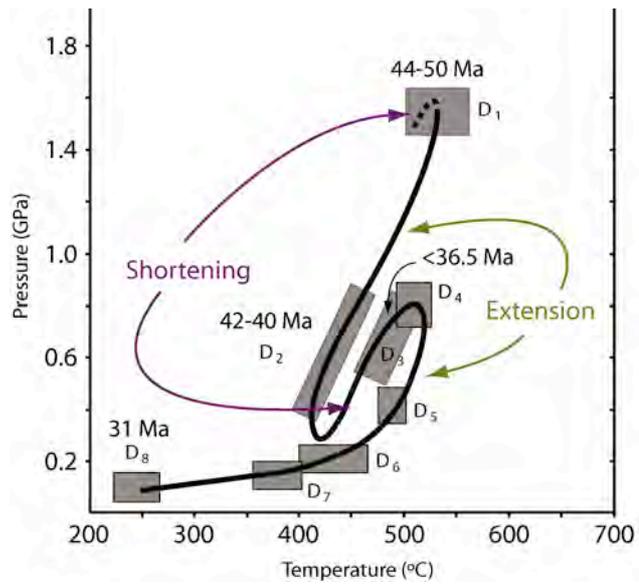


Figure 2.

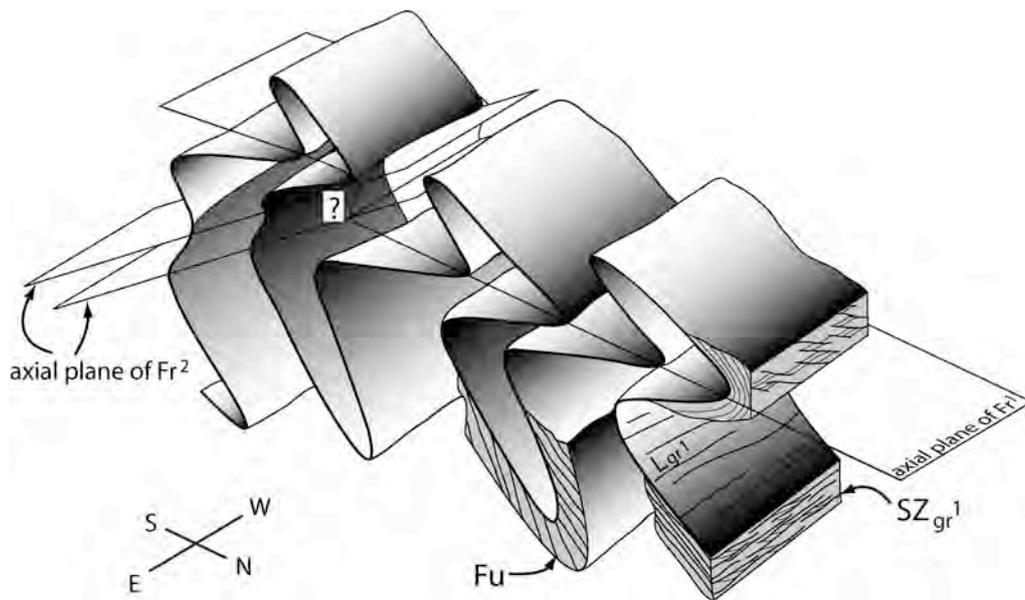


Figure 3.

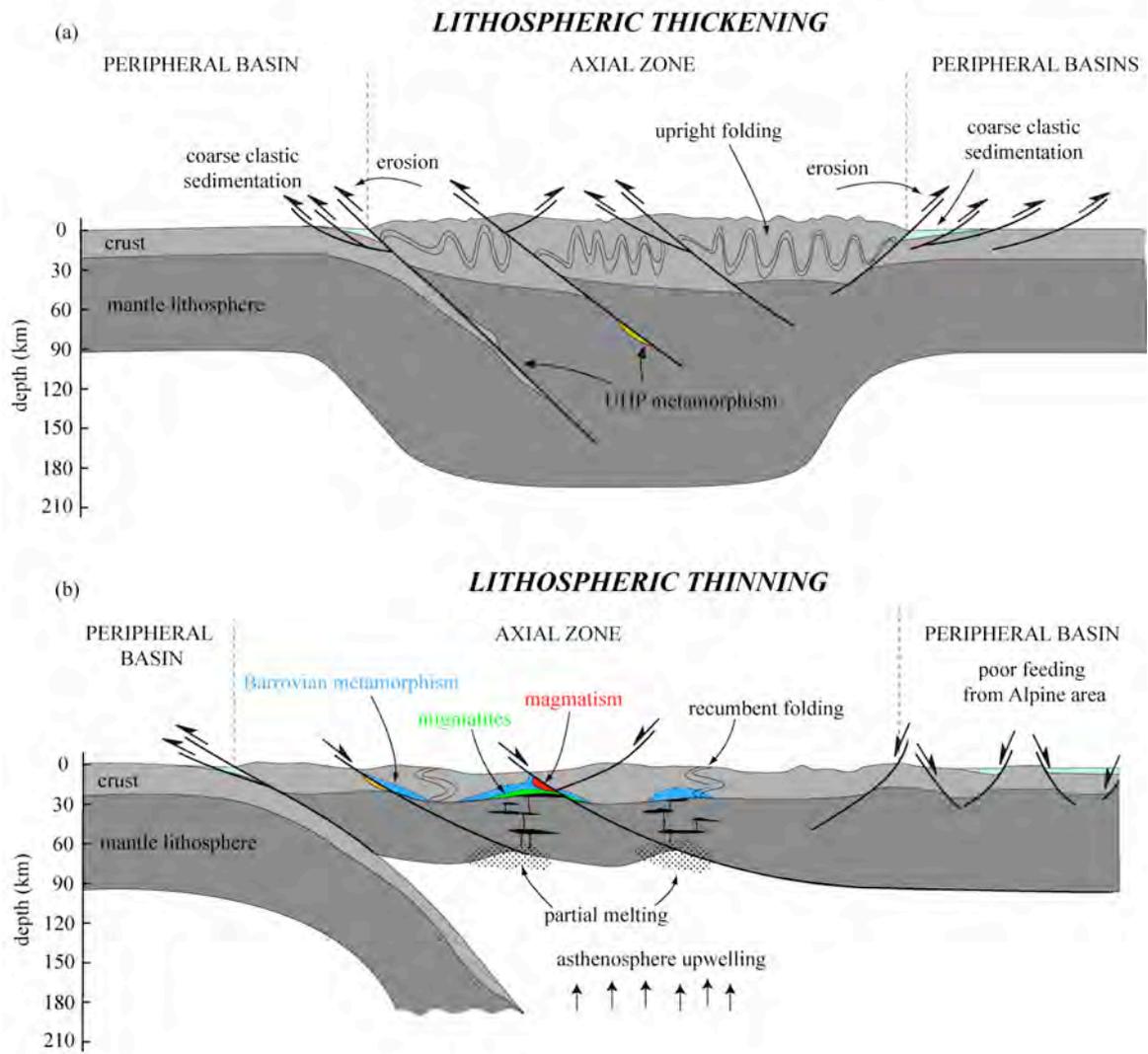


Figure4

Evidence for competing movement patterns influencing the evolution of the Sagaing-Sumatra wrench fault system

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The evolution of the Sumatra-Sagaing fault system is being examined using Shuttle Radar Topographic Mission (SRTM) datasets to infer basic characteristics of the evolution of this wrench fault system over ~6000km of its lateral extent.

An SRTM image compiled during the course of this study is shown in Figure 1. The interpreted extent of the Sagaing-Sumatra wrench fault system is also shown, along with particular zones that have been interpreted in detail.

Our analysis shows that whereas the wrench system has an approximate small circle geometry, there are significant deviations that potentially may be caused by flow of the crust related to escape of material from Tibet, and/or arc normal flow (with a westward component) driven by gravitational potential energy and/or the effects of roll-back of the Indian and Australian slabs.

In the south and east the wrench system crosses the Sunda Straits, from Java, into Sumatra. In Sumatra the wrench system is characterized by westward-stepping left-lateral horsetail splays, and this causes local transpression. In the Andaman Sea, the wrench develops eastward-stepping extensional zones, which have developed into a transtensional ocean basin.

In northern Myanmar, now known as the Sagaing fault system, the wrench is again deflected, apparently in response to orthogonal lateral flow, in this case related to westward tectonic escape of the Myanmar crust. Further north the Sumatra-Sagaing wrench system ends. This occurs to the west of Namche Barwa, which is an extensional gneiss dome related to the termination of this right-lateral system.

The movement picture overall is consistent with a right lateral wrench system affected by arc normal outward flow of the crust. The structural geology therefore reflects the effect of this arc normal movement acting in competition with the movement of plates and microplates in the region.

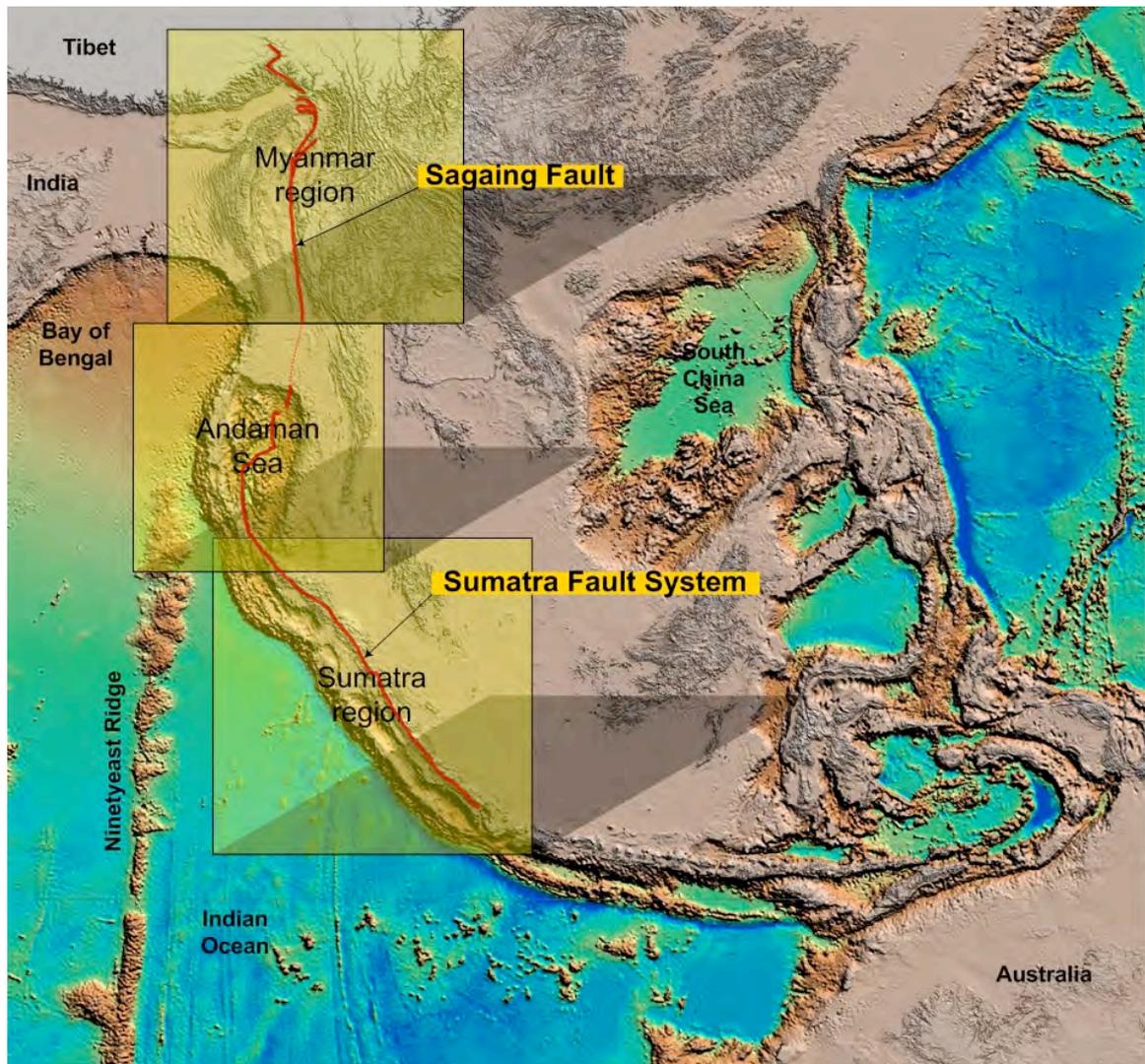


Figure 1. A digital elevation model of the study area from SRTM data, with location of the Sagaing and Sumatra wrench fault system in red.

Tectonic Sequences Diagrams: Is orogeny simple?

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Orogeny is not a simple process, whether it is regarded as progressive or as episodic, complex sequences of events occur throughout the evolution of orogens (Fig. 1). These sequences of events include periods of quiescence, deformational events, and mineral growth events (metamorphism), and thermal events often short in duration, with characteristically complex overprinting of events. As we endeavour to understand the timing of these sequences we must understand how the events that we are dating fit into complex tectonic sequences within the region and/or orogen.

$D_1, D_2 \dots D_n$ schemes are used by structural geologists and metamorphic petrologists to define sequences of events, however these schemes do not reflect the complexity of deformation and metamorphism. In part the problem relates to the way such schemes are constructed (and/or debated). There is often an implicit assumption that all fabrics are related to folds, and episodes of shear zone formation are not taken separately into consideration. Similarly it is often assumed that all deformation is progressive and continuous, so that the labels applied to different 'events' are of little consequence. Complicated areas often have several competing schemes described in different papers, with no thought given as to ways in which the basic data stream provided by structural analysis might be better and more accurately presented.

We advocate a move away from problematic $D_1, D_2 \dots D_n$ notations, for several reasons: a) such notations imply labels that can be readily applied to structures in the field, whereas the reverse is more often the case; b) event sequences inferred by linking mesostructure to microstructure are often more complex than $D_1, D_2 \dots D_n$ schemes allow; c) $D_1, D_2 \dots D_n$ schemes are inherently prone to controversy, due to the natural difficulty in correlating structure across large regions and disputes as to what constitutes D_1, D_2 , etc. d) does not take shear zones into account (Fig. 1 & 2). So what is the alternative: recording all events for each region into detailed 'tectonic sequence diagrams' (TSDs) (Fig. 3). Recording events into 'Tectonic Sequence Diagrams' does away with interpretation and loss of data at the initial data collection phase. TSDs allow dating of events to be fitted precisely into a scheme not an overall 'number'. TSD allow for variation of observations at each location and for adding to the sequence as more data is obtained (Fig. 3).

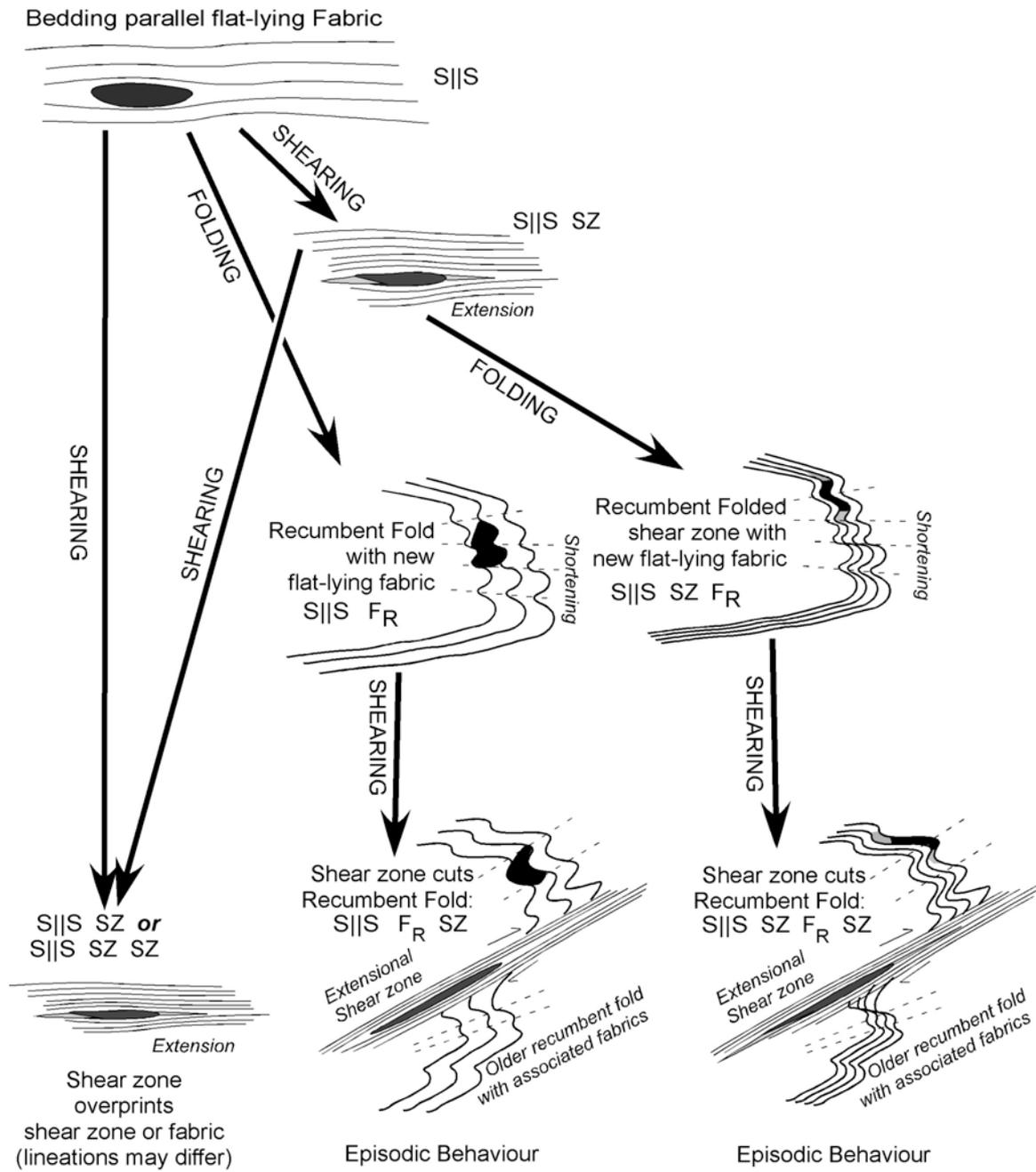


Figure 1. Deformation is not homogenous throughout a region and particularly throughout an orogen. Flat-lying bedding parallel fabrics and shear zones can 'hide' a complex history that is not discernible at only one location. Shear zones must be categorized as a distinct fabric.

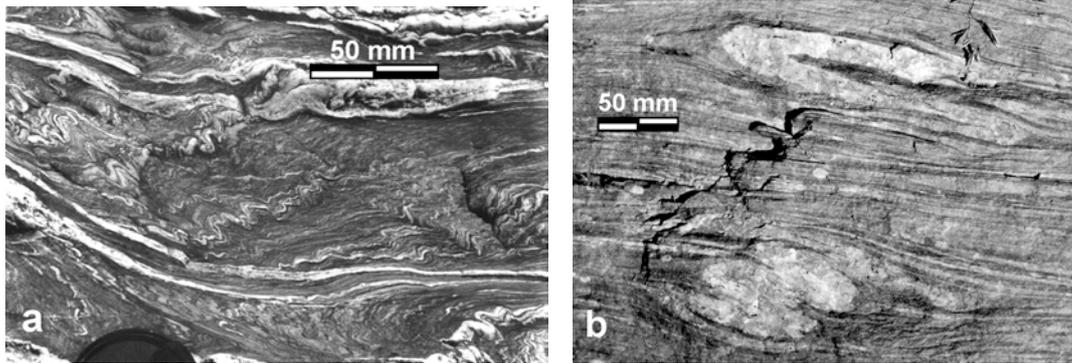


Figure 2. The relation between folds and shear zones has been particularly wrongly diagnosed (e.g. in the Otago Schist, NZ). Careful and regional structural mapping must be carried out to discern the TSD for these structures. A) shear zones overprint and accentuate folds; b) tension gashes are folded during shear zone operation.

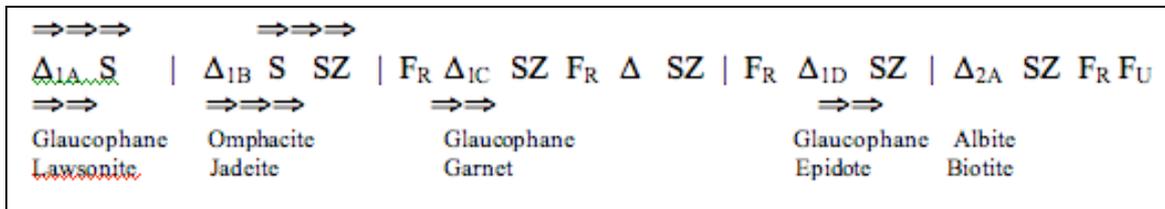


Figure 3. An example of a 'tectonic sequence diagram' (TSD): in this case for the blueschist belt in the Aegean (on the island of Sifnos). The arrows denote the continuation of an event, the Δ is a mineral growth event, S is a fabric, SZ is a shear zone and F is a fold (R is recumbent, U is upright). Distinct sequences are separated by a vertical line.

Forster, M and Lister, G. 2007. Tectonic sequence diagrams and the structural evolution of schists and gneisses in multiply deformed terranes. Journal of Geological Society, London, Accepted.

Pplates – tectonic reconstruction software

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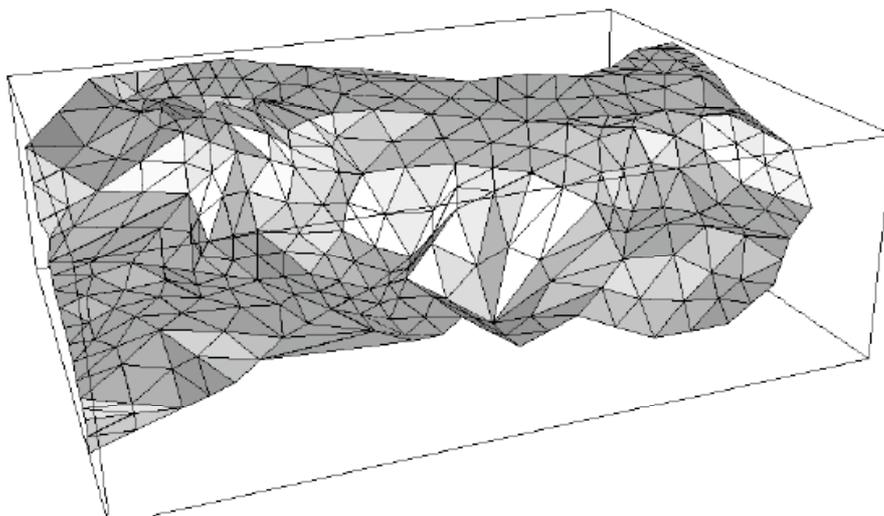
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Pplates is a Macintosh-based tectonic reconstruction program that allows a user to deform the lithosphere, while conserving crustal mass and maintaining isostatic balance. Pplates v 1.0.00 was released early in 2007, on the ACcESS MNRf website [<http://access.edu.au/>]. Simulation of deformation of an elastic mesh on a viscous base allows redistribution of stresses and strains caused by localized distortion. This flexibility permits the use of specific Euler rotation data for different parts of the same plate (e.g. cratons) with the resulting strain between the cratons being sensibly distributed automatically.

Pplates has been used for three tasks in 2007. A pilot project funded by De Beers, Australia, has made use of both the Virtual Earth and Pplates as vital components in developing the exploration-focused examination of the global distribution and emplacement of diamond-bearing kimberlites. Simon Richards used Pplates to track points of interest (kimberlite locations) on the continents as they are moved according to the reconstruction information.

Andrew Barker is currently using Pplates to complete his Honours Project – a reconstruction from the evolution of the Alpine-Himalayan chain, from Greece to the Pamirs. He has used a shaper mesh to simulate the deforming movement of the area around the Anatolian fault. The visualisation capability of the Data Visualisation Laboratory has been enhanced by the ACcESS MNRf, with two fast, multi-core, Intel-based Macintosh computers with large display screens and large RAM and disk memory. The machines also operate Windows XP™ further accelerating the laboratory capability for GIS applications such as MapInfo and ERMapper.

The link between Pplates and high-performance computing has been establishing using GeomSlab and SimParm, written by Kevin Pulo to enable him to view results and adjust parameters during time-consuming calculations¹. The current geometry of the Nazca plate was used as a starting point and "restored" to its initial condition prior to subduction.



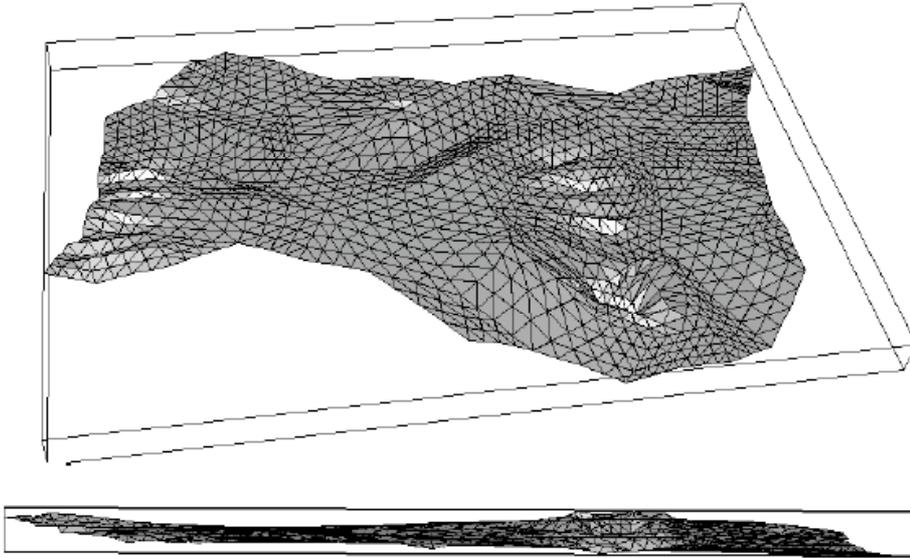


Figure 1. The current geometry of the South American slab was used as a test case for *GeomSlab* HPC software developed by Kevin Pulo at the ANUSF. Oblique and side-on views of the South American slab after restoration using *GeomSlab* to bring the current South American slab back to a nearly at the Earth's surface configuration. As can be seen, the surface extent of this slab is not the same as a straight-forward vertical projection of the original slab

1.Pulo, K, "SimParm: A simple, flexible and collaborative configuration framework for interactive and batch simulation software.". *Internationals Supercomputing Conference 2007*, 26-29 June 2007, Dresden, Germany.

Geodynamics of the Sumatran Earthquakes

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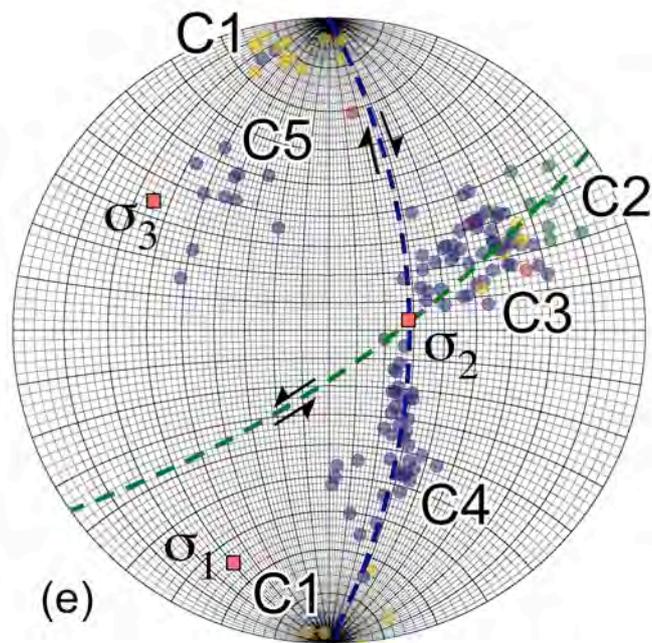
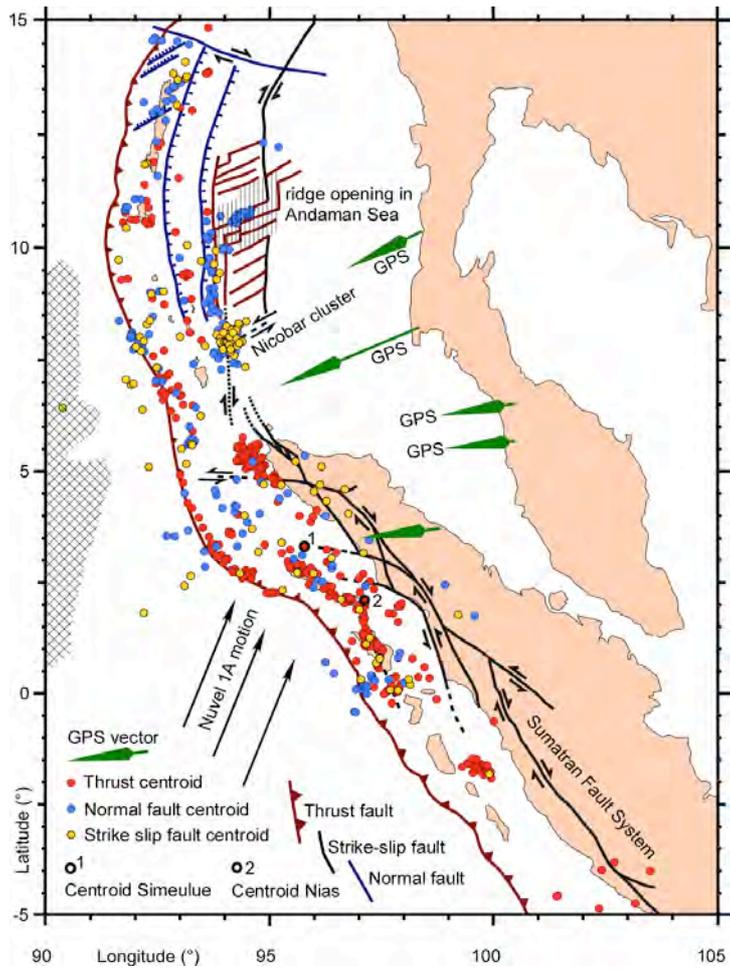
eQuakes allows the analysis of 3D orientation data from earthquakes, either in respect to their location (latitude, longitude, depth) or orientation (using data as provided by the centroid moment tensors for individual earthquakes).

We used *eQuakes* to produce a map (of aftershocks from the Great Sumatran Earthquakes of 2004 (Fig. 1). *eQuakes* has automatically classified the earthquake type: blue dots are normal faults, red dots are thrusts, and gold dots are strike slip faults). The map shows thrusts dominating in the south, while normal faults are prominent in the north. This means there were rather different orientations of the bulk deviatoric stress axes in the lithosphere in the two regions during the aftershock events, and different movement pictures.

We used *eQuakes* to analyse orientation data from a vigorous cluster of aftershocks from near the Nicobar Islands, in the vicinity of the boundary separating these two domains. Perhaps the vigour of the aftershock swarm is related to geometric incompatibility between these two competing movement pictures? To test this hypothesis we derived a lower hemisphere stereographic projection of slip lines from the Nicobar aftershock cluster, using data from centroid moment tensor (CMT) solutions for earthquakes available through the Global CMT project. These data could have been plotted as beachballs, but more often than not, one beachball obscures another, and in any case, such diagrams help little if we really want to understand what the patterns mean.

Ambiguity in the centroid moment tensor data was eliminated by considering only solutions that are compatible with local fault traces discernible in SeaSat data. What can be seen in the resultant stereoplot (Fig. 2) is a definition of five orientation groups: here we show the C1 and C4 slip lines for north-south striking right-lateral strike-slip faults, and the C2 and C3 slip lines for normal oblique-slip left-lateral strike-slip faults. The latter faults operated parallel to what are normally interpreted as sea floor spreading ridges in the Andaman Sea.

The state of stress (red dots) can be inferred from this classic Mohr-Coulomb failure geometry. NE-SW directed compressive stress can be inferred, parallel to the direction of relative plate motion, but with the axis of maximum compression inclined $\sim 30^\circ$ to the plane of the Sumatran megathrust. This is an attitude that suggests continued aseismic slip on the underlying basal Sumatran megathrust during the aftershock sequence, rotating the stress axes away from parallelism with the surface of the Earth.



Geochronology of the Omo Group, Turkana Basin, east Africa

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The Omo-Turkana Basin of northern Kenya and southern Ethiopia developed in the northern Kenya Rift about 4.3 Ma ago in the Early Pliocene. Nearly 800 m of sediments, included within the Omo Group, crop out in the basin. Numerous rhyolitic tuffs in the sequence have facilitated not only secure correlations between the individual formations of the Omo Group but they have also provided material for precise $^{40}\text{Ar}/^{39}\text{Ar}$ age measurements. Ages have been determined on alkali feldspar crystals from pumice clasts within tuffs in the lower part of the Omo Group up to the level of the KBS Tuff, which has previously been dated at 1.87 ± 0.02 Ma. The results from 17 stratigraphic levels encompassing the 2.4 Ma time interval from the base of the group to the KBS Tuff provide a numerical time framework for the geological history of the lower part of the Pliocene sequence. The new ages, which have a precision in the order of one percent, are all consistent with the stratigraphic order, providing confidence that they accurately record the age of the individual volcanic eruptions, with deposition of the tuffs and pumices occurring shortly thereafter. These new ages provide a precise and accurate time scale for the lower part of the sequence in the whole of the Omo-Turkana Basin, and with earlier published results on the upper part, we now have over 30 dated volcanic eruptions recorded within the sequence.

These results are particularly significant as they provide age estimates for the many hominid and other vertebrate fossils recovered from the sequences in the Omo-Turkana Basin, so that individual fossils often can be assigned an age to better than 50 or 100 thousand years. The importance of these results is that the evolutionary history of hominids is constrained directly by age determinations rather than by assumptions as to the evolutionary stage, and also enables comparisons to be made throughout a much wider area, including in areas outside the Omo-Turkana Basin. In addition, some of the tuffs also are recognized in deep sea sedimentary cores from the Gulf of Aden and the Arabian Sea, enabling correlations into the marine sedimentary record to be made with confidence. In turn, this provides the means of correlating the climatological record in the deep sea sediments with that found in the sediments of the Omo-Turkana Basin which is located well within the African continent. The sedimentological record in the Turkana Basin reflects the climatic changes associated with the Milankovitch cycles, which have a profound effect on the intensity of the monsoonal activity most notably in the Ethiopian Highlands.



Figure 1. Tuff outcrop on skyline within the Omo Group sequence, Ileret area, Turkana Basin

Structural reactivation along the Portsoy lineament during extension and coeval High-T, Low-P Barrovian metamorphism

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High-temperature, low-pressure metamorphic rocks of the Buchan Terrain in northeastern Scotland outcrop over an area of approximately 40 x 40 km (Fig. 2). The Buchan Terrain is surrounded on three sides (west, south and east) by complexly deformed and metamorphosed high temperature, moderate pressure rocks that form the Barrovian Terrain. Like many other High-temperature, low-pressure terrains around the world, rocks of the Buchan are characterised by the indicator minerals andalusite, cordierite and sillimanite, which remain as evidence of the positive thermal perturbation experienced by this area during the early Proterozoic evolution of Scotland. We examine the structural and metamorphic history of the Buchan and compare this to the HTLP metamorphism of the eastern LFB where we can demonstrate that metamorphism occurred coeval with periods of extension.

Despite notable differences in the metamorphic grade (both T and P), the Buchan and Barrovian, the two are typically considered as having formed during the same tectonothermal and orogenic events, albeit in different areas (facies) of the orogen.

Recent mapping along Scotland's northeastern coastline between Cullen in the west and Fraserburgh in the east (Fig. 2), revealed that the Buchan terrain exhibits structural and metamorphic evidence of having formed primarily during a phase of regional, asymmetric extension. This can be correlated with the HTLP sillimanite overprint on the classic moderate P mineralogy, exhibited by the structurally underlying Barrovian. Furthermore, our mapping has alluded to the formation and reactivation of major structures such as the Portsoy-Duchray Hill lineament (P-DHL) and how their movements impact on the spatial and temporal tectonothermal evolution of the Buchan and to a lesser degree the Barrovian metamorphic terrain.

The Buchan and associated Barrovian terrain is typically divided into a number of distinct groups; the Appin, Argyll and southern Highland group. Although it has been suggested that the rocks of these three groups experienced the same tectonothermal histories, we suggest that there are distinct structural and metamorphic differences between some of these groups and that these differences demonstrate different tectonic evolution of the two terrains.

The complex rock associations within and adjacent to the Portsoy-Duchray Hill Lineament (P-DHL), denote its importance as a locus for tectonic reactivation, suggesting repeated episodes of extension and compression. Evidence for this includes: 1) the termination of the Moine Super group against the lineament; 2) the parallelism of isotherms and reorientation of isotherms and isobars near the lineament; 3) highest grade rocks aligned parallel to the lineament; 4) repeated injection of magmas along the lineament; 5) the juxtaposition of rocks of contrasting metamorphic grade and age; 6) transposition of earlier-developed structures, and 7) the reactivation of the zone at different pressures and temperatures (see review by Goodman, 1994).

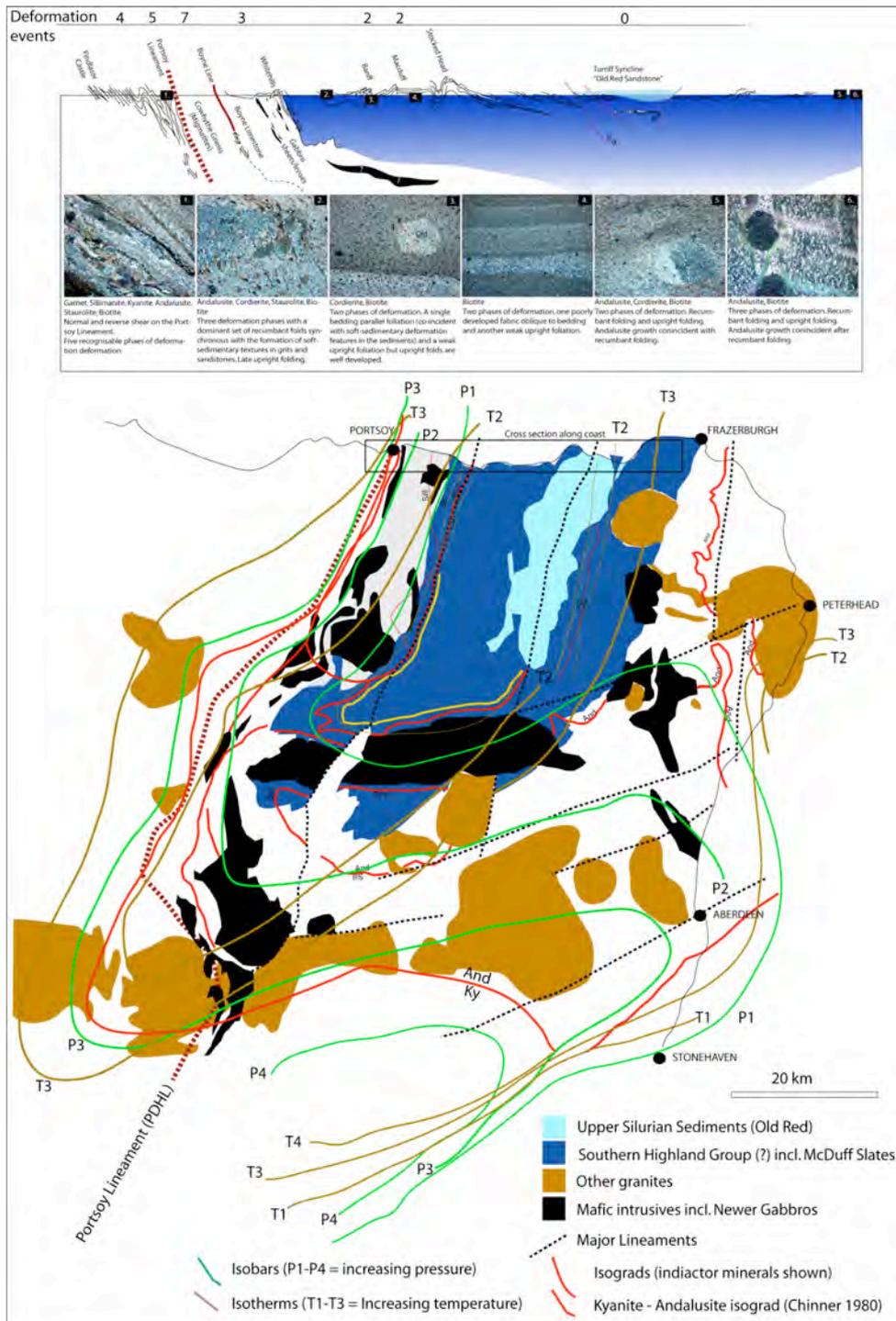


Figure 2. Map of the northeastern Buchan and Barrovian Terrains located in NW Scotland. Cross section also provided with thin sections from rocks within each zone labeled 1-6. The map highlights outlines of Isotherms and Isobars from Chinner (1980). Buchan rocks are outlined in blue. Cross section illustrates the geometry of the dominant form surface in each region in a cross section along coastal exposures. The number of deformation events (folding and shearing) are also listed showing that rocks at the base of the Buchan exhibit evidence of up to 7 deformation events while those that lie above the Buchan (i.e. the old red sandstone) exhibit little or no deformation. This disparity is especially evident in the thin section photomicrographs provided for each zone.

These observations suggest that the lineament has a complex and potentially long-lived history of evolution. The highly variable rock associations found within and adjacent to the lineament are interpreted as packages of rock with contrasting metamorphic and deformation histories.

These potentially different structural and tectono-magmatic units have been isolated and juxtaposed within the shear zone, during repeated periods of extension and compression.

Asymmetric extension is proposed as the primary mechanism leading to the positively perturbed geotherm exhibited by the Buchan Terrain. Movement and strain partitioning along the P-DHL controlled east-directed continental and lithospheric extension. Extension was also accommodated by the Boyne Line, which resulted in detachment of the Boyne Limestone Group from the underlying Cowhythe Gneiss and the Barrovian terrain to the south. Incremental emplacement and progressive inflation of the Newer Gabbros at the boundary between the Buchan and underlying Barrovian Terrain during this period of extension is envisaged. The emplacement of the magmas was also focussed along the major structures that facilitated crustal and lithospheric extension, as reflected in their linear regular pattern outcrop pattern. Their emplacement resulted in the HTLP metamorphism in the Buchan and a HTLP metamorphic overprint (sillimanite) on the northern part of the Barrovian. Oblique compressive deformation following extension was again focussed along the P-DHL and resulted in asymmetric differential thrusting of the Buchan over Barrovian metamorphic rocks to the west. The amount of extension and subsequent thrusting was greatest in the north at Portsoy, while only small amounts of extension and thrusting are interpreted to have occurred in the Duchray Hill Area, considered the pivot (hinge) point of the shear zone.

The southeastern Lachlan Fold Belt (SE LFB) is characterised by a predominantly N-S trending tectonic grain defined by the alignment of parallel granite batholiths (e.g. Bega Batholith, Wyangala Batholith, Murrumbidgee Batholith), extensional basins (e.g. Hill End Trough, Tumut Trough) and multiple generations of upright folds that formed during episodic, approximately E-W directed shortening of the upper plate. Early-Silurian and Devonian sediments were deposited in N-S trending extensional basins that overly multiply deformed Ordovician rocks. These younger basin sediments are typically folded during a shortening cycle but were subsequently unconformably overlain by younger sediments and volcanics that appear to be confined to the same reactivated extensional basin (e.g. Hill End Trough). The eastern LFB has undergone multiple extension and compression cycles. The younger sediments preserve a simpler deformation history than the underlying Ordovician rocks in a style that we would see as comparable to the relationship between the complexly deformed Barrovian Basement rocks, the overlying Southern Highland Group (incl. the Mc Duff Slates) and then the relatively undeformed upper Silurian Old Red Sandstone.

We would also suggest that both the Lachlan HTLP metamorphic complexes and the Buchan Terrain in Scotland formed during extension. Heating for metamorphism is derived from conductive and advective heat transfer associated with lithospheric thinning and emplacement of voluminous mafic magmas in both terrains.

Goodman, S., (1994) The Portsoy-Duchray Hill Lineament: a review of the evidence. *Geology Magazine*. 130: 407-415.

Chinner, G. A. (1980) Kyanite isograds of Grampian metamorphism. *Journal of the Geological Society of London*, 137, Part 1: 35-39.

Virtual Earth

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A digital 3D interactive, editable and updatable "Virtual Earth" is being constructed to examine some of the complexity behind global-scale geodynamic interactions, including mineralization, subduction and continental breakup. The current version of the Virtual Earth, as it is developing, is a 3D interactive computer model that is currently focused on delineating the geometry of subducted crust and lithosphere (slabs) at convergent margins using P-wave tomographic datasets, earthquake hypocenter data and a plethora of other global datasets such as mineral deposit occurrences, surface geology, geophysical data including gravity and magnetics and SRTM digital elevation data. The Virtual Earth includes interpreted slab geometries for the Banda Arc (Richards et al., 2007), the Pamir-Hindu Kush (described below), Northern Burma, South America, the Aleutians, Tonga and many smaller slabs located in the SW Pacific.

3D geometry and origin of the Pamir-Hindu Kush seismic zone

A 3D model of the mantle structure below the Pamirs and Hindu Kush has been created. The results illustrate that the unusual seismogenic zone below the Pamirs and Hindu Kush represents two converging "plates". The seismicity below the Pamirs defines a south-dipping sheet-like domain that projects to the southern margin of the Tarim Basin but continues west to below the eastern Hindu Kush and below the Alai Valley. Further west, the south-dipping seismic zone appears to project to the southeastern margin of the Amu-Darya - Tadjik basin (Fig. 1). The geometry of the seismic zone below the Hindu Kush differs. It defines a north-dipping surface that steepens from around 40 degrees dip near the surface to vertical at 350 kilometers depth. We suggest that the seismicity plots toward the surface where it links with the Shyok Suture, which also represents a major terrain boundary of the Indian western syntaxis. **Interpretation:** The seismicity below the Hindu Kush represents the remnant "tail" of the subducted slab associated with the closure of the Meso-Tethys that occurred during the late Jurassic to early Cretaceous (e.g. Van der Voo et al., 1999).

In contrast, the seismic zone below the Pamirs is interpreted to be the underplated western Tarim Basin (Tarim plate). The Tarim Basin and Amu-Darya basin have similar, south-deepening, wedge-shape geometries and exhibit similar sedimentation histories pre- and post-dating collision between India and Asia during the Eocene. Prior to collision, the two basins may have been linked through what is now the narrow Alai (Fig.1).

Interpretation:

The Tarim plate forms a continuous basement plate between the Amu-Darya and Tarim basins but following collision between India and Asia, the plate was depressed in a foreland-basin type setting below the overriding Pamirs and Hindu Kush. Continued northward movement of the Pamirs and Hindu Kush resulted in the closure of the link between the two basins and formation of the present-day geometry western syntaxis.

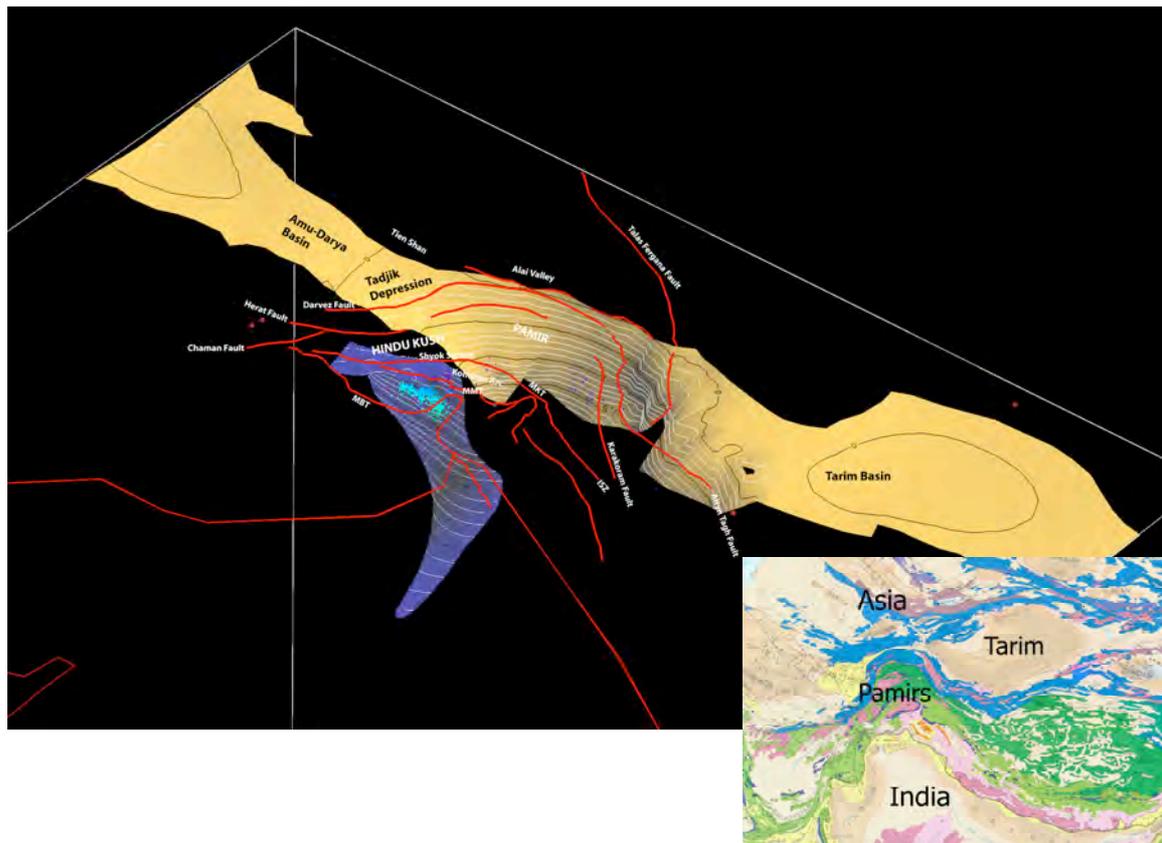


Figure 1. 3D image of the interpreted Tarim plate (brown) and the remnant subducted slab that lies below the Hindu Kush (blue) looking from southeast to northwest across the western syntaxis of India. Major faults are shown in red. In this image we show the Tarim plate as relatively flat below the Tarim Basin (east of Pamirs) and the Amu-Darya Basin-Tadjik depression (west of Pamirs) but between the two, the plate has been under-thrust below the overriding Pamirs. The contoured surface outlines the geometry and depth of the south-dipping plate. In contrast, seismicity below the Hindu Kush is interpreted to illustrate the north-dipping remnant slab associated with closure of the Meso-Tethys. The slab (shown here in blue) "rolls over" below 350 kilometers depth where it is an inverted, south-dipping slab eventually terminating at around 600 kilometers depth. (MBT – Main Boundary Thrust; ISZ – Indus Suture Zone; MKT – Main Karakoram Thrust; MMT – Main Mantle Thrust). Earthquake hypocenter locations (small colored points) from the EHB catalogue (Engdahl et al., 1998).

Engdahl, E.R., R. van der Hilst, R. Buland (1998) Global teleseismic earthquake relocation with improved travel times and procedures for depth determination. *Bulletin of the Seismological Society of America*. 88, 722–743

Richards, S., Lister, G.S., Kennett, B. L. N. (2007) A slab in depth: 3D geometry and evolution of the Indo-Australian Plate. *G. Cubed*. In Press.

van der Voo, R., Spakman, W., Bijwaard, H. (1999). Tethyn subducted slabs under India. *Earth and Planetary Science Letters* 171: 7-20

Barrovian and Buchan metamorphism in Scotland as the result of lithospheric-scale extension during orogenesis

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Extension imparted on thickened crust provides an attractive context for brief Barrovian-type metamorphic episodes due to the availability of small-scale sources for metamorphic heat in the middle crust, including magmas derived from decompression melting, localised fluid flux and mechanical work. Large differential crustal movements along crustal-scale dislocations can also produce the intense metamorphic gradients observed in the Barrovian sequence.

A class of model involving lower- and upper-plate extension at non-coincident localities connected by a crustal-scale extensional dislocation is capable of simultaneously producing the Barrovian and the Buchan series of the Grampian Terrane. Such asymmetric extension models predict development of the Barrovian and Buchan sequences in the hangingwall and footwall, respectively, of large-scale extensional shear zones (Fig. 1). According to the model, high T/P metamorphism in the hangingwall must post-date middle T/P metamorphism in the footwall. Lower plate extension leads to decompression melting and syntectonic mafic magmatism that, by advection from the asthenosphere, supplies a significant amount of the heat required for metamorphism.

The distribution of peak metamorphic pressures (P) and temperatures (T) in the classic Barrovian series suggests increasing T with (generally) increasing P to the NW, away from the Highland Boundary Fault (HBF). Despite the influence of post-metamorphic isograd re-orientation by steep belt formation in the SE, Barrovian isotherms group toward the HBF, suggesting elevated geothermal gradients in the low-grade zones (Harte & Hudson, 1979). If the metamorphic pattern was the result of a single episode, these data imply that the Barrovian sequence developed by heating beneath a 'cold' thermal boundary.

Harte & Hudson (1979) proposed a syn-metamorphic extensional dislocation near to the current HBF to account for the P-T pattern displayed in the Barrovian series. Detailed mapping carried out on the Scottish E coast within correlative units to those of the classic Barrovian sequence has shown that an intense, shear-related fabric developed coeval with metamorphic mineral growth. Abundant shear sense indicators suggest a top-to-the-SE movement sense. Muscovite ⁴⁰Ar/³⁹Ar step-heating ages across the Barrovian display an abrupt younging (in the direction of increasing grade) within the biotite zone.

White micas used for the ⁴⁰Ar/³⁹Ar were characterised geochemically and it was found that those that grew during the Barrovian metamorphism displayed lower Si and higher Ti concentrations than those that texturally pre-date it, suggestive of decreasing P and increasing T in a single unit during the Barrovian metamorphism. The results of ⁴⁰Ar/³⁹Ar geochronology and white mica geochemistry are consistent with exhumation of the Barrovian series in the footwall of a major, normal-sense shear zone during Barrovian heating. Units to the SE, having been kept at close proximities to the cold hangingwall, retain detrital ⁴⁰Ar/³⁹Ar age patterns.

East and north of the Buchan series, thinly sliced stratigraphy and intense deformation are associated with the Portsoy shear zone (PSZ). Kinematic indicators in the PSZ imply a history of both top-E and top-W movement. Dramatic pressure changes are recorded in the metamorphic history of footwall rocks (Beddoe-Stephens, 1990) and the presence of shear-bounded, Grenvillean-age basement slices flanked by Dalradian sediments within the PSZ suggests the zone experienced a long history of movement involving both thrust and normal-sense movements. Buchan (high T/P) metamorphism would result from late-stage magmatic heating by translation of the Buchan block (the hangingwall to the PSZ) over the region of maximum lower plate stretching during top-E, normal-sense movement across the PSZ.

The model necessitates that Buchan metamorphism in the hangingwall post-dates Barrovian metamorphism in the footwall, a situation which is observed when metamorphic timing is considered with respect to structure in Scotland. Late, top-W movement has modified the metamorphic transition across the PSZ since the Barrovian/Buchan tectono-metamorphic episode.

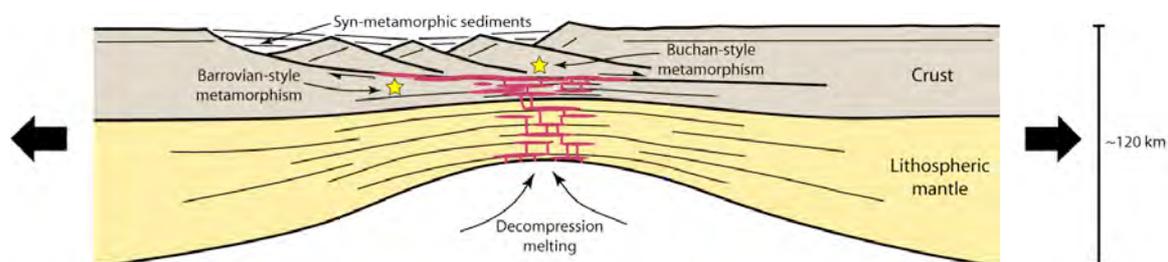


Figure 1. Schematic diagram illustrating locations for Barrovian and Buchan metamorphism during asymmetric, syn-orogenic extension

Beddoe-Stephens B, (1990) Pressures and temperatures of Dalradian metamorphism and the andalusite-kyanite transformation in the Northeast Grampians. *Scottish Journal of Geology* 26:3-14
Harte B, Hudson NFC (1979) Pelite facies series and the temperatures and pressures of Dalradian metamorphism in E Scotland. In AL Harris, CH Holland, BE Leake (Eds.), *The Caledonides of the British Isles: Reviewed* (pp. 323-337). London, Geological Society of London

Research Activities

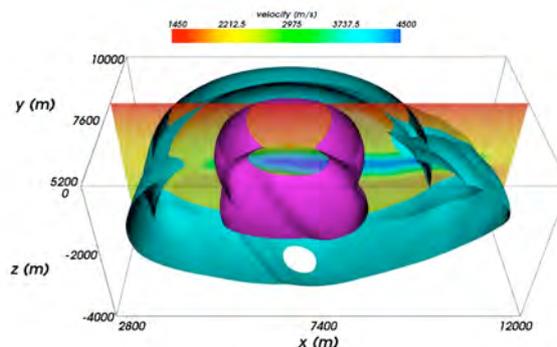
Earth Physics

Earth Physics Introduction

Research into the structure and dynamics of the Earth uses a range of physical and mathematical techniques and is grouped into the three main themes of Seismology and Mathematical Geophysics, Geophysical Fluid Dynamics, and Geodynamics and Geodesy. The work spans observational, theoretical, laboratory, computational and data oriented studies, all directed towards understanding the structure and physical processes in the earth's interior, the crust or the earth's fluid envelope.

New staff commencing during 2007 include two new continuing faculty members: Dr H. Tkalcic in observational seismology and Dr A. McC. Hogg in ocean modelling. Postdoctoral staff members P. Arroucau and M. Salmon joined the seismology group. PhD students A. Abdulah, J. Hauser and E. Saygin graduated.

RSES is taking a major role in Component 13 of the National Cooperative Research Infrastructure Strategy (NCRIS) "Structure and Evolution of the Australian Continent". A company limited by guarantee, AuScope Ltd., has been established as the vehicle to administer the \$42.8M grant over 5 years, and ANU was the first to sign the necessary agreements. As outlined in more detail below, RSES hosts activities in Earth Imaging with support of portable instrumentation and transects, Geospatial with gravity measurements and testing of portable equipment for satellite laser ranging, and Simulation & Modelling with continuing of 'pPlates' software for tectonic reconstruction. As a linked activity between the AuScope components Imaging, Geospatial and Access and Interoperability, the Terrawulf II cluster computer has been installed at RSES to provide capability in geophysical inversion.

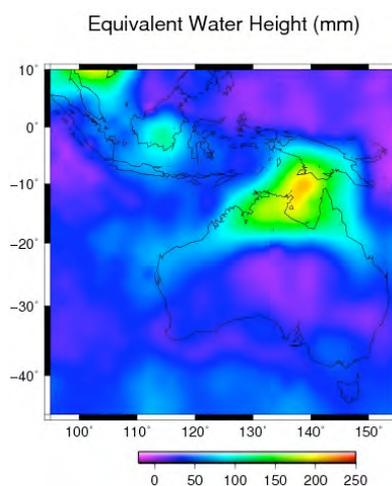


An example of the use of the wavefront construction principle, the basis of a new scheme for the computation of multi valued travel times that arise from smooth variations in velocity. Two snapshots of the wavefront computed in the SEG/EAGE salt dome model. The orange sphere denotes the source location. The wavefront is plotted at 3.375 s (magenta) and 4.125 s (cyan). Part of the wavefront surface has been removed to facilitate visualization.

In the Centre for Advanced Data Inference a major upgrade of the Terrawulf compute cluster used for intensive Earth science applications has been made possible by NCRIS funding, combined with support from RSES. A new and more powerful cluster has been constructed. Terrawulf II consists of 96 dual processor dual core 2.8GHz Opteron systems with 8GB of memory per node, connected with Gigabit Ethernet. Half of the nodes are also connected through higher bandwidth switches which significantly extend the range of potential applications of the cluster to both 'tight' and 'loosely' coupled codes. The new compute nodes have been delivered and are currently being installed and configured by Alexander Technologies, with the expectation of commissioning early in 2008. The Terrawulf II cluster will be integrated into the AuScope grid and used for a broad range of geoscience data processing as well as continuing development of state of the art inversion and data inference software.

NCRIS funding also enabled a major initiative during 2007 for the geodynamics group - the commencement of the Geospatial component of AuScope. \$15.8M was allocated for investment in geodetic infrastructure throughout Australia, including three new Very Long Baseline Interferometry (VLBI) sites, a national Global Navigation Satellite System (GNSS), terrestrial gravimeters, a test of a mobile Satellite Laser Ranging (SLR) system and a contribution towards the new Terrawulf II linux cluster. Members of the geodynamics group are involved in the AuScope Executive Committee, the Geospatial Steering Committee as well as the gravity, VLBI and Grid Computing subcommittees charged directly with the acquisition and deployment of the infrastructure. The ANU component of the above equipment includes the acquisition of a FG5 absolute gravimeter (currently on order) and a relative gravimeter (yet to be ordered), a gravity technician and a SLR technician. Dr Jason Zhang commenced in November 2007 as the SLR technician and will be involved in the instrument test in Burnie, Tasmania from December 2007 to April 2008.

For the first time, surface deformations caused by two earthquakes (magnitudes $< M_w=5.0$) have been detected in Australia from analysis of Interferometric Synthetic Aperture Radar (INSAR) imagery. The epicentres and depths of these shallow events (< 3 km) are more precisely constrained by the InSAR analysis than by available seismic observations. The combination of InSAR and seismic data is currently underway and has the potential to provide new insights into the nature of the Southwest Seismic Zone.



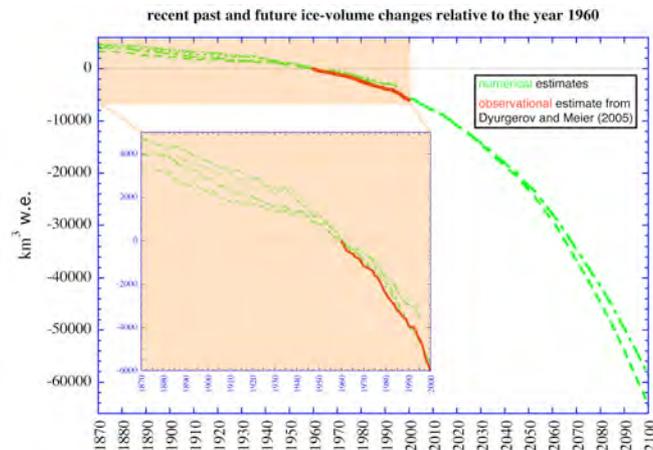
Amplitude of annual variations in mass in the Australian region (expressed in terms of mm of equivalent water height) as estimated from 5 years of GRACE observations.

A new research direction commenced in 2007 was the use of data from the Gravity Recovery and Climate Experiment (GRACE) to quantify changes in distribution of mass on the Earth. The data were used to estimate temporal changes related to glacial isostatic adjustments, as well as groundwater variations in the Murray-Darling basin caused by the ongoing drought and calibration/validation studies using the annual variations in sea surface heights in the Gulf of Carpentaria. New collaborative links have been created with the Groupe de Recherche de la Géodésie Spatiale at the Centre Nationale des Etudes Spatiales (Toulouse, France), with reciprocated visits in 2007 between the two institutions.

Field and numerical experiments were undertaken using data from infrasound networks to quantify the performance of existing infrasound networks and to derive an optimal network configuration for the detection of distant explosions as part of the Comprehensive Nuclear Test-ban Treaty.

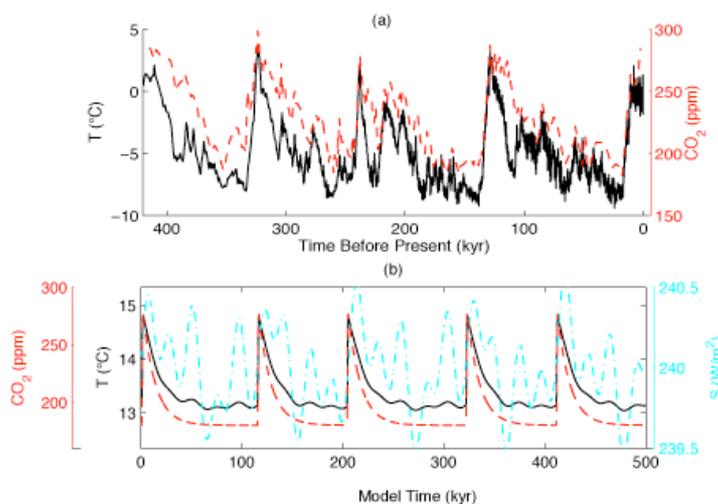
Other field experiments undertaken in 2007 included: the coring of lakes in southwest Greenland to provide additional constraints on the timing of deglaciation processes; the installation of a new, remote GPS site in Enderby Land, Antarctica to ascertain

whether the positive gravity anomaly observed by GRACE is caused by glacial isostatic adjustment; coral sampling along the coast of Western Australia to extend the record of relative sea level changes; and ongoing GPS observations in Papua New Guinea to study the kinematics of present-day tectonic motion.



A numerical model of mountain deglaciation, which reproduces the observational estimates for the recent past very well and can be used to make projections for future ice-volume changes.

Highlights of work in geophysical fluid dynamics this year included theoretical modelling of the role of CO_2 in the glacial cycle. Whether temperature changes led to CO_2 concentration changes in the earth's atmosphere, or vice versa, as been the source of much misinformation in recent public debate on climate change, largely because there is no scientific consensus on the mechanism controlling glacial cycles. A new simple model proposed by RSES, however, predicts the evolution of global temperature and carbon dioxide over the glacial-interglacial cycle and demonstrates that CO_2 acts to amplify, but not trigger, the glacial cycle. Deglaciation is triggered by variation in the earth's orbit; thus, temperature rises lead CO_2 increases at the end of glaciation, but it is the feedback between these two quantities that drives the abrupt warming during the transition from glacial to interglacial periods.



Observed records of Antarctic temperature and CO_2 over the last 400,000 years (a) and modelled insolation, global temperature and CO_2 (b).

Studies of the ocean thermohaline overturning circulation continued in the geophysical fluid dynamics laboratory, with a change of focus from steady-state dynamics to the transient behaviour forced by small changes in the surface boundary conditions, as implied by global warming. In particular, laboratory experiments addressed the dynamics underlying the possibility of a potential shut-down of the deep sinking leg of the circulation, and predicted that changes to surface buoyancy fluxes of a few percent could lead to shut-down. The circulation was also shown to be sensitive to differences between the buoyancy fluxes in the Northern and Southern hemispheres.

As the main sinking leg of the global overturning involves density-driven overflows of sills or ridges, the amount of mixing in these flows was investigated. The mixing is dependent on a mixing efficiency (the amount of potential energy released that goes into mixing rather than viscous dissipation) and this was found to be 8% to 11%, only weakly dependent on the form of the topography.

In another laboratory study, this one of importance to the biological productivity and human use of coastal waters, the dynamics of wakes behind islands and headlands were shown to be sensitive to eddy disturbances or turbulence carried from upstream of the topographic feature. The incident disturbances cause a faster dissipation of wake instabilities with distance downstream, hence a smaller recirculation region. This study utilised a new ultrasonic Doppler velocimeter.



Exchange flow over a sill in the laboratory, showing shear instability and mixing.

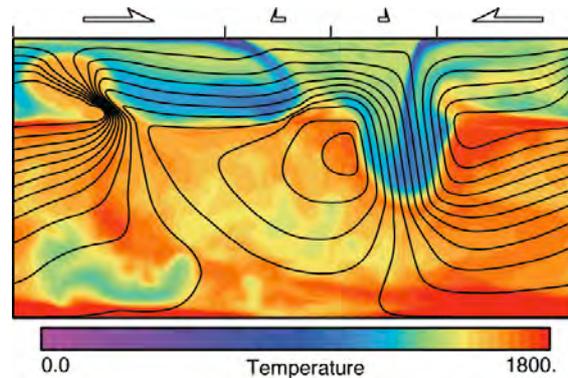
Laboratory and theoretical fluid dynamics studies also again included modelling of lava flows, where cooling, solidification and yield-strength are important factors. Solutions were obtained and tested experimentally for the spreading of solidifying fluid on a slope, which leads to channellisation of the flow. A variety of inertial, viscous, plastic and cooling-controlled flow regimes were also elucidated for flow down a sloping channel.

In mantle dynamics, laboratory work in previous years on three-dimensional flow in subduction zones was extended to understand the complicated interaction of ascending mantle plumes and subduction zones, with a view to explaining the distribution and ages of volcanism from the Yellowstone hotspot. This work involves a close collaboration with the University of Rhode Island.

Computer modelling of the interaction of mantle dynamics with mantle chemistry and plate tectonics continued with the aid of new three-dimensional numerical models. The models were integrated over the age of the earth and include the "basalt barrier", an effect involving oceanic crust becoming buoyant once it sinks to depths more than 660km in the mantle. Large overturn events were found and explain why continental crust was formed in bursts rather than continuously.

In a new project modeling the interior dynamics of exo-planets, the thermal evolutions have been calculated for planets with Earth-like compositions and masses ranging from 0.1 to 10 Earth masses. The more massive planets are predicted to be more active, though not drastically so, as the rate of processing of the mantle through

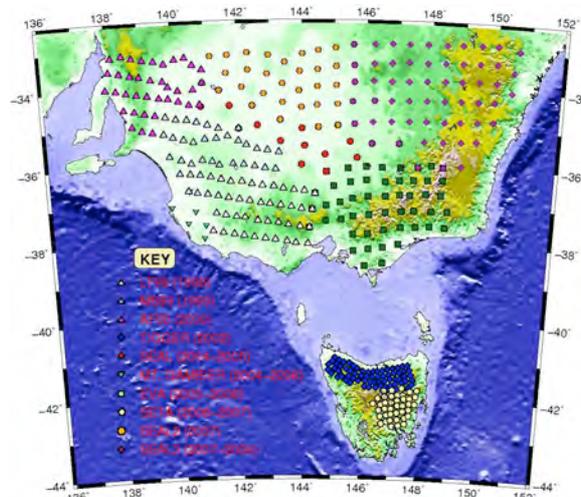
melting zones (a proxy for the rate of interaction between the interior and the surface) scale roughly in proportion to the mass.



The beginning of a mantle overturn, in which cold upper-mantle material sinks into the lower mantle (right), while hotter material from the lower mantle rises into to upper mantle (left).

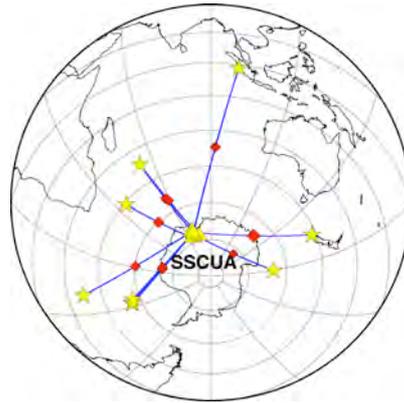
During the course of 2007, several complementary seismic experiments took place in southeast Australia. The 40-instrument SETA array, deployed in eastern Tasmania in October 2006, was removed in August this year. During its 10 month recording period, hundreds of teleseismic events were detected, as well as several blasts detonated by the University of Tasmania to generate wide-angle data. This high quality dataset is currently the subject of tomographic analysis, and should yield much new information on the deep structure beneath Tasmania. In February 2007, 31 short period and 5 broadband recorders were deployed in southwest NSW for a 9 month period as part of the SEAL2 experiment. Shortly after the retrieval of these instruments, the SEAL3 array was deployed in southeast NSW.

In this case, the array comprises 57 3-component short period instruments, and will continuously record for a 10 month period. In July, AuScope funds supported the first work on transects with 200 km of reflection profile supplementing 1200 km of work undertaken by Geoscience Australia and the Geological Survey of Queensland. This transect provides 3-D control on the nature of the Tasman Line in north Queensland. The aim of these experiments is to improve the passive seismic data coverage of southeast Australia in order to allow various classes of imaging techniques to constrain the deep structure beneath this region.



Location of all seismic arrays that currently comprise the WOMBAT experiment.

With the appointment of H. Tkalcic, the research interests of the seismology group expanded to include the structure of the Earth's core and the lowermost mantle. New observations have been made at RSES this year, of the hitherto unobserved reflections from the inner and outer core at very short epicentral distances. In addition, a new dataset of core-sensitive seismic waves recorded at one of the RSES deployments in Antarctica has been collected. The waveform data from the short period deployments are being prepared and analysed for the purpose of an inversion of the high resolution topography and P-velocity structure of a well sampled patch of the core mantle boundary north of Australia. These data are crucial for the interpretation of the internal workings of our planet.



Distribution of events (stars) with clear PcP arrivals recorded at SSCUA stations in Antarctica (triangles). The red diamonds are bouncing points of the PcP waves at the CMB.

The past decade has seen a revolutionary growth in the way we study the Australian lithosphere using seismic data. Numerous temporary deployments were installed across the continent, and with each deployment, the quantity of seismic data has kept increasing. The data are stored on various media in various formats and a serious pressure is imposed on our technical officers to keep in balance with constantly growing demands from researchers. Therefore, we have embarked on a major task of reformatting, reorganisation and storing our data in a form that will enable more functional data selection and acquisition resulting in user-friendly waveform formats of desired seismic stations and time periods. We started from the most recently collected dataset from Western Australia, by converting them to the so called 'miniseed' format, following broadly accepted seismological standards in data and metadata managing. We created a user-friendly internet-based acquisition tool and are now making progress towards converting the data from our past experiments into the established database scheme. We purchased more than 8 Tb of new disk space, that should be helpful in achieving these goals (Thanks Ross for your contribution!). A remaining challenge is to create metadata files, compatible with the world standards, from past seismological experiments.

Enhanced infrasound monitoring stations for CTBT verification

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The signing of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) on 24 September 1996 has led to a rapid development in infrasound monitoring technology for Treaty verification. A 60-station global infrasound monitoring network is under construction and nearing completion. This network is designed to reliably detect infrasonic signals from a 1-kiloton atmospheric nuclear explosion at two network stations. Global three-station detection capability is desirable since this would greatly enhance network reliability, lower detection thresholds and improve location estimates. Work carried out at the ANU during the last year on monitoring array design and background noise suppression suggests that the performance and reliability of the infrasound component of the International Monitoring System (IMS) can be enhanced considerably.

A detailed investigation of the spatial correlation of infrasonic signals from distant explosions has shown that the low degree of signal correlation between elements in many existing monitoring arrays may limit detection capability for regional and distant explosions. A new technique based on the Mack and Flinn coherence model has been developed to calculate the complete azimuthal variation of the array-averaged correlation coefficient for arbitrary array configurations. This azimuthal pattern provides a unique array characteristic that can be used directly as a measure of array performance. This technique has been applied to a wide variety of arrays, ranging from 3 to 9-element arrays, in an attempt to find an optimal design for an IMS infrasound monitoring array. The results of this investigation show that the detection capability of IMS stations with a small number of array elements for distant explosions may be marginal when the array aperture exceeds 1 kilometer. These studies also show that the performance of many existing 7- and 8-element arrays in the IMS is not optimal. The performance of these arrays decreases rapidly at high frequencies and the sensitivity may exhibit significant azimuthal variation in the monitoring passband. A careful examination of a large number of possible array configurations shows that an optimal array for nuclear explosion monitoring can be achieved by using a 9-element array configuration arranged in the form of a small aperture (350 m) centered triangle sub-array located at the center of a larger aperture (1 km) pentagon array. This array design is recommended for future use at IMS infrasound monitoring stations.

Wind-generated noise in the primary monitoring passband (0.4 to 1.2 Hz) is a serious problem at many infrasound stations. Stations located in open exposed areas are often subject to unacceptably high levels of background noise. Currently used wind-noise-reducing pipe arrays provide a significant reduction in background noise levels, but the degree of wind-noise-reduction may not meet CTBT verification requirements, especially during the daytime when the boundary layer winds are coupled to the surface. In order to meet essential monitoring requirements, wind-noise-reducing systems need to provide at least two orders of magnitude reduction over that provided by currently used pipe array systems. We have therefore developed a new wind-noise-reducing system that is capable of effectively eliminating wind noise in the monitoring passband at most infrasound monitoring stations. This system is based on the use of a series of screens which effectively degrade turbulent eddies and lift the turbulent boundary layer over the sensor inlets. This device is referred to as a turbulence-reducing enclosure. A large number of designs have been tested. Initially, these enclosures were constructed as open enclosures with concentric porous walls with overlapping deep serrations along the top of each wall inclined away from the center of the enclosure. These structures provided more than two orders of magnitude noise reduction. Thus, these structures may be used in some cases with existing pipe arrays to achieve acceptable background noise levels. The latest version of the noise-reducing enclosure is, however, much more efficient. This version is constructed in the

form of a closed enclosure with a porous screened roof, internal baffles, and multiple interior chambers. This highly efficient noise-reducing system has been tested with both a small 6-port pipe array and with a single-inlet port system located at the center of the enclosure. This system provides more than 4 orders of magnitude noise reduction (see Figure 1) in winds of up to at least 6 m/s at a height of 2 m above the surface. It is interesting to note that the single inlet port system is more efficient than the 6-port pipe array at frequencies above 0.7 Hz. This new system can therefore be used in some cases as a stand-alone system that does not require a pipe array. We recommend, however, that this new noise-reducing system should be used at IMS stations in conjunction with existing pipe arrays in order to completely eliminate wind-generated background noise in the monitoring passband.

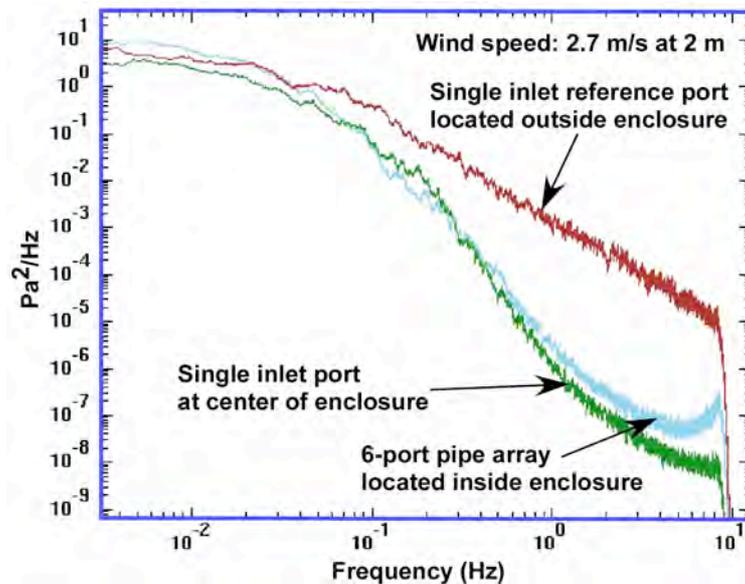


Figure 1. Power spectral density of background noise data recorded simultaneously inside and outside a turbulence-reducing-enclosure during typical daytime wind conditions at IMS monitoring station IS07 Warramunga.

Geophysical Applications of Interferometric Synthetic Aperture Radar

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² *Geoscience Australia*

Interferometric Synthetic Aperture Radar (InSAR) is a high resolution imaging technique. InSAR is used to both estimate surface topography and precise temporal surface deformation from satellite observations.

Our research has focused on temporal image stacking applied to the observation of 'slow' (~1mm/yr) deformation processes and the application of new modelling techniques to regions where InSAR is known to not work as effectively, including humid, heavily vegetated regions, and areas with significant agricultural activity. The principal motivation and contribution of our research is to: a) demonstrate, 'tune' and develop new temporal InSAR analysis techniques, for the observation of 'slow' geophysical deformation phenomena in InSAR-adverse regions; and b) improve the accuracy, precision and computational efficiency of these techniques.

We have made the first InSAR observations of coseismic deformation on the Australian continent, including magnitude 4.4 and 4.8 earthquakes in the South West Seismic Zone of Western Australia (Fig. 1). We have also tested the new ALOS PALSAR sensor, launched in 2006, for characterizing topography and surface deformation (Fig. 2). Our research will now focus on quantifying the spatial and temporal deformation of the Perth basin, associated with ground water extraction.

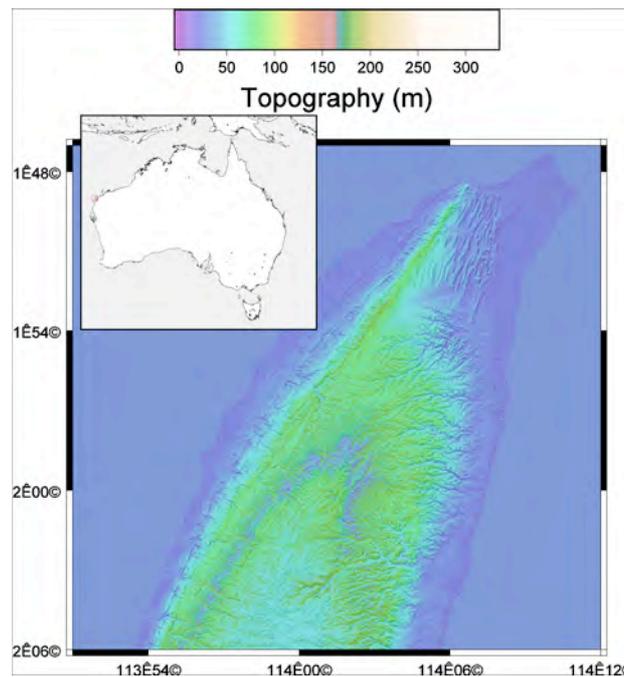


Figure 2. Topography estimated from ALOS PALSAR observations. Resolution is 15 metres.

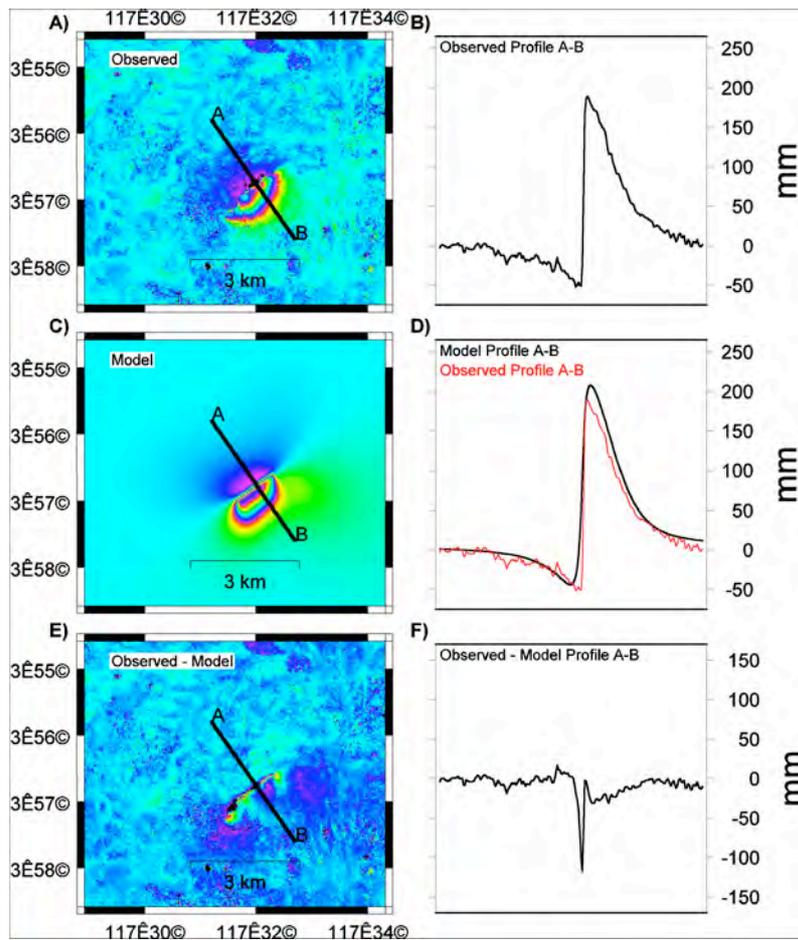


Figure 1. Magnitude 4.8, 10/10/2007 Katanning, Western Australia, earthquake: observed and modelled (L-Band) interferograms. Each fringe (or full color cycle) represents the line-of-sight range change of one half of the radar instrument wavelength (i.e. 0.118 m), the wavelength of the ALOS PALSAR instrument was 0.236 m. The ascending pass line-of-sight (target to satellite) unit vector was -0.596 , -0.139 , 0.792 in the east, north and up components respectively. A) Observed interferogram. B) Computed line-of-sight deformation along profile A-B. C) Modelled interferogram. D) Modelled line-of-sight deformation along profile A-B (observed repeated in red). E) Observed minus modelled interferogram. F) Observed minus modelled along profile A-B.

Uplift of the Catania Coastline Constrained by Submerged Speleothems and Archaeological Evidence

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³ ENEA - Special Project Global Change, Rome, Italy

We have established the rate of uplift along the Catania coastline (southeast Sicily, Italy) over the last glacial-interglacial cycle using U-series ages of submerged speleothems and archaeological evidence from the late Holocene for sea level position. The precisely determined ages of these sea level benchmarks were compared with the expected relative sea level position based on glacio-hydro-isostatic modeling to assess the rate of uplift in this region.

Siculo-Calabrian rift zone is coupled with strong regional uplift of Calabria and northeastern Sicily, which progressively decreases toward the north and the south, spectacularly documented by flights of marine terraces developed along the coasts. The region chosen for this study is the Augusta-Siracusa area, which is located at the southern tip of the Siculo-Calabrian rift zone.



Submerged speleothems have been collected from a range of depths between 17 and 36m below sea level. The age of speleothem calcification has been determined to constrain periods of time when sea level was below the elevation of these respective caves. These ages were determined using U-Th dating of speleothem calcite using a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). An example is shown in Figure 1, which displays the growth history of one of the speleothems recovered from a submerged cave in the Siracusa region.

When combined with the age of various archaeological sites that have been recently described and characterized in terms of their functional position relative to sea level (Scicchitano et al., submitted) these data collectively define a very low rate of uplift along this portion of the Sicilian coastline. This interpretation rests on the observation that all of the aforementioned benchmarks for sea level fall above the predicted elevation of sea level for this area determined from glacio-hydro-isostatic modeling.

Figure 1.

Scicchitano, G, Antonioli, F, Berlinghieri, EFC, Dutton, A, Monaco, C (submitted) Submerged archaeological sites along the Ionian coast of south-eastern Sicily (Italy) and implications with the relative sea level change during the late Holocene, *Quaternary Research*

Projected sea-level changes from glacier melt in the 21st century

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The IPCC (2001) report estimates a global sea-level rise of between 0.11 to 0.77 m by the end of this century, a substantial part (between 0.05 and 0.11 m) will come from mountain glaciers. The latest IPCC (2007) report further notes that the melting of mountain glaciers will be a major contributor to sea-level rise for the rest of this century. For future projections, in particular, it becomes important to know how much ice is stored in mountain glaciers at present. Raper and Braithwaite (2005) estimated the potential sea-level rise from land based ice based on the areas of glaciers and ice caps of 522,000 km², not including glaciers at the periphery of the Antarctic and Greenland ice sheets. Their relationship between changes in area and volume of glaciers consequently results in an ice mass in glaciers and ice caps of 88,000 km³ equivalent water. In total, this means that glaciers and ice caps have the potential to contribute 0.241±0.026 m to global sea-level rise, 41% from glaciers and 59% from ice caps.

A seasonally and regionally differentiated numerical model of mountain deglaciation has been developed which reproduces the observational estimates for the recent past very well (see Figure 1) and can therefore be used to make projections for future ice-volume changes. This approach needs to be treated with caution, in particular since (i) glacier-area changes with time and (ii) dynamic changes are not included. These effects operate in different directions but it is difficult to estimate the extent to which they cancel each other out. Order of magnitude estimates for (i) can be calculated for individual glaciers assuming the area-volume relationship of Chen and Ohmura (1990). For example, a glacier at the Seward Peninsula (Alaska) with an average ice-volume loss of 0.0079 km³ year⁻¹ w.e. over the first decade of the 21st century and an initial area of 10 km² would be gone by 2050. A glacier in the St. Elias Mountains (Alaska) with an average ice-volume loss of 0.0541 km³ year⁻¹ w.e. within the period 2000-2010 and an area of 100 km² would just make it to 2100. The predicted ice-volume loss at the Svalbard Archipelago of 0.0033 km³ year⁻¹ w.e. means that glaciers with an area smaller than 10 km² are unlikely to survive the 21st century.

In summary, glaciers of the order of a few hundred km² are likely to survive this century, while all smaller glaciers will probably disappear by 2100 or earlier at the current melting rate predicted with the numerical model. Two estimates of global cumulative ice-volume changes within the 21st century determined by the numerical model are shown in Figure 1. In total, ice-volume changes equivalent to a eustatic sea-level rise of between 146 and 162 mm over the period 2000-2100 are determined. This indicates that over 60% of the total ice mass of mountain glaciers is gone by 2100 based on the estimate of current glacier mass by Raper and Braithwaite (2005) of 241±26 mm w.e..

Figure 2 shows the spatial distribution of ice-volume loss over the 21st century predicted by the numerical model. According to this result, northwest America, central Asia, and northeast America are the biggest contributors to the total, accounting for 33%, 28%, and 14%, respectively. Glaciers on the archipelago of Svalbard alone contribute almost 4%.

On these regional scales the results of the numerical model only partly agree with other studies. These discrepancies reflect the problems of accurately estimating contributions to future global sea-level rise from continental ice-mass loss and identify particular areas for further study.

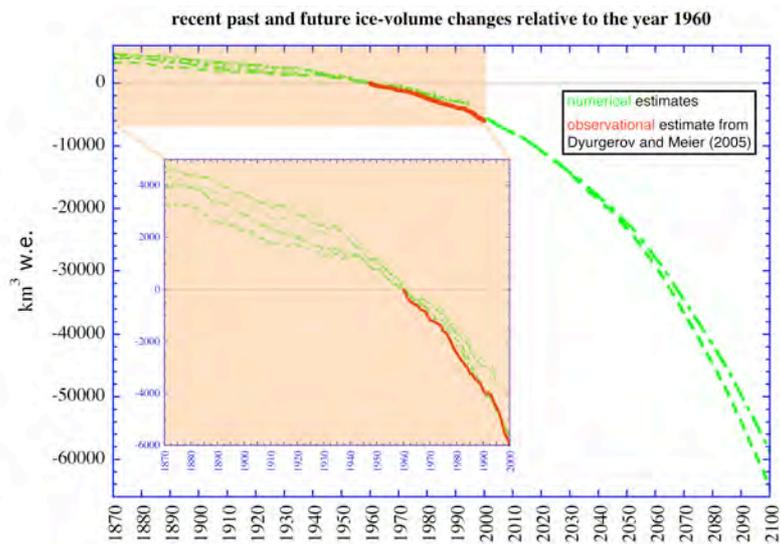


Figure 1.

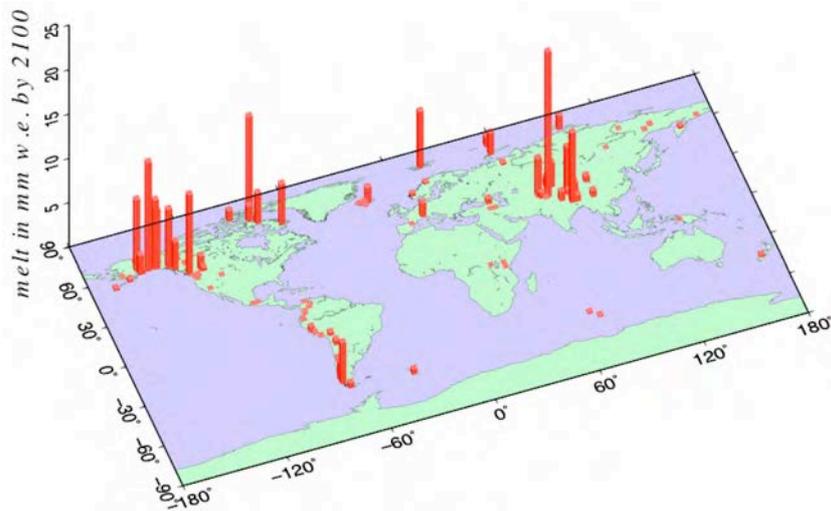


Figure 2.

Chen, J. and Ohmura, A. (1990). Estimation of alpine glaciers water resources and their change since the 1870s. In: Lang, H. and Musy, A., Editors, *Hydrology in Mountainous Regions. I. - Hydrological Measurements: The Water Cycle*, number 193, pages 127–135. IAHS Publications.

Dyurgerov, M. B. and Meier, M. F. (2005). *Glaciers and the changing Earth system: A 2004 snapshot*, Occasional Paper No. 58. Technical report, Institute of Arctic and Alpine Research, University of Colorado.

IPCC (2001): *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 892 pp.

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Raper, S. C. B. and Braithwaite, R. J. (2005). The potential for sea level rise: New estimates from glaciers and ice cap area and volume distribution. *Geophysical Research Letters*, 32(L05502).

Studies of water signals using space gravity data

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The Gravity Recovery and Climate Experiment (GRACE) space gravity mission was launched in 2002 and has had a profound effect on the detection and interpretation of changes in the Earth's gravity field. The temporal variations in the Earth's gravity field induce changes in the distance between the two GRACE satellites. Such gravity changes can be caused by hydrologic signals, glacial isostatic adjustment, oceanic phenomena as well as changes in the cryosphere – both melting and accumulation. The interpretation of the observed changes requires that the changes be correctly associated with one of many geophysical processes that may cause such effects.

Analysis of GRACE data at RSES commenced in 2007, with a 3 month visit of Dr G. Ramillien (CNRS, Toulouse, France), a 6 month Advanced Studies Course project by PhB student Jennifer Zhu, a 6 month research project by MSc student Nick Brown. To assess the accuracy of GRACE estimates, a study of mass variations in the Gulf of Carpentaria was undertaken, a zone where there is a non-gravitational variation in sea surface height of ~ 0.5 m with an annual period. Tide gauge measurements at Groote Eyreland provide an independent estimate of sea surface height variations against which the GRACE estimates were validated. SSH variations from the GRACE solutions of the Groupe de Recherche en Géodésie Spatiale were found to match well the tide gauge records in both phase and amplitude, thus demonstrating that the analysis of GRACE data in the Australian region holds considerable – yet unexploited – potential for investigating variations in water – in particular groundwater – in Australia.

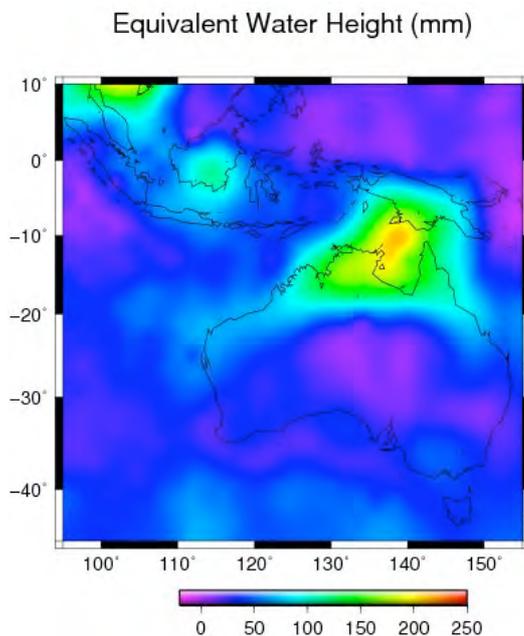


Figure 1. Amplitude of annual variations in mass in the Australian region (expressed in terms of mm of equivalent water height) as estimated from 5 years of GRACE observations.

Mantle Evolution: Integrating Dynamics, Chemistry and Tectonics

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The mantle may have undergone episodic layering punctuated by dramatic overturns that would have been major magmatic and tectonic events, according to new results of numerical modelling of evolving mantle dynamics incorporating a "basalt barrier" mechanism. The overturns died out after 1.5-1.8 Ga in the models because tectonic plates become thicker and heavier as the mantle cools. The overturn events may be recorded in the D" region of the bottom of the mantle by trace element and isotope signatures of the mantle melting that would have accompanied the overturns. It is possible that overturn events like these could account for the continental crust having been formed in bursts rather than continuously. During an overturn hotter and more fertile material from the lower mantle floods into the upper mantle and generates enough primary melt to resurface the Earth to a depth of 10 km in basaltic lava flows.

The new results were obtained in the continuation of a project using numerical modelling to understand the dynamics of the early mantle. The mantle controls surface tectonics and the present geochemistry of the mantle. Previously we have reported how models of this type, in both two and three dimensions, can account for geochemical observations of mantle heterogeneity, stratification and an apparent age of around 1.8 Ga. The new models extend previous models by computing the complete evolution of the models over the age of the Earth, with declining internal radioactive heating and by incorporating the basalt barrier. The barrier occurs because subducted oceanic crust is expected, on the basis of laboratory experiments, to be buoyant just below the mantle transition zone at 660 km, down to a depth of about 750 km.

The new results raise the prospect of a single mantle model being able to explain tectonic history and the present chemical and physical structure of the mantle, even including the noble gases, which have been quite enigmatic. Until now it has not been clear how all of the relevant observations might be reconciled.

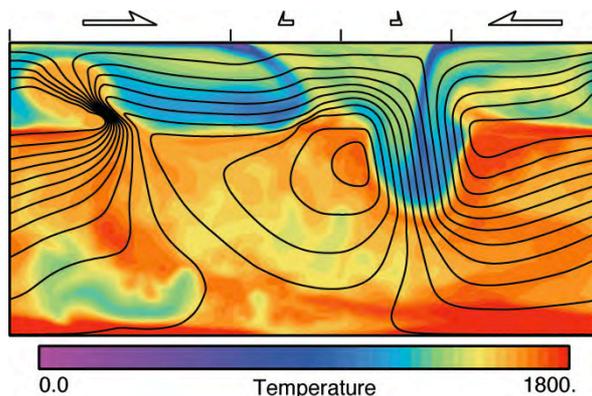


Figure 1. The beginning of a mantle overturn, in which cold upper-mantle material sinks into the lower mantle (right), while hotter material from the lower mantle rises into to upper mantle (left).

Huang, J. and Davies, G. F., Stirring in three-dimensional mantle convection models and its implications for geochemistry: Passive tracers, *Geochem. Geophys. Geosystems*, 8, 17 pp, doi:10.1029/2006GC001312 (2007).

Davies, G. F., Controls on density stratification in the early mantle, *Geochem. Geophys. Geosystems*, 8, 17 pp, doi:10.1029/2006GC001414 (2007).

Huang, J. and Davies, G. F., Stirring in three-dimensional mantle convection models and its implications for geochemistry II: Heavy tracers, *Geochem. Geophys. Geosystems*, 8, 15 pp, doi:10.1029/2007GC001621 (2007).

Davies, G. F., Episodic layering of the early mantle by the 'basalt barrier' mechanism: implications for tectonic and geochemical evolution, submitted, *Geochem. Geophys. Geosystems* (2007).

Exchange flows between ocean basins

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Ocean straits and sills act as valves that control the rate of transport of water around the deep oceans and flow between shallow seas and the oceans. The transport commonly occurs through straits and over bottom sills, such as the Denmark Strait between the Arctic and North Atlantic Oceans, or a host of channels and sills through the mid-ocean ridges connecting abyssal basins. The exchange flows involve strong velocity and density gradients between the water flowing in different directions, and the flow becomes turbulent. Using laboratory experiments we have measured both the amount of mixing that occurs and the rate at which water is exchanged.

This year we have clarified the effects of different geometries, such as short or long straits, and straits with sills. Mixing in the flow reduces the exchange rate by approximately 16% relative to that predicted by inviscid hydraulic theory. Friction leads to a further reduction that depends on the length of the channel. However, our main focus is the mixing, which we describe in terms of a mixing efficiency. The mixing efficiency is defined as the proportion of the available potential energy released by the flow that is used to raise the centre of mass by vertical mixing, and is independent of whether the strait is narrow or wide, or short or long. For large Reynolds numbers the mixing efficiency takes a constant value of $11 \pm 1\%$. The mixing is also only weakly dependent on the presence of a smooth sill or a steep-sided ridge, the smallest value measured being 8.4% when there is a sill with gently sloping sides (figure 1).

These measurements are in agreement with our scaling theories that predict both the observed exchange rate and the mixing efficiency. We expect these results will be useful in estimating the contribution of exchange flows to the total interior mixing in the oceans.

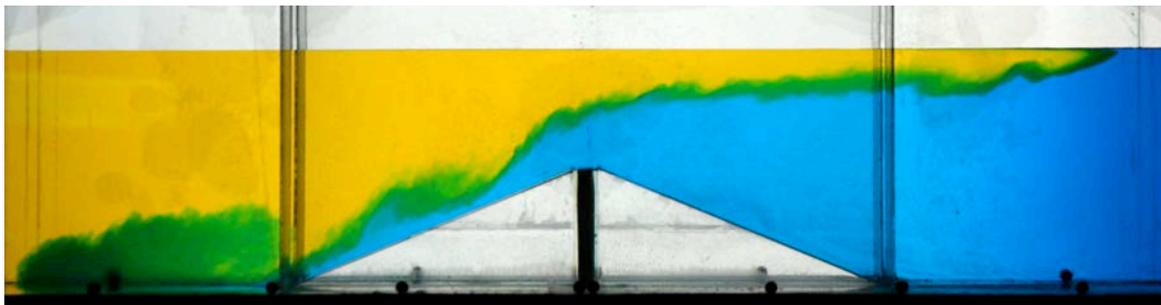


Figure 1. Exchange flow over a sill in the laboratory, showing shear instability and mixing.

Prastowo, T. J., Griffiths, R. W., Hughes, G. O. and Hogg, A. McC. (2007) Mixing efficiency in controlled flows. *J. Fluid Mech.*, submitted.

Glacial Cycles and Carbon Dioxide

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The earth's climate over the last million years is punctuated by a 100,000 year cycle of ice ages and warm interglacials. Air temperature over Antarctica, as determined from ice core data, goes through four glacial cycles in the past 430,000 years (see Fig. 1a; reproduced from Petit et al. 1999). At the end of each glaciation temperature increases rapidly, as does CO₂, producing a sawtooth pattern.

The role of CO₂ in the glacial cycle has been the source of much misinformation in recent public debate on climate change, largely because there is no scientific consensus on the mechanism controlling glacial cycles. Here I propose a simple model which predicts the evolution of global temperature and carbon dioxide over the glacial-interglacial cycle. In this model, CO₂ acts to amplify, but not trigger, the glacial cycle. Deglaciation is triggered by variation in the earth's orbit; thus, temperature rises lead CO₂ increases at the end of glaciation, but it is the feedback between these two quantities that drives the abrupt warming during the transition from glacial to interglacial periods (shown in Fig. 1b).

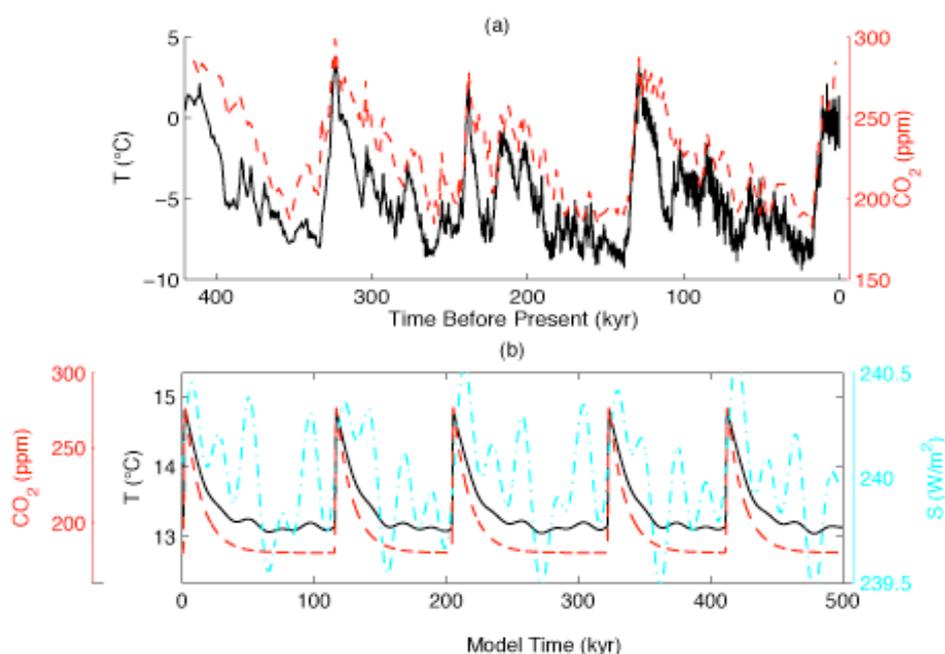


Figure 1. (a) Observed records of Antarctic temperature and CO₂ over the last 400,000 years. (b) Modelled insolation, global temperature and CO₂.

Modelling the sensitivity of the ocean thermohaline circulation to changing forcing

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Oceanographers have been examining the question of whether the overturning circulation of the oceans will change in response to global warming, with consequent feedbacks to climate. A particular concern is a potential shut-down of the deep sinking leg of the circulation.

We have modelled the adjustment of a convective circulation to changing surface boundary conditions, such as atmospheric warming or increased freshwater inflow in high latitude oceans. In experiments such a circulation was brought to its equilibrium (balanced) state and then the surface boundary conditions were changed. This disturbs the fine balance within the circulation and causes one of two dramatic responses in the flow. Increased surface cooling rapidly leads to a large increase in the rate of overturning, followed by an exponential decay toward a new finely balanced state similar to the initial state. The measured exponential timescale is easily predicted from a simple theory.

On the other hand, a surface warming can lead to a shutdown of the deep sinking and the circulation quickly becomes confined to a shallow upper ocean layer. The shallow overturning is temporary, and a full-depth overturning circulation comparable to the initial state is eventually restored. A new theoretical solution for the equilibrium state (Hughes *et al.* 2007) helps us to understand the surface changes that will lead to shut-down. The results are consistent with the effects of increased melt water input, published last year, which indicated that shut-down can occur with a 4% change in the surface buoyancy forcing.



Figure 1. A photograph of dye in the convective overturning when a larger polar cooling flux is applied to the right hand quarter of the upper surface, a weaker polar cooling flux is applied to the left hand quarter of the surface, and the equatorial region is heated such that there is no net heat input. The blue dye reveals a weaker sinking and shallow circulation while the red dye shows a strong full-depth overturning. The blue-dyed water is also entrained into the stronger plume and cycled throughout the box.

We have also shown this year that the circulation is sensitive to the relative fluxes in northern and southern hemisphere sinking regions. These regions generate waters of different density (the Antarctic Bottom Water and North Atlantic Deep Water) and a few percent change in the density or volume flux in one relative to the other can lead to a substantial modification of both the patterns of ventilation in the deep circulation and cross-equatorial transport in the upper ocean (figure 2). We have undertaken a review of the physics governing horizontal convection (Hughes and Griffiths, 2008) and are currently studying the role of flows between ocean basins, which occur through straits and over sills, in controlling the rate of overturning.



Figure 2. The stream function from a numerical simulation of the experiment in figure 1. The black contour lines represent streamlines of the flow; close contour lines mean faster flow velocities.

Hughes, G.O., Griffiths, R.W., Mullarney, J.C. and Peterson, W.H. (2007) A theoretical model for horizontal convection at large Rayleigh number. *J. Fluid Mech.* 581, 251–276.

Hughes, G.O. and Griffiths, R.W. (2008) Horizontal convection. *Annu. Rev. Fluid Mech.* 40, in press.

The stability of strongly tilted mantle plume tails

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Mantle plumes are produced by heat conducted into the Earth's mantle from the underlying core. This heating forms a thermal boundary layer of hot, low viscosity fluid, which focuses into narrow plumes that rise through the mantle. At the Earth's surface, partial melting of the plumes produces flood basalts from plume heads and volcanic island chains from plume tails.

As plume tails rise through the mantle, they are deflected by large-scale convection driven by the subduction of cold lithospheric plates. The behaviour of these plume tails was first investigated in the laboratory by shearing compositional plumes (e.g. Whitehead, 1982; Richards and Griffiths, 1988). In these studies, the plume tails became gravitationally unstable if their angle to the horizontal became less than a critical angle. However, in subsequent laboratory experiments with sheared thermal plumes (Richards and Griffiths, 1989; Kerr and Mériaux, 2004), this gravitational instability has never been seen, even when the plumes were deflected to almost horizontal orientations.

To examine whether this contrasting behaviour is due to diffusion, we have investigated theoretically and experimentally the gravitational stability of a horizontal cylindrical region of buoyant fluid. At low Reynolds numbers and large viscosity ratios, the convective flow depends on only one dimensionless parameter: the Péclet number Pe . We find that the flow is stable at small Pe (Figure 1), and unstable to gravitational instability at large Pe (Figure 2). The critical Péclet number is about 140. These results explain the stability of the sheared thermal plume experiments of Richards and Griffiths (1989) and Kerr and Mériaux (2004). The results also predict that sheared thermal plume tails are gravitationally stable in both the upper and lower mantle.

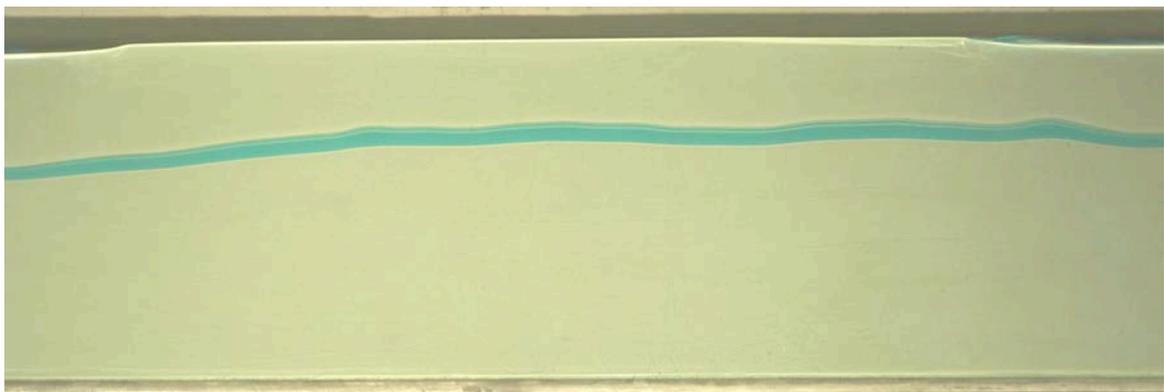


Figure 1. A stable rising cylinder of buoyant fluid, at $Pe = 82.5$.

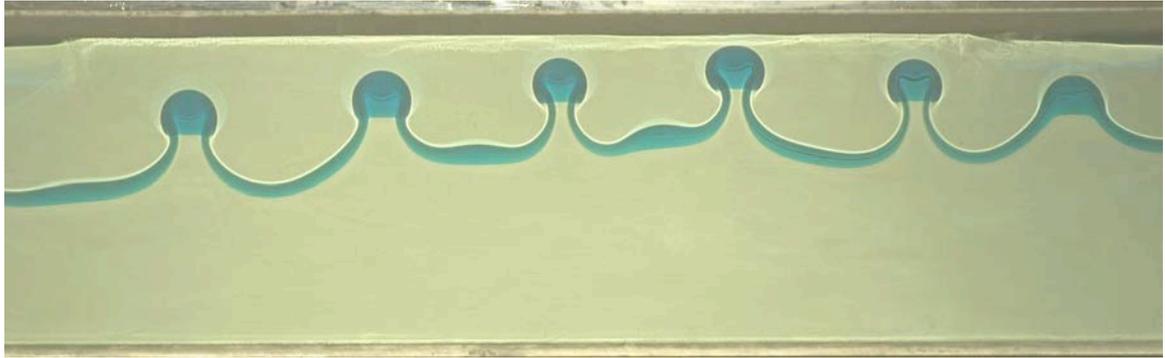


Figure 2. Gravitational instability of a rising cylinder of buoyant fluid, at $Pe = 533$.

- Kerr RC, Mériaux C (2004) Structure and dynamics of sheared mantle plumes. *Geochemistry Geophysics Geosystems* 5: Q12009, doi:10.1029/2004GC000749
- Richards MA, Griffiths RW (1988) Deflection of plumes by mantle shear flow: experimental results and a simple theory. *Geophysical Journal* 94: 367-37
- Richards, MA, Griffiths RW (1989) Thermal entrainment by deflected mantle plumes. *Nature* 342: 900-902
- Whitehead JA (1982) Instabilities of fluid conduits in a flowing earth - are plates lubricated by the asthenosphere? *Geophysical Journal of the Royal astronomical Society*. 70: 415-433

Effects of upstream disturbances on headland wakes in coastal waters

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² *School of Mathematics, University of New South Wales, Sydney, NSW 2052, Australia*

Wakes are important features in the coastal environment. Flows around islands and headlands bring nutrients up from deeper waters, influence the distribution of sediments and provide favourable environments for marine biota. These flows also affect pollutant dispersal and must be considered in offshore disposal strategies. While many wake studies have assumed a smooth steady oncoming flow, Nature provides a more complex flow that often contains eddies and turbulence from other topographic features upstream. These may alter the size and stability of the wake, along with rates of exchange between the wake and the surrounding water.

We have modelled headland wakes, with and without disturbances carried from upstream, using a 3-metre flume and ultrasonic Doppler velocity measurements. A surprising finding is that over a range of conditions, the disturbance to the upstream flow results in a wake that both contains weaker eddies overall and decays more rapidly with distance downstream of the headland (figure 1). Incident disturbances modify the stability of the shear at the edge of the wake and partially suppress the formation of coherent eddy structures in the lee of the headland. The kinetic energy in the region of the wake close to the headland is distributed over a greater spanwise extent and a broader range of (eddy) frequencies, which results in a more rapid dissipation of the eddies with distance downstream. We are currently investigating the interactions of flow structures in the lee of the headland that facilitate this behaviour, and exploring more fully the range of conditions under which such interactions occur.

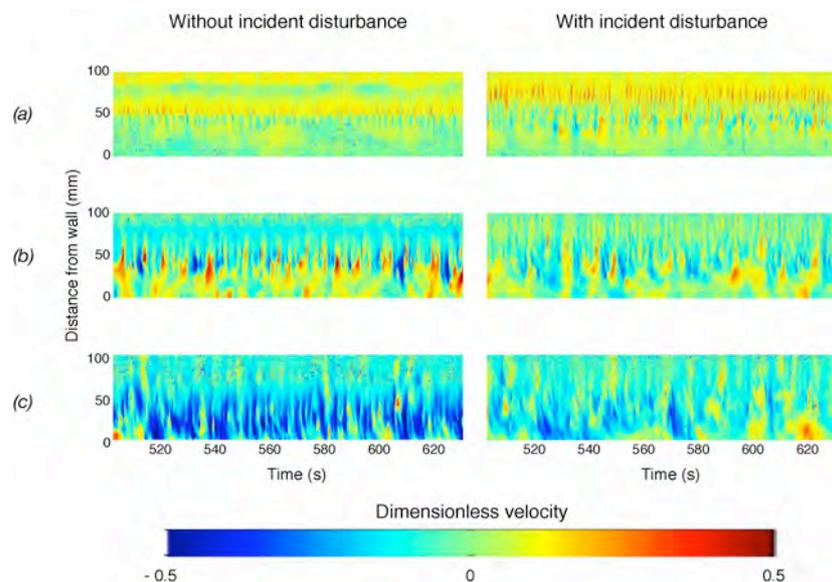


Figure 1. Cross-stream velocities without and with an incident disturbance, measured across the headland wake at (a) just behind the headland, (b) one headland diameter downstream and (c) two diameters downstream. Note the rapid decay in velocity, and therefore kinetic energy, in the right column as you move downstream. (Velocities are normalised by the freestream velocity; positive velocities indicate motion away from the wall, negative indicates motion towards the wall).

Internal Activity and Evolution of Exoplanets

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More than 250 planets have been discovered orbiting other stars, and the smallest of these have masses about 5 times Earth's mass. The discovery of smaller and more Earth-like planets is anticipated over the next few years. Whether conditions on such planets might be suitable for life depends on many factors. The internal activity of the planet is one important factor, as volcanic activity is expected to strongly influence the composition of the atmosphere, which is a key component of the surface environment. Some spectroscopic information has already been obtained for an exoplanet and as such observations are accumulated the composition of their atmospheres will become clearer.

It is possible to calculate the expected level of mantle activity, and hence of tectonic activity, as a function of the planets' mass using already-published calculations of their internal structure, which controls mantle depth, gravity and other parameters. It is also possible to calculate an approximate internal thermal evolution using the 'parameterised convection' approximation that is well-established for Earth. We have calculated thermal evolutions for planets with Earth-like compositions and masses ranging from 0.1 to 10 Earth masses.

The Figure shows the rate at which mantle material is processed through melting zones near the surface, as this is a useful measure of the rate of interaction between the interior and the surface. The more massive planets are more active, though not drastically so, as the processing rates scale roughly in proportion to the mass. Even after 10 billion years planets of 5-10 Earth masses would have tectonic activity comparable to Earth's at present, whereas the smallest planet would be 10-100 times less active, as is true of Mars (0.12 Earth masses) in our solar system.

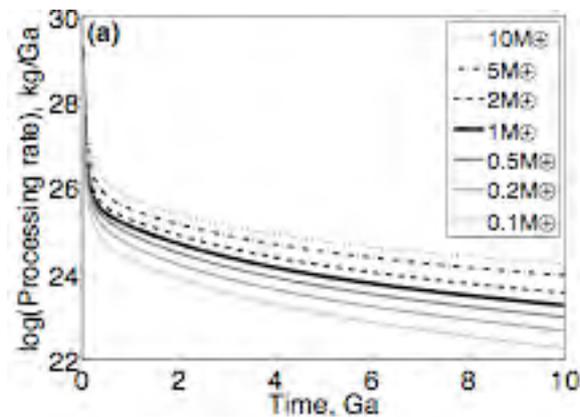


Figure 1.

Papuc, A. M. and Davies, G. F., The internal thermal evolution and activity of Earth-like planets, submitted, *Icarus* (2007).

Kinematics and flow patterns in deep mantle and upper mantle subduction models: Influence of the slab to mantle viscosity ratio and the mantle depth

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Subducting slabs are the primary driving force for plate tectonics and mantle convection on Earth. It has been found that subduction of oceanic lithosphere is accomplished not only by trenchward motion of the subducting plate but also by retrograde (oceanward) motion of the trench itself. On a global scale, trench retreat is responsible for about 1/4 of the total subduction rate [Schellart *et al.*, 2007], but it varies considerably for different subduction zones. This variety can be explained by the variety in slab widths observed on Earth [Schellart *et al.*, 2007], but the effect of each of these two modes on mantle flow patterns remains uncertain. Another uncertainty regards the magnitude of the slab/mantle effective viscosity ratio on Earth, and its influence on plate motion and trench migration.

In the last three years, three-dimensional fluid dynamic laboratory experiments have been conducted at RSES that investigated the subduction process in upper mantle models and deep mantle models for various subducting plate/mantle viscosity ratios ($h_{SP}/h_M = 59-1375$) [Schellart, in review]. The models were conducted to investigate the mantle flow field, geometrical evolution of the slab, sinking kinematics, and relative contributions of plate motion and trench migration to the total rate of subduction.

All models show that the subducting plate is always moving trench-ward due to slab pull. Furthermore, all deep mantle models show trench retreat, as do upper mantle models in the initial stage of subduction before slab tip-transition zone interaction. Upper mantle models with a low h_{SP}/h_M (66, 217) continue to show trench retreat after interaction. Upper mantle models with a high h_{SP}/h_M (378, 709) show a period of trench advance after interaction followed by trench retreat. Upper mantle models with a very high h_{SP}/h_M (1375) show continued trench advance after interaction.

The difference in trench migration behavior and associated slab geometries is attributed to both h_{SP}/h_M and the mantle depth to plate thickness ratio T_M/T_{SP} . Four subduction regimes are defined: Regime I with trench retreat, slab draping and a concave trench; Regime II with episodic trench migration, slab folding and a concave trench; Regime III with trench advance, slab roll-over geometries and minor trench curvature; Regime IV with trench retreat, slab draping and a rectilinear trench. Trench retreat and rollback motion of the slab induce quasi-toroidal return flow around the lateral slab edges towards the mantle wedge. Rollback-induced poloidal flow around the slab tip is not observed (Fig. 1). Comparison between the upper mantle models and subduction zones in nature imply that the slab/mantle effective viscosity ratio in nature is less than 10^3 and of the order $1-7 \times 10^2$.

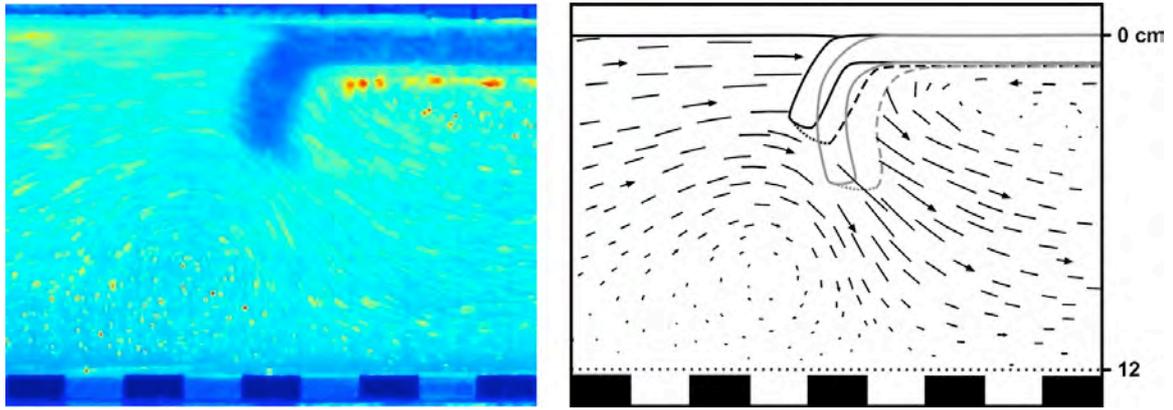


Figure 1. Side view of laboratory subduction model illustrating slab geometry and poloidal mantle flow patterns in the centre of the subduction zone. Left is composite photograph and right is interpretation.

Schellart, W.P., J. Freeman, D.R. Stegman, L. Moresi, and D. May, Evolution and diversity of subduction zones controlled by slab width, *Nature* 446, 308-311, 2007.
 Schellart, W.P., Kinematics and flow patterns in whole mantle and upper mantle subduction models: Influence of the slab to mantle viscosity ratio, *Geochemistry Geophysics Geosystems*, in review.

AuScope

RSES is taking a major role in Component 13 of the National Cooperative Research Infrastructure Strategy (NCRIS) "Structure and Evolution of the Australian Continent".

A company limited by guarantee, AuScope Ltd., has been established as the vehicle to administer the \$42.8M grant over 5 years. ANU was the first to sign the necessary agreements. RSES hosts activities in Earth Imaging with support of portable instrumentation and transects, Geospatial with gravity measurements and testing of portable equipment for satellite laser ranging, and Simulation & Modelling with continuing of pPlates software for tectonic reconstruction. As a linked activity between Imaging, Geospatial and the AuScope grid, the Terrawulf II cluster computer has been installed at RSES to provide capability in geophysical inversion.

In July, AuScope funds supported the first work on transects with 200 km of reflection profile supplementing 1200 km of work undertaken by Geoscience Australia and the Geological Survey of Queensland. This transect provides 3-D control on the nature of the Tasman Line in north Queensland.

Tomography with self adaptive parametrisation

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In standard tomography, the model is parametrized by a uniform grid. The inversion process consists of finding the velocity for each cell. The problem is often weakly non-linear and an iterative linearised inversion technique is commonly used. We have developed a method which uses voronoi cells instead of a regular mesh for the parametrization. The voronoi cells are defined by their centres which are able to move. That is, the position of each cell defining the velocity model becomes an unknown to be inverted for.

A Monte Carlo sampler has been implemented in a Bayesian context. At each step of the chain, a change from the current model is proposed: we either change the velocity or the position of one random cell. The forward problem is computed and provides new estimated travel times. The new misfit to observed travel times is compared to that of the current model. The proposed model is either accepted or rejected using a predefined probabilistic threshold.

Consequently, the chain samples the model space and converges towards models with improved data fit. The method takes as a solution the average of a family of models with satisfactory fit to the data. Each model in the family has a different parametrization but the average often looks smooth without obvious 'parametrization' artefacts. The standard deviation of the family forms a continuous map and can be used as a proxy for the error for the solution model. Note that this estimation of uncertainty is obtained without need of prior estimation of data noise.

We have been working on the optimisation of the algorithm so only a part of the full forward problem needs to be recomputed at each sample. This optimisation together with the computing power of the Terrawulf facility available at RSES (CADI) will enable us to use this technique of parameter search on tomography problems with a larger number of unknowns.

The method has been tested on synthetic situations where the ray coverage is not uniform and where the parametrisation is an issue. One advantage is that the method does not need to use any regularisation. The results look better than when a standard method is used. This new approach can be viewed as a 'self regularizing approach'. The technique has also been tested on real data and gives promising results.

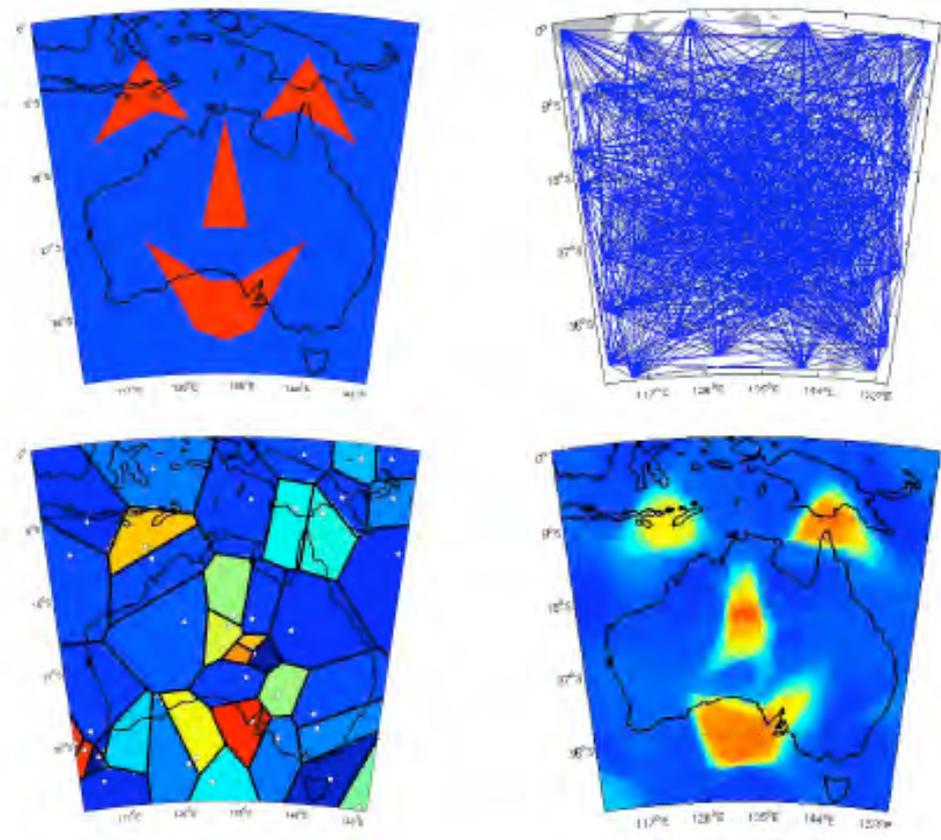


Figure 1: Upper left map shows the true model. The upper right map shows the ray geometry. The lower left map shows the model sampled with the best fit to the data and the lower right map shows the average estimated solution.

Imaging seismic discontinuities of the lithosphere beneath Southern Australia

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We are determining the variation in crustal and lithospheric thickness through exploitation of recordings of distant earthquakes in a corridor extending from the Curnamona craton to the east coast of Australia, crossing the transition from Precambrian to Phanerozoic belts. We use the data recorded by recent broad-band deployments (Figure 1) that we realized in Southern Australia: MT GAMBIER (2005-2006), MBALE and SOC (2007-2008). Receiver functions are time series obtained from three-component seismograms by deconvolving one component with respect to another to remove common contributions acquired well away from the seismic receiver. The *P* receiver functions technique uses the radial component along the great-circle between source and receiver deconvolved with the vertical component. An example of *P* receiver function is shown in Figure 2. We are using an inversion method, the neighbourhood algorithm (Sambridge, 1999), to determine the crust and upper mantle structure that can explain the observed receiver function (Figure 3).

The *S* receiver function technique recently developed by Farra and Vinnik (2000) uses the seismic phases converted from *S* to *P* at the seismic discontinuity beneath the stations to map the depths of seismic transitions. The research team at the GFZ Potsdam has associated a seismic discontinuity mapped from *S* receiver function studies with the base of the lithosphere in several regions of the world, for instance in the vicinity of Hawaii (Li et al. 2004). We are combining in Southern Australia the *S* receiver functions with the more conventional *P* receiver functions technique that can exploit shorter periods and provide a good determination of the Moho topography. We are working on improving the *S* receiver functions technique by taking into account the anisotropy beneath the receiver.

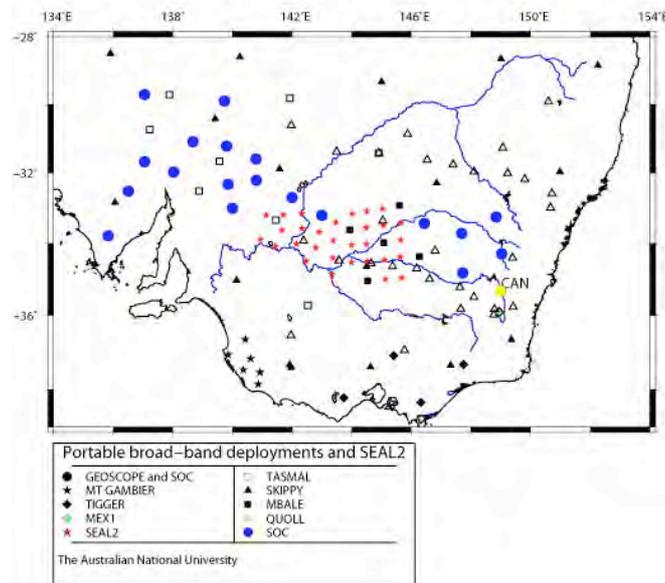


Figure 1. Map of recent deployments in South Australia.

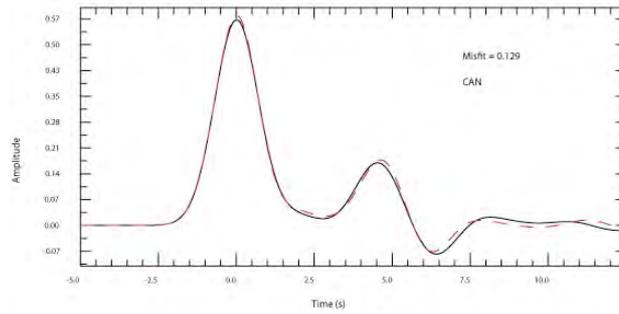


Figure 2. Example of observed (solid line) and predicted (dashed line) receiver functions obtained at Canberra.

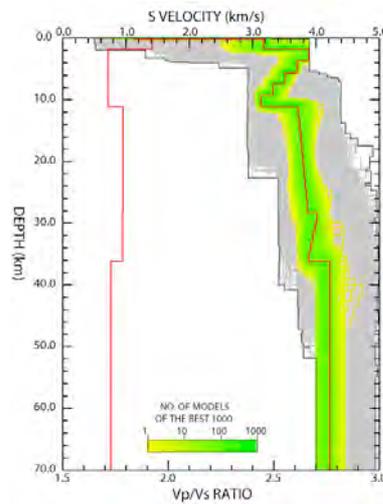


Figure 3. Seismic velocity profile obtained with the neighbourhood algorithm for Canberra.

- Farra V and Vinnik L (2000) Upper mantle stratification by P and S receiver functions. *Geophys. J. Int.* 141:699-712
- Li X, Kind R, Yuan X, Wölbern I, Hanka W (2004). Rejuvenation of the lithosphere by the Hawaiian plume. *Nature* 427:827-829
- Sambridge M S, (1999) Geophysical inversion with a neighbourhood algorithm. I. Searching a parameter space. *Geophys. J. Int.* 138:479-494

Multi arrival wavefront tracking in three dimensions

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The traditional focus in seismology has been on the first arrivals of wavefronts, despite the potential for a wavefront to triplicate if it propagates in the presence of velocity perturbations. This means that at a given receiver, one might observe several later arrivals. These later arrivals provide additional structural information, as they have taken different paths through the medium compared to the first arrivals.

The wavefront construction principle is used here as the basis of a new scheme for the computation of multi valued travel times that arise from smooth variations in velocity. The wavefront is represented as a set of nodes with a triangular topology. Local ray tracing can then be used to advance the wavefront in a series of discrete time steps. As the wavefront propagates nodes and hence triangles have to be added and removed from the wavefront in order to maintain a fixed density of points. Describing a surface with a given accuracy is a well-known problem in the field of computer graphics, where algorithms for surface refinement and simplification have been known for the last 25 years. The idea is therefore to use these methods together with a refinement and simplification criteria based on the phase space distance between nodes to maintain a given point density on the wavefront as it propagates.

A smoothed version of the SEG/EAGE salt dome model is used to test this new approach. The model consists of a plunging salt stock (see figure 1) surrounded by sand layers and lenses. The wave speed contrast between the salt and surrounding sediments is more than 30%. A source is placed above the salt stock and as the wavefront propagates it starts to triplicate once it reaches the salt sediment transition. Despite having smoothed the model the wavefront eventually becomes very complex with several smaller swallowtails superimposed on the major swallowtail (see figure 2). The swallowtails also start to intersect each other. The results show that the mesh refinement and simplification strategy chosen in this work can handle wavefronts which become far more complex than those computed with previous wavefront tracking techniques.

Potential applications of multi valued travel times include seismic tomography where later arrivals can provide additional constraints. Combining multi arrival wavefront tracking with the Gaussian beam method could also help to understand crustal multipathing of incoming teleseismic waves, which might be observed in receiver functions.

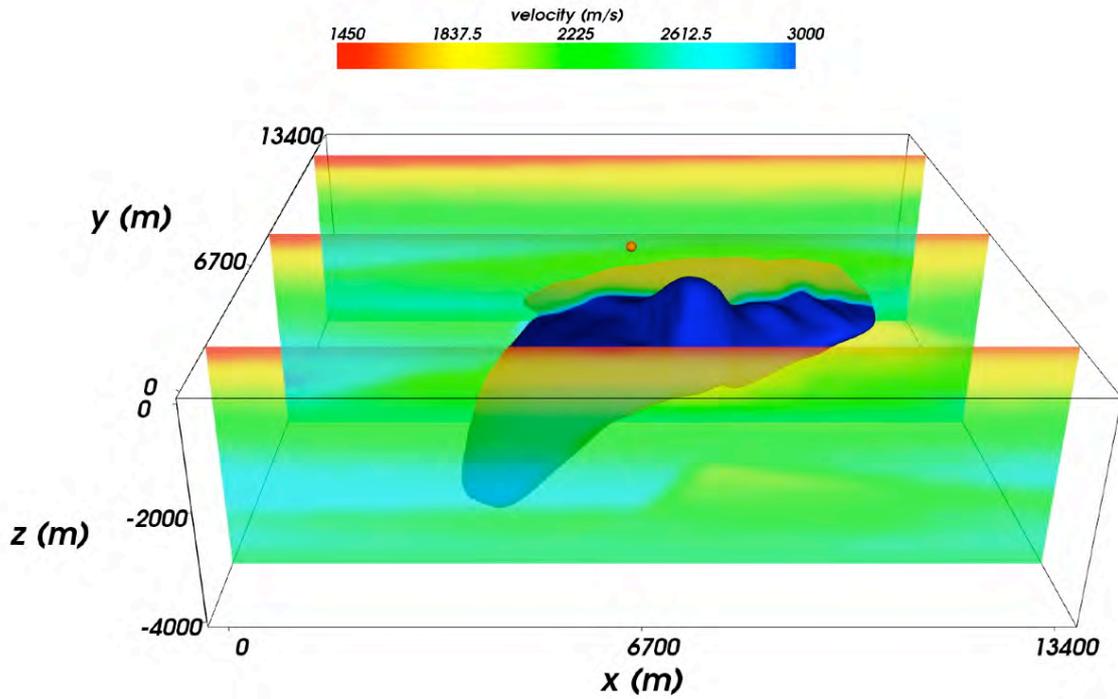


Figure 1. Slices through the smoothed version of the SEG/EAGE salt dome model. The 3000 m/s isosurface corresponds roughly to the boundary of the salt dome.

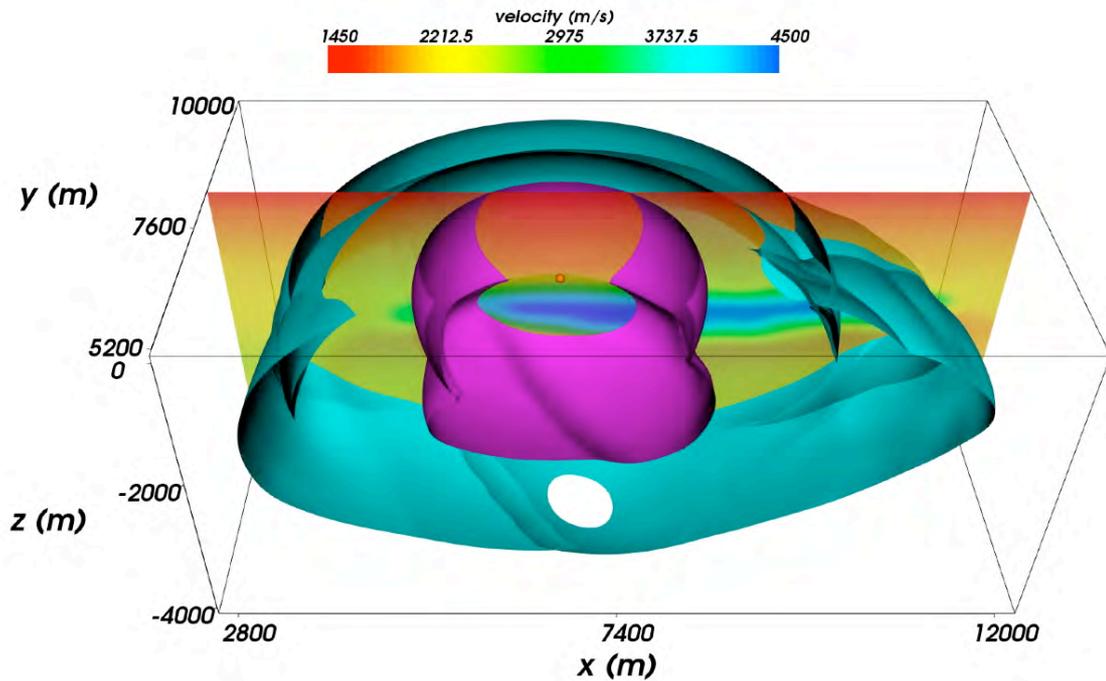


Figure 2. Two snapshots of the wavefront computed in the SEG/EAGE salt dome model. The orange sphere denotes the source location. The wavefront is plotted at 3.375 s (magenta) and 4.125 s (cyan). Part of the wavefront surface has been removed to facilitate visualisation.

WOMBAT: An evolving seismic array experiment in Australia

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Over the last decade, a rolling array of seismometers (known as WOMBAT – SE) has been sequentially deployed throughout southeast Australia to record passive seismic activity. To date, nearly 400 separate sites have been occupied with nominal station spacings of 40–50 km on the mainland and 15–20 km in Tasmania (see Figure 1). Deployment periods for each of the 10 arrays installed so far have varied between 4–10 months, and the number of simultaneously recording instruments has ranged between 20–80.

The majority of seismic sensors used have been vertical component short periods, although a number of arrays included a mix of short period and three component stations due to an upgrade of the short period seismometer pool. A long term goal of the WOMBAT experiment is to continue deploying stations throughout eastern Australia in order to achieve high density coverage of the Palaeozoic Orogens that underpin the Tasmanides.

The intra-plate location of the Australian land mass does not readily permit detailed seismic imaging with local earthquakes. However, the frequency and distribution of large earthquakes associated with the surrounding plate boundary regions makes teleseismic tomography an ideal tool for mapping the 3-D wavespeed structure of the crust and upper mantle beneath the seismic array cluster. So far, four separate teleseismic tomography studies have been published using data from different locations. These results have yielded valuable insight into the architecture of the Australian plate. For example, the possible presence of sizable fragments of Proterozoic continental lithosphere beneath the Paleozoic Lachlan Orogen in eastern Australia; and evidence of a diffuse mantle source for the late Tertiary and Quaternary volcanism in Victoria.

The sheer volume and diversity of passive seismic data recorded in southeast Australia by the rolling array of seismometers makes it a valuable resource for other classes of study, including ambient noise tomography, shallow receiver functions (using the three-component data), and array seismology (e.g. illumination of the core-mantle boundary). One current line of research aims to combine teleseismic data from all arrays in a single inversion for a unified image of the 3-D structure beneath southeast Australia.

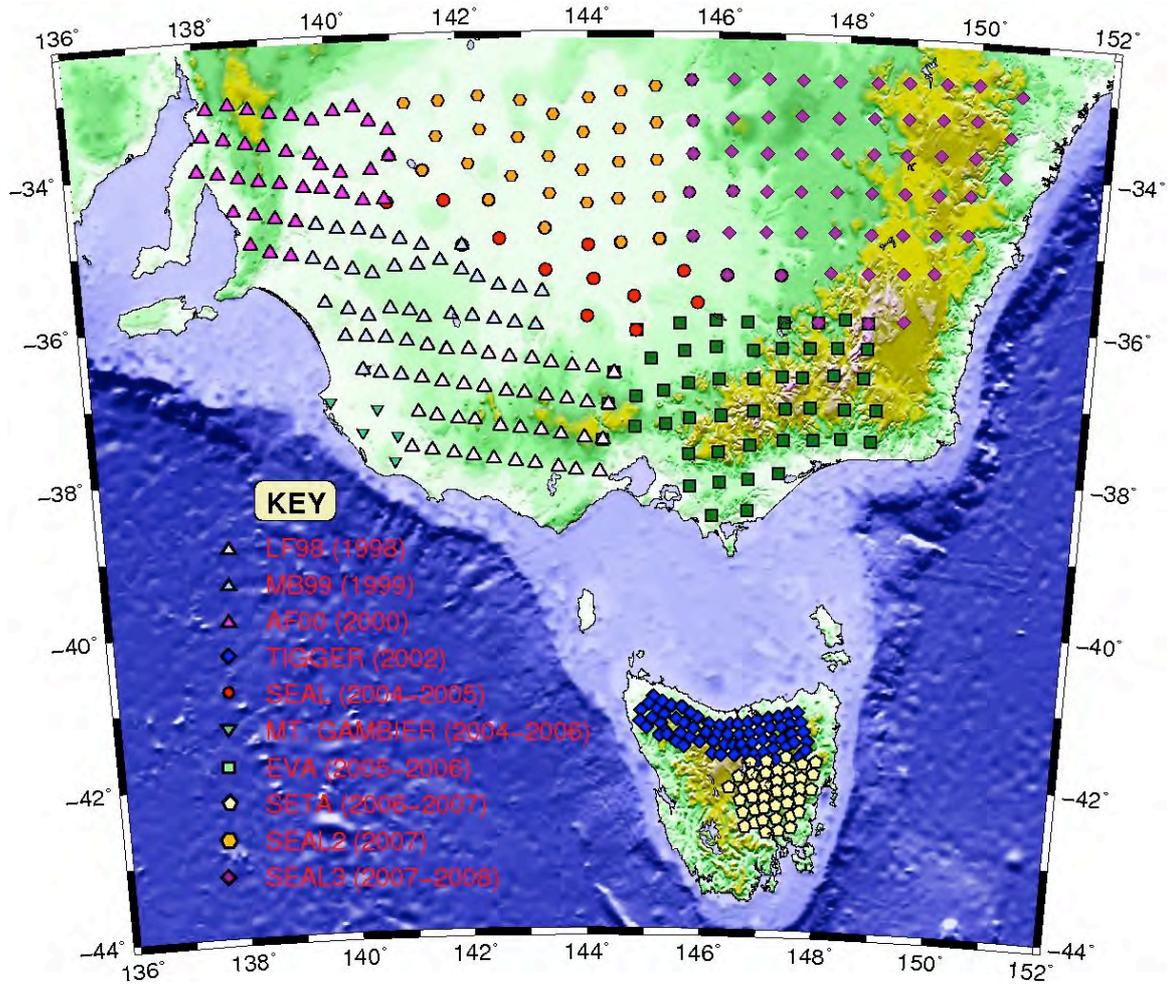


Figure 1. Location of all seismic arrays that currently comprise the WOMBAT experiment.

Teleseismic tomography of the upper mantle beneath the southern Lachlan Orogen, Australia

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In the 2005–2006 EVA experiment, 50 short period seismic stations were deployed across the southern end of the Great Dividing Range in Victoria (southeast Australia) to record distant earthquakes (see Figure 1). This study forms part of an ambitious long term experiment undertaken by RSES, called WOMBAT-SE, to use rolling deployments of dense seismic arrays to cover much of Eastern Australia. A total of 7452 relative P-wave arrival time residuals from 169 teleseismic events have been extracted from the continuous records of EVA using an adaptive stacking technique, which exploits the coherency of global phases across the array. These residuals are mapped as 3-D perturbations in P-wavespeed in the upper mantle beneath the array using a recently developed iterative non-linear tomographic procedure, which combines a grid based eikonal solver and a subspace inversion technique. The capability of the new scheme to include interface geometry is utilised in order to investigate the effects of *a priori* Moho topography on the resolution of upper mantle structure.

The resultant images show a pattern of P-wavespeed anomalies that lacks a predominant orientation, and therefore does not favour a purely W-E subduction-accretion model for the formation of the Lachlan Orogen. One of the main features of the 3-D model is a zone of elevated wavespeed beneath the northern end of the array (Figure 2), which extends to a depth of approximately 150 km, and contrasts with significantly lower wavespeeds to the south. This anomaly, which does not appear to be an artifact of arrival time residual contributions from the adjoining mountainous terrane, may reflect the presence of a substantial piece of Proterozoic lithosphere incorporated within the Phanerozoic subduction-accretion setting of the Lachlan Orogen. Another key feature of the solution model is a zone of relatively low velocity beneath the Newer Volcanic Province northwest of Melbourne (Figure 2), which extends from the crust to a depth of approximately 200 km. This is likely to represent the signature of elevated temperatures associated with a diffuse mantle source for the Quaternary volcanism in Victoria.

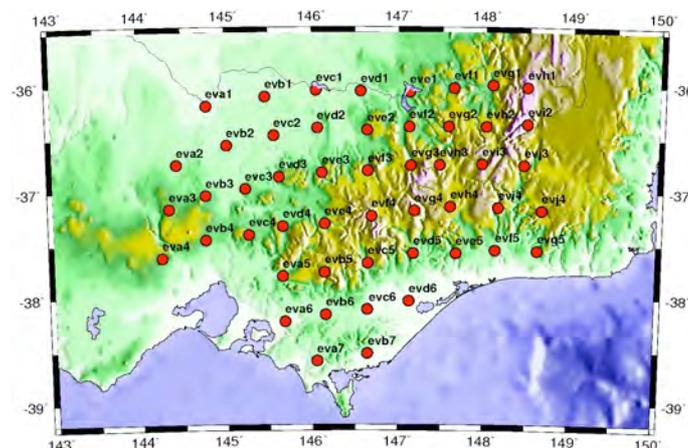


Figure 1. Location of 50 EVA stations (open triangles) used in this study. Sites vary in elevation between 9 m (evd6) and 1724 m (evh1).

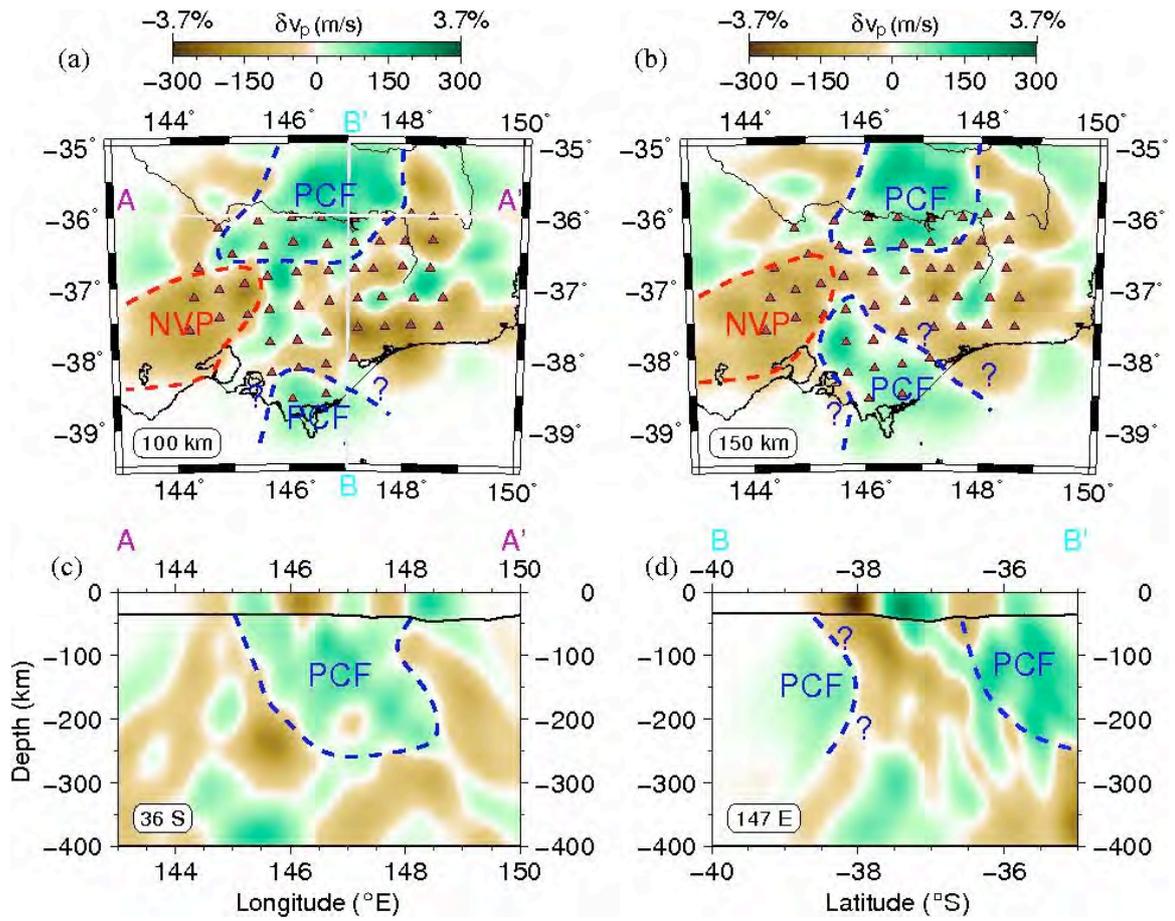


Figure 2. A selection of slices through the solution model with several features of interest highlighted. (a) Depth slice at 100 km; (b) depth slice at 150 km; (c) E-W cross-section at 36° S; (d) N-S cross-section at 147° E. NVP = Newer Volcanic Province; PCF = Proterozoic Continental Fragment.

Use of coda wave interferometry for estimating properties of earthquake sources

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The waves arriving later in a seismogram arise from scattering and are known as coda waves. Most techniques for studying earthquake source properties such as location and mechanism do not use the coda. Coda wave interferometry relates the variation between two earthquake sources and the cross correlation of their coda waves. In this project we are researching the applicability of coda wave interferometry (CWI) for constraining the location and mechanism of double couple events.

Snieder (2005) demonstrate how the separation between two double couple events with identical source mechanisms can be estimated using CWI. We have conducted numerical experiments in stochastic heterogeneous media to explore the range of applicability of CWI for estimating source separation. We observe that CWI estimates of separation are within one standard deviation of actual separation when the perturbation is less than one fifth the dominant wavelength. Moreover, we have demonstrated how CWI estimates of separation should be interpreted with the aid of a probability density function (PDF) which computes the probability of different actual separations for a given CWI estimate (Robinson, 2007a). We have also extended existing CWI theory to show how a change in the source mechanism between two identically located double couple sources can be estimated from the correlation of their coda.

We are currently comparing the performance of CWI for constraining earthquake locations by using data recorded in the Paradox Valley, Colorado. The earthquakes that we are studying were induced as part of local salinity control which includes injection of saline water to depths exceeding 4km. These induced earthquakes were recorded in an ideal recording situation with good azimuthal coverage. Therefore, existing location techniques are expected to perform well. We can use these data to explore the usefulness of CWI in locating earthquakes. In particular, we can resemble poorer recording situations by randomly discarding data and we can compare the performance of CWI against traditional location techniques which are known to perform badly when azimuthal coverage is poor. The figure demonstrates that CWI has the potential to produce accurate estimates of earthquake separation for each station separately and suggests that the technique may be useful when azimuthal coverage is poor.

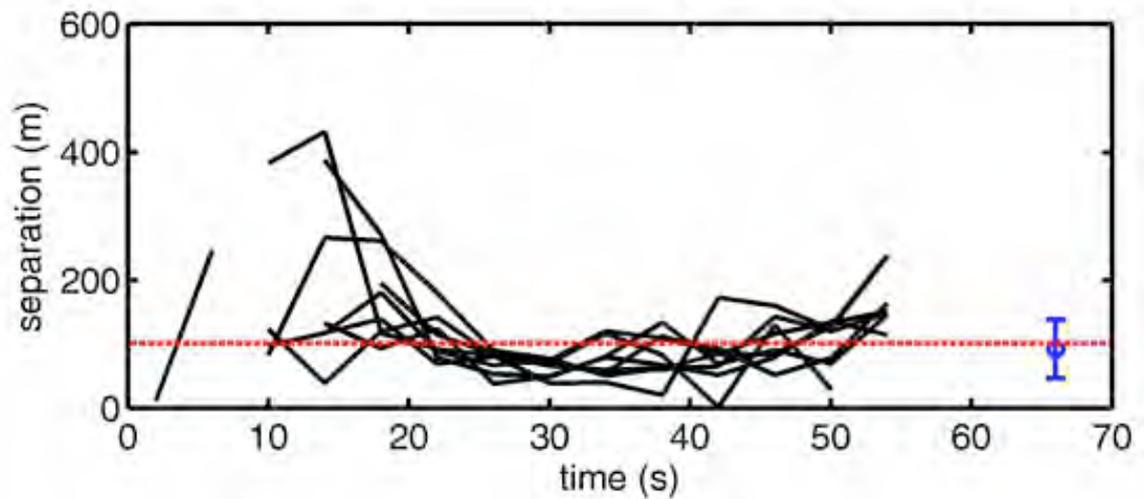


Figure 1. CWI estimates of separation as a function of sliding time window (white lines) for a pair of events from Paradox Valley which previous modelling has suggested are 100 m from on another. Each white line represents data from a different channel-station combination. The yellow error bar represents the mean and +/- one standard deviation when data from all channel-station combinations are included.

Snieder, R., and M. Vrijlandt, Constraining Relative Source Locations with Coda Wave Interferometry: Theory and Application to Earthquake Doublets in the Hayward Fault, California, *J. Geophys. Res.*, 110, B04301, 10.1029/2004JB003317, 2005

Finite-fault Slip Inversions for the Australian Tsunami Warning System

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A component of the developing Australian Tsunami Warning System is to rapidly estimate the slip pattern on an earthquake fault using body and surface wave seismic data. The results of finite-fault slip inversions can be fed into numerical models to calculate far-field tsunami potential and hence wave height at distant coasts. In an operational context this has to be done rapidly and in a robust manner, which creates a problem because the inversion process is non-unique and under-determined. This forces the introduction of hyper-parameters that must be chosen to balance the trade-off between spatial smoothness of the solution and the fit to the data. Previously, this has been done using a time-consuming, trial-and-error process requiring human intervention, which would be unsuitable in an operational context where results are required rapidly and preferably without human intervention.

A solution to this problem has been developed using a cross validation approach to selecting hyper-parameters. This technique requires many repeated inversions to be performed on subsets of the original data set, each of which is tested against its ability to predict data left out of the inversion. Cross validation involves a suite of such tests to determine optimal values for the smoothing hyper-parameters. Initial results are encouraging and suggest that the approach is able to reproduce the results of human experts, at the expense of increased computations. Future work focuses on parallelization of the algorithms (e.g. on RSES Terrawulf facility) to make them efficient enough for an operational context and further application to a range of data sets.

Earthquake slip inversion results for 2006 Kuril event.

40 seismic waveforms fitted
4677 data equations
1676 model parameters

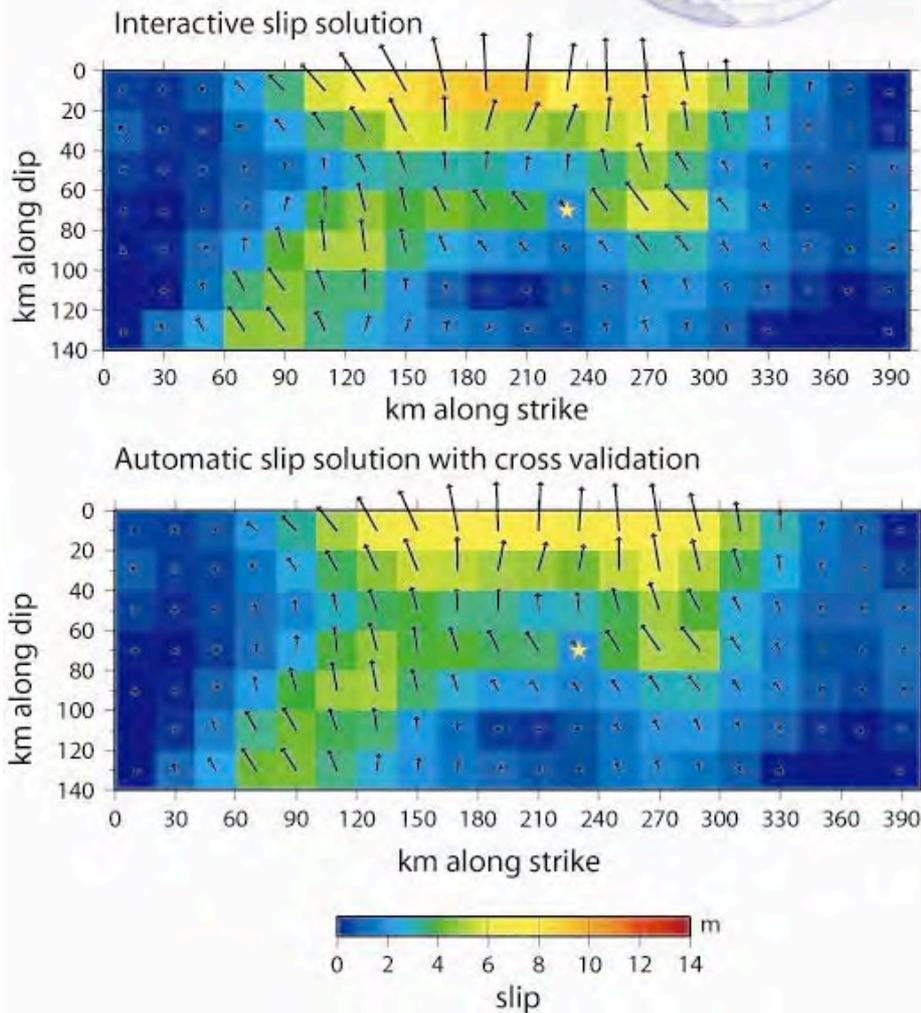


Figure 1. Shows a comparison between inversion results with an automatic choice of hyper-parameters by cross validation and an interactive choice by an expert. The slip results are very similar showing that the cross validation approach can achieve a similar quality of solution without human intervention.

Patching the holes in ray-path coverage of the lowermost mantle in the southern hemisphere: PcP waves observed in Antarctica

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² University of Tasmania, Hobart Campus, Hobart, Tasmania 7001, Australia

The progress in the understanding of the deep Earth properties is partly inhibited by the lack of reliable P wave velocity models of the lowermost mantle. P-wave velocity maps are not well constrained in much of the southern hemisphere, in particular from deep earth-sensitive body waves such as PKP and PcP (Tkal_i_ et al. 2002). SSCUA project was a multiyear deployment of broadband seismic stations throughout Australian Antarctic Territory from 2002 to 2005 www.rses.anu.edu.au/seismology/Expt/sscua/.

During the time of its operation, the stations recorded about 100 teleseismic earthquakes of magnitude larger than 5.5 at epicentral distances between 30 and 75°, suitable for producing core-reflective PcP waves.

The high microseismic noise and non-operation during Antarctic winter prevented recording a large number of high quality data. However, we observed 10 clear PcP arrivals on various SSCUA stations and measured PcP-P differential travel times by hand-picking and cross-correlation. This is insufficient to make any definitive conclusions about the lowermost mantle structure, however these observations will be useful in the context of improving global maps of the lowermost mantle properties. We also studied the radiation pattern at the source and found that it significantly influences whether PcP waves would be detected at a given location.

In addition, several events originating in the South Sandwich Islands region (SSIR) were detected and we found that the PcP wave travel times were fast relative to the P wave travel times. This indicates that there is a fast anomaly in the mantle that has an impact on travel times of PcP waves and therefore could have important implications for inner core anisotropy studies since the anomalously fast PKP waves originating in the SSIR are used to support strong inner core anisotropy.

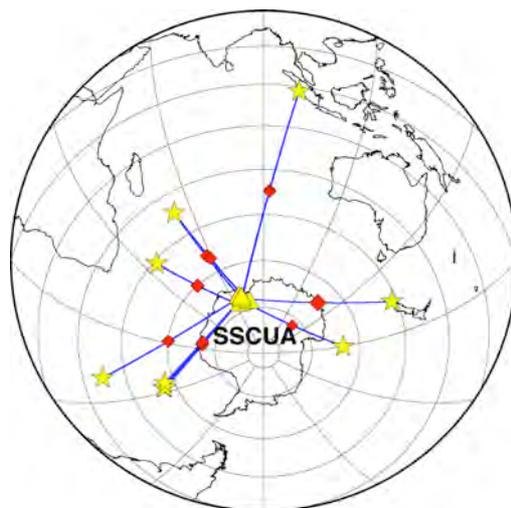


Figure 1. Distribution of events (stars) with clear PcP arrivals recorded at SSCUA stations in Antarctica (triangles). The red diamonds are bouncing points of the PcP waves at the CMB.

Event: 111202B_SSI -56.49 -26.89
 Station: BVLK -70.8034 68.1741
 PcP waves radiation pattern

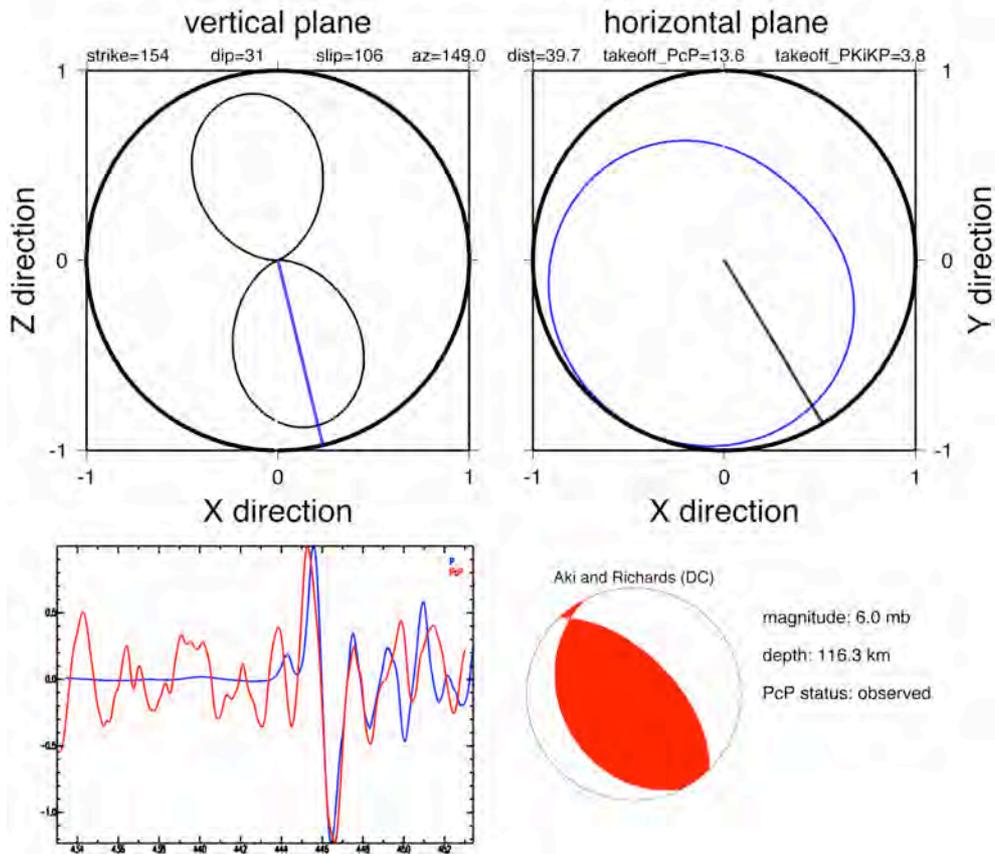


Figure 2. An observation of PcP waves at station BVLK is shown with the radiation pattern, focal mechanism and cross-correlation of the P and PcP unfiltered waveforms to obtain a differential travel time measurement.

Tkal_i_ H., Romanowicz and N. Houy, Constraints on D'' structure using PKP(AB-DF), PKP(BC-DF) and PcP-P travel time data from broadband records, Geophys. J. Int. 149(3), 599-616, 2002.

On the inner-outer core density ratio from previously unobserved steep-incidence inner core reflections

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Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

The density contrast at the inner-outer core boundary (ICB), which has significant geodynamical implications, has long been a subject of controversial findings. Seismological 1D models of the Earth indicate that this contrast is larger than it would be for just a phase transition. However, until recently, seismological studies using body waves and normal modes have given significantly different values for this ratio.

When the ray theory is used, part of the problem lies in the fact that the convincing observations of PKiKP and PcP for epicentral distances less than 70 degrees are extremely rare. The relative amplitudes will be particularly sensitive to attenuation and radiation patterns, that are not identical in the mantle. For short distances the mantle components are almost in common, and so the estimates of density contrasts should be most reliable.

We observed clear PKiKP arrivals at very short epicentral distances, sampling nearly the same path from the source to the reflection point and from the reflection point to the receiver. These observations are first such clear observations made, and are result of a systematic analysis of a global dataset of IRIS Passcal seismic broadband waveforms, nuclear explosions and several regional networks such as JARRAY in Japan. We are examining the reflection characteristics for the major discontinuities and study how they effect the amplitude of the observed seismic waves. Our preliminary results indicate that the density contrast at the ICB could be lower than predicted from 1D models of the Earth, but such estimates are more influenced by short-scale heterogeneity and topography at the core mantle boundary than by possible complex topography at the ICB.

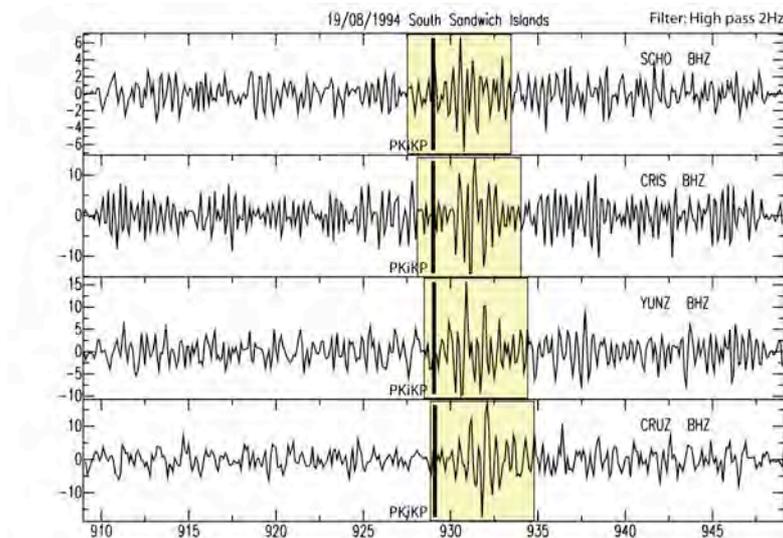


Figure 1. PKiKP waves observed at very short epicentral distances ($\sim 7^\circ$) for an earthquake from the South Sandwich Islands region. Vertical bars are predicted PKiKP travel times from the radially symmetric model ak135.

Research Activities

PRISE

PRISE Introduction

PRISE operates as a unique entity within the Research School of Earth Sciences, providing commercial and collaborative access to the Research School's specialised equipment and expertise in areas of geochronology, geochemistry and petrology.

PRISE staff are involved in wide-ranging collaborative research projects with academic colleagues throughout the world, as well as providing research and analytical skills to industry and Government agencies on a commercial basis. During 2007 PRISE hosted thirty-three visitors from Australia and overseas, most of whom undertook collaborative projects using the SHRIMP, Laser ablation- and solution ICPMS, electron microprobe and TIMS analytical facilities. PRISE staff participated in a number of field-orientated studies in Australia, Africa, South America and Europe.

As members of a self-funded research group, PRISE scientists also undertake their own research projects and supervise postgraduate students, both within the Research School and internationally.

Some areas of current research include:

- Constraints on the timing of world-wide Neoproterozoic glacial events: the "Snowball Earth" hypothesis
- Planetary perspectives on early evolution of the solar system
- High pressure experimental investigations into melting of heterogeneous upper mantle
- Use of sulphur isotopes to aid in understanding the origin and conditions of formation of metal sulphides
- Geological Connection between West Antarctica and Patagonia since the late Paleozoic: Tectonism, Paleogeography, Biogeography and Paleoclimate
- Bioarchaeology in early Cambodian populations and in situ oxygen and strontium analysis of human teeth
- New techniques for interpretation of indicator minerals used in diamond exploration
- Linking of geochemical and petrographic data with regional tectonic models to improve predictive capabilities with respect to the quality of petroleum reservoirs

Rapid *in situ* measurement of sulphur isotope ratios: new developments and results using the SHRIMP II

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As the most important group of ore-forming minerals, sulphides are of enormous economic interest, and studies of sulphide isotope geochemistry provide fundamental information on the genesis of these ore deposits. Sulphur isotope studies also provide unique information on the geochemistry and evolution of mantle, crustal, hydrothermal, biogeochemical and atmospheric systems, and the processes within and between these reservoirs. This information is gathered from the measurement of the natural variations of the stable sulphur isotopes, recording mass-dependent and mass-independent fractionation from a variety of processes.

Sulphur isotope ratio measurements are made using a number of methods, but the pioneering work by Eldridge et al. (1988, 1989) showed the advantages and insights to be gained from *in situ* analyses using the high spatial capabilities of the SHRIMP I.

This technique allows the measurement of isotope ratios on ~20µm spots in a variety of sulphide minerals. Unfortunately this research and analytical capability ceased some years ago, but with recent technical developments on the SHRIMP II instrument at the Research School of Earth Sciences, ANU, renewed efforts have been made to further explore the possibility of redeveloping this analytical capability, but with the potential for greater precision and accuracy than previously possible. In particular, the dual developments of a Cs⁺ primary ion source and a multicollector system have significantly improved sensitivity, stability and the time required for measurement of sulphur isotopes, and indeed, other stable isotopes.

The accuracy of sulphur isotope measurements is critically dependant on the quality of the standards available. Matrix effects also require the standards to be matched to the composition of the unknown sulphides. Great effort, therefore, has gone into the quest for standards with homogeneous sulphur isotope compositions, with several of the international standards currently available being assessed. An important additional development which has improved analytical precision is the use of the larger mega-mounts developed for the SHRIMP oxygen isotope analytical protocol (see Hiess et al, 2006 RSES Annual Report).

Although we anticipate that further improvements in our analytical and sample preparation techniques will evolve into further improvements in analytical precision, we are currently obtaining precisions of the order of ± 0.3 permil or less for any analytical session. These standards have been used to accurately measure the isotope ratios in a number of ore deposits, including Au-bearing horizons of the Witwatersrand Basin, magmatic systems of the Bushveld Complex and a number of other deposits from various environments and settings.

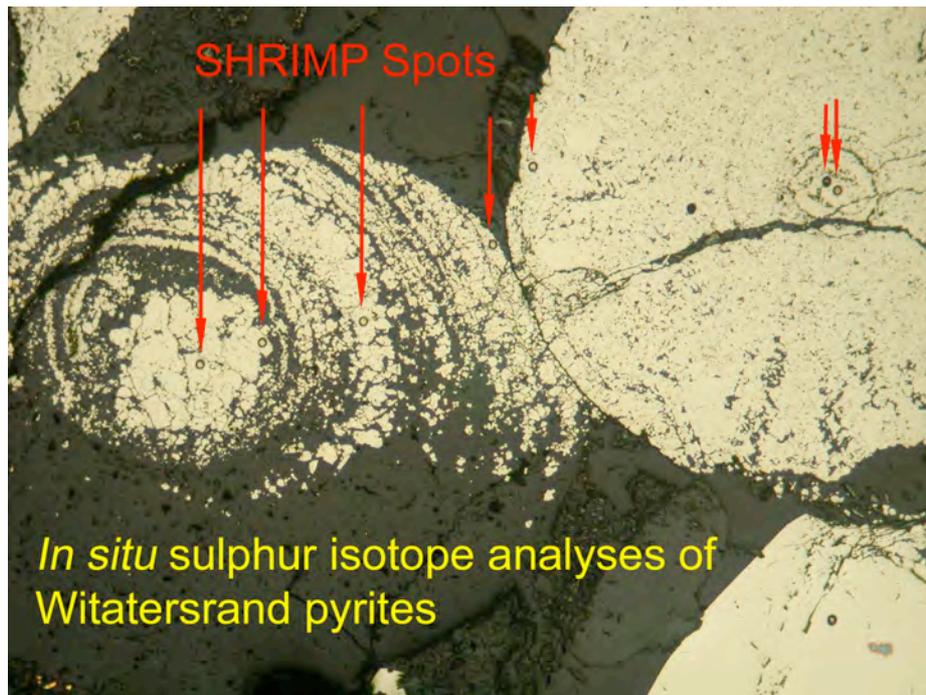


Figure 1. SHRIMP analytical spots across pyrite from the Witwatersrand gold deposit, South Africa. The SHRIMP spots are approximately 20 μm in diameter.

Future development work includes analysis of ^{33}S in order to assess, *inter alia*, the presence or absence of mass-independent fractionation in sulphides from anoxic Archaean and early Proterozoic environments (e.g. Farquhar and Wing, 2005) and the unraveling of complex mass-dependant and mass-independent fractionation patterns relating to early biological activity.

- Eldridge, CS, Compston, W, Williams, IS, Both, RA, Walshe, JL, Ohmoto, H. (1988) Sulfur-isotope variability in sediment-hosted massive sulphide deposits as determined using the ion microprobe SHRIMP: 1. An example from the Rammelsberg orebody. *Economic geology* 83: 443-449.
- Eldridge, CS, Compston, W, Williams, IS, Walshe, JL, (1989) Sulfur isotope analyses on the SHRIMP ion microprobe. *U.S. Geological Survey Bulletin* 1890: 163-174.
- Farquhar, J, Wing, BA (2005) The terrestrial record of stable sulphur isotopes: a review of the implications for evolution of Earth's sulphur cycle. In: McDonald, I, Boyce, AJ, Butler, JB, Herrington, RJ, Poyla, DA (eds): *Mineral Deposits and earth Evolution*, Geological Society, London, Special Publication 248: 167-177.

The Petrography and Chemistry of Cosmic Spherules from Lewis Cliff, Antarctica

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Micrometeorites are meteoritic particles less than 1mm in size found in the deep sea, sediments, swamps and the ices of Antarctica. These particles come in a variety of sizes, shapes and textures. The micrometeorite flux to Earth has been estimated at about 30,000 tons a year and make up the majority of material accreted to the present day Earth (Love and Brownlee, 1993). More importantly, these micrometeorites can provide insights into what kinds of materials that have been accreting to Earth as early as the Achaean (Deutsch et al., 1998). Micrometeorites can originate from a variety of sources such as asteroids, comets, planets, and interstellar dust clouds (Bradley et al., 2003).

We have classified 120 spherules from the Lewis Cliff Ice Tongue Moraine deposit based upon their petrography, major element compositions determined by electron microprobe, and we have measured bulk trace element abundances on 71 of these by laser ablation ICPMS. This increases the number of previously studied spherules from this locality by about a factor of four.

Similarities in petrography and major element chemistry among cosmic spherule collections from diverse localities around the Earth suggest a consistent source supplying the spherules, and analogous processes acting on the spherules during their entry through the atmosphere. The trace element data suggests that the majority of the stony cosmic spherules derive from material similar in chemistry to chondrites, leaning towards CM (carbonaceous) or H (ordinary) type chondrites in particular. The trace element data also demonstrate significant losses of volatile lithophile and chalcophile elements such as Rb and Cu probably due to atmospheric heating, and fractionation of siderophile elements such as Pt and W. There is also a clear depletion of siderophile elements in the silicate spherules while iron-rich cosmic spherules exhibit complementary enrichment. We interpret this as evidence for the formation, migration and possibly separation of an immiscible iron-rich core during melting.

Results of this study were presented at the 7th Australian Space Science Conference, Sydney, Australia, 24–27th September.

Bradley JP, Heinrich DH and Karl KT (2003) Interplanetary Dust Particles. In *Treatise on Geochemistry* (ed. K. K. Turekian), 689–712. Pergamon, Oxford.

Deutsch A, Greshake A, Pesonen LJ and Pihlaja P (1998) Unaltered cosmic spherules in 1.4-Gyr-old sandstone from Finland. *Nature* **395**:146–148.

Love SG and Brownlee DE (1993) A Direct Measurement of the Terrestrial Mass Accretion Rate of Cosmic Dust. *Science* **262**:550–553.

New Perspectives on the Lunar Cataclysm from Pre-4 Ga Impact Melt Breccia and Cratering Density Populations

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³*Lunar and Planetary Science Institute, 3600 Bay Area Boulevard, Houston TX 77058 USA*

⁴*NASA Johnson Space Center, Houston TX 77058 USA*

Crystallisation ages of impact melt breccias from the near-side equatorial regions of the Moon show a pronounced clustering between 3.75 and 3.95 billion years. This age distribution was unexpected and produced competing hypotheses for the early impact flux in the inner Solar System. In one scenario the impact flux spiked dramatically about 4 billion years ago. In this 'late heavy bombardment' scenario several of the nearside lunar basins formed within a relatively brief interval of time. A late cataclysmic bombardment would have significant implications for Solar System dynamics perhaps involving migration of the outer planets. Alternatively, the impact flux may have declined steadily with relatively small fluctuations since formation of the Moon. In this scenario older impact deposits were destroyed and/or buried by more recent events.

Recently, we measured an absolute age of 4.20 ± 0.07 Ga on the Apollo 16 crystalline breccia 67955, which we interpret as an impact melt breccia (Figs. 1, 2). This is the first definitive evidence for a discrete melt-forming impact event older than 4.0 Ga so far documented from the Apollo lunar sample collection, but the significance of a single sample for defining the lunar impact cratering history prior to 3.9 Ga is difficult to assess. Monte Carlo models suggest that a genuine gap in major impact events between 4.2 and 3.9 Ga would constitute strong evidence favouring a late cataclysm (Turner, 1979) but the effects of megaregolith evolution and burial bias on the age distribution of sampled impact melt rocks needs further clarification (Hartmann, 2003; Chapman et al., 2007).

As a complementary approach we evaluated the long-term lunar impact flux using crater densities preserved within large basins. This analysis provides strong evidence for a steep cratering flux early in the stratigraphic sequence of lunar basins but the implications for changes in the cratering flux through time depends on the absolute ages of lunar basins, which are not well established. A late cataclysm would be strongly supported if the South Pole-Aitken (SPA) basin, stratigraphically the oldest basin on the Moon, has an absolute age not much older than the younger basins (i.e. ~ 4 Ga). Older assumed ages for SPA (e.g. 4.4 Ga or 4.2 Ga) produce cratering flux curves indicating an early heavy bombardment, and weaker evidence for a late cataclysm. However, the absolute age of stratigraphically intermediate basins such as Nectaris play a dominant role in interpretations of the cratering density curves for a late cataclysm.

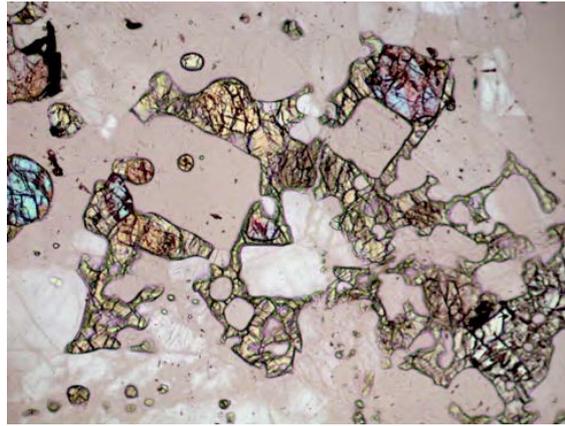


Figure 1. Thin section photomicrograph of lunar sample 67955.

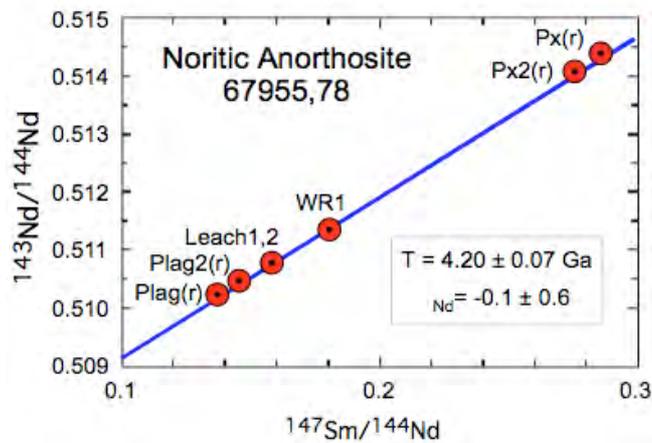


Figure 2. Sm-Nd mineral isochron age of lunar sample 67955 (from Norman et al., 2007)

Chapman C.R., Cohen B.A., Grinspoon D.H. (2007) What are the real constraints on the existence and magnitude of the late heavy bombardment? *Icarus* 189:233-245

Hartmann W.K. (2003) Megaregolith evolution and cratering cataclysm models – Lunar cataclysm as a misconception (28 years later). *Meteoritics & Planetary Science* 38:579-593

Norman M.D., Shih C.-Y., Nyquist L.E., Bogard, D.D., and Taylor, L.A. (2007) Early impacts on the Moon: crystallization ages of Apollo 16 melt breccias. *Lunar and Planetary Science Conference 38*, abstract #1991. The Lunar and Planetary Institute, Houston

Turner G. (1979) A Monte Carlo fragmentation model for the production of meteorites: implications for gas retention ages. *Proceedings of the 10th Lunar and Planetary Science Conference*:1917-1941

Exploring the melting behaviour of the Earth's heterogeneous upper mantle.

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² *Institute of Geological Sciences, University of Bern, Bern, Switzerland*

Melting behaviour and high pressure phase relations of heterogeneous mantle comprised of mixed lithologies (e.g. discrete bodies of mafic eclogite or pyroxenites and diverse types of metasomatised, re-fertilised or depleted mantle) are poorly constrained. However, based mainly on isotopic and trace element data, a widely held view is that such heterogeneities contribute significant melt components to intraplate and island arc magmas derived from the upper mantle.

My project aims to systematically determine solidus temperatures, phase relations and partial melt compositions during decompression partial melting of upwelling eclogites (oceanic crust composition), residual garnet-bearing and garnet-free pyroxenites and refertilised lherzolites as functions of pressure, temperature and bulk composition. The phase relations thus determined control minor and trace element behaviour during partial melting and will be essential constraints on models of isotope evolution and mixing used to explain the isotopic heterogeneity of mantle-derived magmas. The approach uses techniques of high pressure and temperature experimental petrology. The experimental data will be applied during parallel studies of carefully selected natural heterogeneous mantle samples (the layered peridotites from the Almklovdaalen peridotite massif, Norway), using a range of micro-analytical techniques (electronprobe microanalysis, laser-ablation ICP-MS, FTIR and Raman spectroscopy).

Experimental work completed so far

1. Phase and melting relations of a residual coesite-bearing garnet clinopyroxenite

This project is designed to explore the melting behaviour of subducted crust in an inhomogeneous, buoyant, upwelling mantle. I am tracking a sequential process in which melts are redistributed from the (initially) low temperature melting of average oceanic crust, and then from the residues (garnet pyroxenite) until the solidus of the latter equals or exceeds the solidus of refertilised peridotite.

Composition Res2 is the melting residue of an anhydrous altered MORB composition (GA2 of Spandler et al., in press) at 5 GPa near the point of coesite out, and hence is a model for recycled eclogite which has lost a siliceous melt component during mantle upwelling (Rosenthal et al., 2007). It is therefore depleted in incompatible minor elements, with 2.2 wt% Na₂O and a CaO/Na₂O ratio of 4.9.

Because it proved impossible to eliminate H₂O and CO₂ from our experiments, FTIR and Raman spectroscopy was performed on carefully selected Res2 samples to quantify different volatile species within the charges.

2. Phase and melting relations of coesite-bearing residual garnet clinopyroxenites with varying CaO/Na₂O ratios

This study is designed to reveal systematically solidus temperature, phase relations, and partial melt compositions during decompression melting of compositionally different residual garnet-bearing pyroxenites in terms of their Na/Ca ratios to various degrees (Res3, Res4 and Res5) from 3.0 to 6.0 GPa and ~1200-1500°C. The residual composition Res2 is used as the "basis" composition. Res3 is identical to Res2, but has higher CaO/Na₂O ratio of 11.5. The particular focus will lie on the comparison of Res2 and Res3 in terms of the influence of varying bulk CaO/Na₂O on melting and phase relations.

High pressure partial melting of gabbro and its role in the Hawaiian magma source

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We conducted high-pressure experiments on a natural oceanic gabbro composition (Gb108), with the aim of testing recent suggestions that Sr-enrichment in rare primitive melt inclusions from Mauna Loa, Hawaii, may have derived from melting of garnet pyroxenite formed in the magma source regions by reaction of peridotite with siliceous, Sr-enriched partial melts of eclogite of gabbroic composition.

Gb108 is a natural, Sr-enriched olivine gabbro, with a strong positive Sr anomaly superimposed on an overall depleted incompatible trace element pattern, reflecting its origin as a plagioclase-rich cumulate. At high pressures it crystallises as a coesite eclogite assemblage, with the solidus between 1300 and 1350°C at 3.5 GPa and 1450 and 1500°C at 4.5 GPa. Low degree partial melts are highly siliceous in composition, resembling dacites. Coesite is eliminated between 50-100°C above the solidus.

The whole-rock Sr-enrichment is primarily hosted by clinopyroxene. This phase dominates the mode (>75 wt%) at all investigated PT conditions, and is the major contributor to partial melts of this eclogite composition. Hence the partial melts have trace element patterns sub-parallel to those of clinopyroxene with 10x greater overall abundances and with strong positive Sr anomalies.

Recent studies of primitive Hawaiian volcanics have suggested the incorporation into their source regions of eclogite, formerly gabbroic material recycled through the mantle at subduction zones. The models suggest that formerly gabbroic material, present as eclogite in the Hawaiian plume, partially melted earlier than surrounding peridotite (i.e. at higher pressure) because of the lower solidus temperature of eclogite compared with peridotite. This produced highly siliceous melts which reacted with surrounding peridotite producing hybrid pyroxene + garnet lithologies. The Sr-enriched nature of the formerly plagioclase-rich gabbro was present in the siliceous partial melts, as demonstrated by our experiments, and was transferred to the reactive pyroxenite. These in turn partially melted, producing Sr-enriched picritic liquids which mixed with normal picritic partial melts of peridotite before eruption. On rare occasions these mixed, relatively Sr-rich melts were trapped as melt inclusions in primitive olivine phenocrysts.

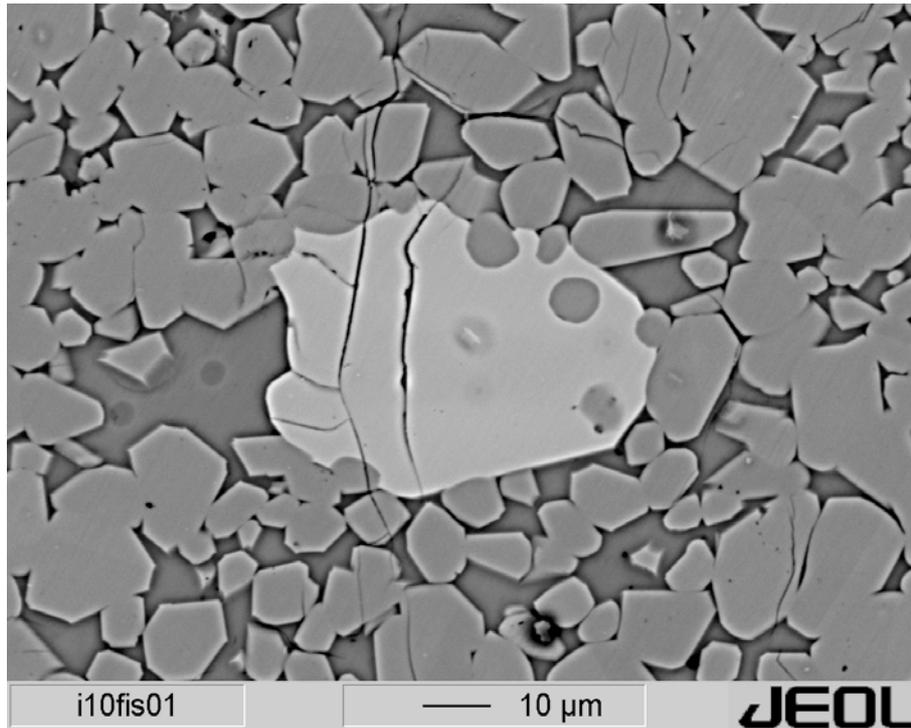


Figure 1. Back-scattered image of Gb108 experiment run at 3.5 GPa and 1400°C. The lightest phase is garnet, the mid-grey phase is omphacitic clinopyroxene and the darkest, interstitial phase is glass, which quenched from a siliceous liquid at the termination of the experiment.

Research Support

Electronics Group

Introduction

In 2007 the Electronics Group has vastly improved precision fabrication capabilities with the acquisition of a professional surface mount component reworking station complemented by dual dynascope vision systems, acquired with funding received from Vice Chancellor's development fund 06. The new facility will allow the group to utilise advances in current electronic technologies to ensure our designs are modern and relevant to RSES.

The February 2007 storm inflicted serious damage to the electronics workshop facilities causing considerable disruption to output, which is reflected in the year's administrative overheads. Despite the disorder the group has successfully supported the schools academic pursuits.

Demand for Electronic engineering has remained high during the year with developments into innovative Electrometer technologies, digital magnetic field control, stimulated emissions control and vacuum management. The Electronics Group continued to support RSES this year with resources distributed between electronic engineering development / fabrication, technical maintenance, and administrative tasks.

Task	Percentage	HOURS	Comment
Electronic Engineering Development and Fabrication	47.81%	3112	December figures not yet available.
Technical Maintenance	15.22%	990	December figures not yet available
Administration Trainee development Service to wider University Electrical Safety testing General admin Feb 2007 storm recovery	33.75%	2196	Increase due to storm recovery.
TOTAL		6509	

Table 1 Electronic Group Human Resources 2007

Developments and fabrications

Throughout 2007, RSES Electronics Group has continued to engineer and plan electronic instrumentation requirements for Earth Chemistry's new SHRIMP SI project. Also the Group has developed major and minor electronic devices for all RSES departments. The notable developments undertaken included;

Development projects

- Earth Chemistry

DVS Distributed Vacuum management System (Design complete) Cassar. The DVS is a microprocessor controlled intelligent emergency vacuum shut down system. It has the ability to autonomously instigate correct venting and valve closing procedures during power failure to save vacuum integrity. Electronic engineering of DVS progressed throughout 2007 with initial design completed in October. The project has begun fabrication phase and is scheduled to commence system testing by early 2008.

IFLEX Electrometer (Design complete) Schram, Corrigan. In 2006 development began on a new concept for electrometer design based on experience gathered from previous Electronics Group projects namely the INSB1. The IFLEX is an ultra low noise analogue electrometer incorporating switchable range selection, charge mode facilities and improved construction feasibility. Electronic engineering of the IFLEX continued throughout 2007 by Schram and the project was extensively bench tested. Precision mechanical engineering of vacuum components were designed and constructed by Corrigan for the project. In 2007 the IFLEX project has produced a fully functional prototype. The design has undergone testing on SHRIMP 2 and progress towards commercial design has begun with the new technology destined for the SHRIMP SI project.

Beam Modulator (Complete) Redman. The Beam Modulator project incorporates additional electronics to the existing high voltage electrostatic lens steering. The improvement allows variable rastering of the Ion beam on SHRIMP RG. Electronic engineering design and prototype complete, integration onto SHRIMP RG to begin by Redman after trainee exchange period.

FC4 Field Controller 4 (Complete) Latimore. Development of the FC4 project continued throughout 2007 with major improvements in technology gained from expansion into faster and larger digital Field Programmable Gate Arrays. The technology will also be utilised in a range of future developments. The prototype was extensively bench tested and construction of commercial design to be complete by the end of 2007. The project is scheduled for system implementation on SHRIMP SI in 2008.

RHVC 3 Remote High Voltage Controller 3(Active development) Latimore, Schram.

The RHVC 3 project comprises control, management, distribution, enclosing and packaging of all SHRIMP SI high voltage power supplies. The project is currently at early the planning stage with hardware purchased ready to implement into the system.

SIADU Analogue Distribution Unit (Active development) Sasaki. The SIADU project involves processing all analogue signals available from the SHRIMP SI and displaying them in real time to the user via a virtual meter LCD screen. This development eliminates the need to employ analogue meters as user interface. The project filters and drives signals to National Instruments acquisition technology. Electronic design is complete and the first ADU is currently under construction.

SICMC Collector Motor Controller(Active development) Schram.

Fabrication projects

- Earth Chemistry

Low Field Tesla Tamer 3a (Complete) Cummins.

Normal Field Tesla Tamer 3a (Complete) Cummins

Medium Voltage Amplifiers (Complete) Redman, Sasaki

Beam Monitor (Complete) Cummins, Sasaki

- Earth Materials & Processes

One Atmosphere Furnace upgrade. (Complete) Cassar

- Earth Environment

IICU Integration and Interface Control Unit (Active development) Cummins.

The IICU project provides two main functions in the Photon Counting Imaging System; it provides independent fully programmable current sources to drive Light Emitting Diodes as an alternative optical stimulation, and interfaces to the existing Minisys to allow control of the Liquid Nitrogen CCD camera system and other peripherals. The project utilizes microprocessor technology to create an autonomous controller for the Photon Counting Imaging System. Electronic engineering of the project is currently in its final stage and hardware construction is scheduled for December 2007.

Graphitization Furnace Control and Pressure Acquisition System (Complete)

Schram. This device designed and built by Schram, enables automation of the proposed 12 channel Graphitization Furnace utilized for Accelerator Mass Spectrometer sample preparation. The project provides electronic control of temperature and digital acquisition of pressure. Electronic Engineering of the project is complete and the system is currently installed on the Graphitization Furnace waiting final system testing.

- Earth Physics

Heating Mat Controller - Power Linearization (Active development) Cassar,

Tempra. The Heating Mat Controller project was first built in 2006 by Forster (now retired) and has been implemented in several projects for Earth Physics. The need arose for an improvement in the accuracy and linearization of power control. A superior method was tested for the acquisition of true RMS current and voltage enabling, in theory, vast improvements in absolute power measurement. The project is currently proceeding though bench-testing before addition to existing controllers.

Staffing

Early in 2007 the Electronics Group management changed hands, relieving managerial duties from Schram and appointing Latimore as new group leader. Due to planned retirements of key staff during 2006 the group was required to appoint personnel in May 2007. The group has undergone a significant human resources change by promoting Cassar and Cummins into the ranks as qualified Electronics Technical Officers and also appointing two new Trainee Technical Officers Redman and Sasaki. The group now consists of an eclectic mix of experience, youth and enthusiasm with one Engineer - Latimore, two Senior Technical Officers - Schram, Corrigan, two

Technical Officers -Cassar, Cummins and two trainee Technical officers - Redman, Sasaki.

In October 2007 Electronics Group joined the Research School of Physical Sciences and Engineering's trainee exchange program that allowed Redman a position at the RSPHySE Electronics Unit for a three month period, concurrently Trainee Technical Officer Daniel Tempra joined the RSES Electronics Group and has made considerable contributions.

Planning

The 2008 labour forecast for Electronics Group reveals high electronic engineering development time due to the continuation of SHRIMP SI projects. The group will move into fabrication and implementation of designs generated in 2007 with intention to remain focused on completing the SHRIMP SI project. The Electronics Group will continue our maintenance and technical counsel workload in 2008 which has remained a steady employment of resources each year and predicted to continue into the future. Further work will be required in 2008 for the proposed disassembling and reconstruction of SHRIMP 2, the proposal will inevitably shift the SHRIMP SI completion back relatively. The Electronics Group's commitment to developing younger staff will continue through 2008 with extra funds and labour budgeted to training. We will endeavour to maintain our high standard of electronic competency now and into the future.

Engineering Group

With the construction of SHRIMP SI in full swing the time in the Engineering Workshop was in high demand this year.

63% of total hours for the year were devoted to charged RSES internal work. The total work done for clients outside RSES accounted for 10% of our time and 29% of our time was uncharged.

Internally the main commitments were:

SHRIMP SI- Mostly Multicollector and Source internal components (Mr G. Woodward, Mr C. Were, Mr D. Thomson, Mr B. Taylor, Mr B. Butler, Mr N. Best, Mr A. Wilson)

Some 250 hours of overtime was also completed on the SHRIMP SI (Mr D. Thomson, Mr B. Butler, Mr N. Best, Mr L. Gair)

General SHRIMP Maintenance (Mr D. Thomson, Mr C. Were, Mr A. Wilson)

Steel adapter plates designed and manufactured to allow Polycrystalline cubes to be used in the multi-anvil press in place of Tungsten Carbide cubes. (Mr B. Buttler)

Continuation of LA-ICPMS for Prof M. McCulloch (Mr B. Butler, Mr A. Wilson)
Manufacture of various field work equipment including speliotherm coring drills (Mr C. Were)

Precision diamond grinding of samples and pistons for use in high pressure/temperature experiments in the Rock Physics laboratories for Dr I. Jackson (Mr G. Woodward, Mr C. Were, Mr D. Thomson, Mr B. Butler, Mr A. Wilson)

Heater canisters and various vacuum fitting and lab equipment for Dr S. Fallon (Mr B. Butler, Mr C. Were, Mr A. Wilson, Mr B. Taylor)

Mult-Anvil capsules from various materials including Ir/Fe, MgO and Graphite for Dr R. Rapp and Prof H. O'Niell (Mr C. Were, Mr B. Buttler)

Lab items and modifications for Dr J. Brocks (Mr C. Were, Mr B. Taylor, Mr D. Thomson, Mr G. Woodward)

One large external project was taken on this year:

SHRIMP 2 Low Mass Head Assembly for "Australian Scientific Instruments". (Mr G. Woodward, Mr C. Were, Mr D. Thomson, Mr B. Buttler, Mr N. Best, Mr A. Wilson)

Our time was also required by various faculties and research areas across campus for a multitude of smaller tasks.

Uncharged time was split as follows:

16%. Staff Training, both technical and general, including study leave. 38%. Workshop administration- Purchasing, workshop management, OHS Policy development and implementation, school committee work, and time logging.

14%. Workshop Infrastructure. This includes the time taken for improvements and modifications to tooling, machines, workshop layout, workshop storage and assistance with workshop building maintenance. The timber parquetry in the workshop is currently being repaired therefore extra time has been taken up moving machines and benches. 6%. Machine maintenance. 5%. Other- Sydney engineering exhibition, unloading deliveries. 16% of uncharged time was spent recovering from flood damage resulting from the February storm. 5% of uncharged work was spent on miscellaneous uncharged work both internal and from other areas of the ANU.

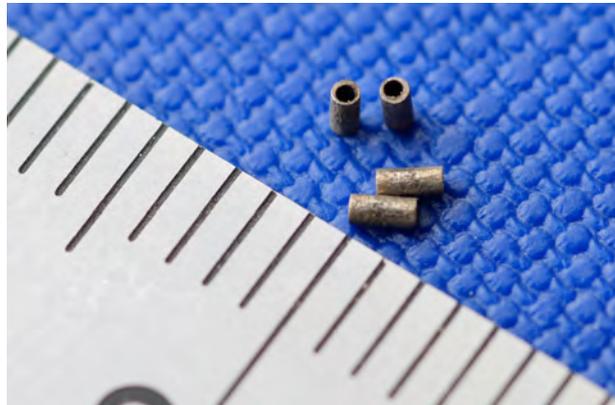
Staffing

Current Workshop Staffing is as follows:

Mr A. Wilson, Mr D. Thomson, Mr G. Woodward, Mr C. Were, Mr B. Butler Mr Brendan Taylor, who left early in the year, is yet to be replaced. In August of this year Mr Nick Best was chosen for a six month secondment to RSES to assist with the SHRIMP SI. Nick has vast experience at the Royal Australian Mint and the John Curtin School of Medical Research; he has helped the SHRIMP SI project appreciably since his commencement with us. Mr Lachlan Gair, also from JCSMR, joined our team for a short stint to assist with SHRIMP SI on overtime.

Other Developments

Funding was granted from the Vice Chancellors infrastructure fund to the RSES Engineering Workshop this year for the purchase of a new CNC Lathe. A machine has been purchased and is due to arrive in early 2008. This machine will be unique to the ANU in that it incorporates both turning and milling.



Iridium/Iron alloy capsules- Produced in the RSES Engineering workshop by Mr Brent Butler and Mr Carl Were using Electro Discharge technology. The capsules are used in high pressure experimentation by Dr Robert Rapp.

2007 Publications by Author

(Listed alphabetically within research areas)

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New grants commenced in 2007

Australian Research Council Grants

Discovery Project Grants

Dr. J. Brocks: Molecular fossils environmental genomics and the natural history of an Australian salt lake. \$26,300 (2007-2010)

Prof. J. Chappell: Exposure dating with manganese-53, neon-21 and beryllium-10: a new toolkit for studying long-term landscape evolution. \$378,000 (2007-2009) Led by Research School of Physical Sciences and Engineering, Australian National University

Dr. S. Eggins: The Southern Ocean's role in determining atmospheric CO₂ levels: new insights from novel biogenic silica records of seawater pH. \$26,200 (2007-2010)

Dr. M. Ellwood: Southern Ocean nutrients and their links to climate change: insights from the isotope and elemental signature of diatoms and sponges. \$39,000 (2007-2009) Led by University of Canberra

Dr. J. Hermann: Experimental and natural constraints on trace element and volatile recycling in subduction zones. \$300,000 (2007-2009)

Prof. B. Kennett: From crust to core: probing the heterogeneity of the Earth with seismic arrays. \$251,000 (2007-2009)

Dr. R. Kerr: Solidification, Channel Formation and Thermal Erosion In Lava Flows. \$157,000 (2007-2009)

Prof. K. Lambeck: Sea Level Change in the Australasian Region: Understanding the Past to Predict the Future. \$361,000 (2007-2009)

Prof. H. O'Neill: An experimental exploration of silicate melt thermodynamics. \$122,000 (2007-2009)

Dr. W. Schellart: Relationship between subduction zone geometry trench kinematics and great subduction earthquakes. \$674,465 (2007-2012)

Linkage Project Grants

Prof. R. Grun: Environmental Evolution of the Willandra Lakes World Heritage Area. \$570,184 (2007-2009)

Dr. J. Mavrogenes: Experimental constraints on Platinum-Group Element geochemistry: developing lithochemical exploration tools for nickel-sulfides in mafic and ultramafic systems. \$180,000 (2007-2009) Led by University of Western Australia

Dr. G. Yaxley: Advancing diamond exploration - novel techniques for the interpretation of indicator minerals. \$367,331 (2007-2010)

Linkage Infrastructure Equipment & Facilities Grants

Dr. M. Honda: A new Generation Noble Gas Mass Spectrometer Facility for Advanced Research in the Earth, Planetary and Environment Sciences. \$800,000 (2007-2008)

Commonwealth Government Grants

Geoscience Australia (GA) Grants

Dr. H. Tkalcic: Green's Functions. \$25,000 (2007)

Australian Antarctic Division (AAD) Grants

Dr. P. Tregoning: Glacial Isostatic Rebound in East Antarctica. \$22,083 (2007-2008)

Other Grants

National Collaborative Research Infrastructure Scheme (NCRIS) Grants

Prof. B. Kennett: AuScope - A4.70 Imaging Capital & Operations (Prof. B. Kennett)
A4.72 Imaging Geotransects (Prof. B. Kennett)
A4.101 Imaging Terrawulf (Dr. M. Sambridge)
A4.11 Geospatial Gravity (Prof. K. Lambeck)
A4.98 Geospatial SLR (Dr. P. Tregoning)
A4.100 Geospatial Terrawulf (Dr. M. Sambridge)
A4.8 Simulation (Pplates) (Prof. G. Lister)
A4.102 Grid Terrawulf (Dr. M. Sambridge)
\$10,200,189 (2007-2011)

Reef and Rainforest Research Centre Grants

Prof. M. McCulloch: MTSRF: RRRC Halting and reversing the decline in water quality. \$47,000 (2007-2010)

National and International Links 2007

Collaboration with Australian universities, CSIRO & industry
International collaboration
Cooperation with government and industry
Collaboration with Australian universities, CSIRO & industry

Collaboration with Australian universities, CSIRO & industry

Earth Chemistry

Dr C. ALLEN collaborates with Dr R. Squire (Monash University), Dating detrital zircons from Western Australia Archaean sediments.

Dr C. ALLEN collaborates with Dr A. Harris, U-Pb dating of felsic intrusions from Cadia NSW.

Dr C. ALLEN collaborates with Mr C. Reepmeyer, PhD Candidate, and Mr W. Ambrose, emeritus, School of Archaeology and Anthropology, on compositional characterization of obsidian artifacts and sources from SW Pacific islands.

Dr J.J. BROCKS collaborates with Prof S. George (Macquarie University), on the organic geochemistry and microbial history of saline Lake Tyrrell.

Dr J.J. BROCKS collaborates with Dr B. Rasmussen (University of Western Australia), on carbon isotopes of Precambrian organic matter.

Dr J.J. BROCKS collaborates with Prof Alan Cooper (University of Adelaide), on molecular indicators of damage in ancient DNA.

Dr I.S. BUICK collaborates with Dr G. Clarke (University of Sydney), on the crystal chemistry and petrogenesis of the mineral boromullite; and with Dr. Chris Clark (Curtin University of Technology) and Dr. Martin Hand (University of Adelaide), on the evolution of the Aravalli-Delhi Orogenic Belt, NW India. Prof I.H. CAMPBELL collaborates with Dr R. Squire (Monash University), on dating detrital zircons from Western Australia Archaean sediments.

Prof I.H. CAMPBELL collaborates with Dr A. Harris, U-Pb dating of felsic intrusions from Cadia NSW.

Prof I.H. CAMPBELL collaborates with Mr C. Reepmeyer, PhD Candidate and Mr W. Ambrose, emeritus, School of Archaeology and Anthropology, on compositional characterization of obsidian artifacts and sources from SW Pacific islands.

Dr M. HONDA collaborates with Prof T.M. Harrison (UCLA), Profs J. Chappell, B. Pillans, G. Lister, K. Fifield (ANU), Profs D. Phillips, A. Gleadow, B. Kohn (University of Melbourne), Profs A. Chivas, R. Roberts, C. Murray-Wallace (University of Wollongong), Prof S. O'Reilly (Macquarie University), and Dr D. Cooke

(University of Tasmania), A New Generation Noble Gas Mass Spectrometer Facility for Advanced Research in the Earth, Planetary and Environmental Sciences.

- Dr M. HONDA collaborates with Prof A. Chivas (The University of Wollongong), Continuation of collaboration on cosmogenic noble gas studies in young basalts;
- Dr D. PHILLIPS (The University of Melbourne), Continuation of collaboration on noble gas studies in diamonds.
- Prof T.R. IRELAND collaborates with Australian Scientific Instruments, Geoscience Australia, Dr P. Vasconcelos (University of Queensland), Dr I. Buick (Monash University), Dr P. Carr & Dr C Fergusson (University of Wollongong), Dr G. Clarke (University of Sydney), Dr R. Large and Dr G. Davidson (University of Tasmania), Dr J Hellstrom (University of Melbourne), Dr A. Kennedy and Dr P. Kinny (Curtin University), and Dr B. McInnes (CSIRO), SHRIMP SI Project.
- Dr C.H. LINEWEAVER collaborates with Dr P.C.W. Davies, (Director of Beyond Center for Fundamental Concepts in Science, Arizona State Univ, Phoenix on theoretical topics in astrobiology and cosmology.
- Dr C.H. LINEWEAVER collaborates with Prof D.W. Schwartzman (Biology Department, Howard University) and with Dr H. Piontkivska (Department of Biological Sciences, Kent State University), on statistical analyses and interpretations of the phylogenetic tree of life and the possible hyperthermophilic origin of terrestrial life.
- Dr C.H. LINEWEAVER collaborates with Dr Tamara Davis (Dark Cosmology Center, Copenhagen, Denmark), on the Interpretation of the Expansion and Acceleration of the Universe and on Common Misconceptions about the Big Bang.
- Dr R. SALMERON collaborates with Assoc. Prof M. Wardle (Physics Department, Macquarie University), on the structure and dynamics of magnetized protostellar disks.
- Mr R. SCHINTEIE collaborates with E. Grosjean (Geoscience Australia), and selected Dr G. Halverson (University of Adelaide) as PhD thesis co-advisor.
- Dr I.S. WILLIAMS collaborates with Australian Scientific Instruments, and Dr Allen Kennedy (Curtin University) on SHRIMP development, and with Prof B.W. Chappell (University of Wollongong) on granite geochemistry.

Earth Environment

- M AUBERT collaborates with Dr John Hellstrom, School of Earth Sciences, The University of Melbourne, on laser ablation Uranium-series dating of fossil teeth.

Dr L. K. AYLLIFFE with Dr G. J. Prideaux (Flinders University), Dr J Hellstrom (University of Melbourne) on U-series dating of cave deposits.

Dr S. EGGINS with Prof. C.W. Murray-Wallace (University of Wollongong) and Dr J. Hellstrom (University of Melbourne), on U-series dating of molluscs.

Dr S. EGGINS and Mr A. SADEKOV with Dr M. KILBURN (University of Western Australian), on nanoSIMS analysis of Mg/Ca banding and trace metal distributions in foraminifera.

Dr M.J. ELLWOOD collaborates with Dr. Edward Butler (CISRO), Dr. Andrew Bowie (ACE CRC) on Trace metals in Southern Ocean waters, and Prof. William Maher (University of Caneberra) on Germanium and silicon isotope fractionation in sponges and diatoms.

Dr S.J. FALLON with CSIRO, Climate from Deep Sea Corals; Southern Cross University, history of rainfall in N. Queensland; Australian Institute of Marine Science, climate records from tropical corals.

Dr K.E. FITZSIMMONS collaborates with Dr T.T. Barrows (ANU) on high resolution geochronology and palaeoenvironmental reconstruction in the southeastern Australian highlands.

Dr K.E. FITZSIMMONS collaborates with Dr J.W. Magee (ANU), Dr E.J. Rhodes (ex-ANU, now Manchester Metropolitan University), and Dr T.T. Barrows (ANU) on the history of aridity in the central Australian dunefields.

Dr K.E. FITZSIMMONS collaborates with Prof. J.M. Bowler (University of Melbourne), and Dr E.J. Rhodes (ex-ANU, now Manchester Metropolitan University), on palaeoenvironmental and archaeological records at Mulan, northwestern Australia.

Dr K.E. FITZSIMMONS collaborates with Prof. P. De Deckker (ANU) on fine resolution geochronology of southeastern Australian cave records.

Dr K.E. FITZSIMMONS collaborates with Dr N. Porch (ANU) on palaeoenvironmental records in western Victoria.

Dr K.E. FITZSIMMONS (as research assistant to Dr E.J. Rhodes (formerly ANU now Manchester Metropolitan University) collaborates with Dr P.C. Fanning (Macquarie University) (western NSW archaeology program); Prof. J.C. Nott (James Cook University) (tropical cyclone and tsunami histories); Dr J.W. Magee (ANU) (arid zone palaeoenvironmental reconstruction); Assoc. Prof. R.T. Wells (Flinders University) (arid zone palaeoenvironmental reconstruction); Dr J.D. Clarke (Geoscience Australia) (fluvial geomorphology, northwestern Australia); Mr M. Mann (ANU) (palaeoenvironmental reconstruction of Willandra lakes); Ms C. Bolton (ANU) (palaeoenvironmental reconstruction of Willandra lakes).

Dr M.K. GAGAN, Dr. L.K. AYLLIFFE, Mr. D. QU and Ms R. BERDIN with Dr. J. Lough (Australian Institute of Marine Science) and Dr G. Meyers (CSIRO Marine and Atmospheric Research), Co-investigators on ARC Discovery Grant DP0663227 (2006-2010): The Indian Ocean Dipole, Australasian drought, and the great earthquake cycle: Long-term perspectives for improved prediction.

Dr M.K. GAGAN, Dr L.K. AYLIFFE and Ms S. BRETHERTON with Dr J.-x. Zhao (University of Queensland) and Dr R. Drysdale (University of Newcastle), Co-investigators on ARC Discovery Grant DP0663274 (2006–2008): Monsoon extremes, environmental shifts, and catastrophic volcanic eruptions: Quantifying impacts on the early human history of southern Australasia.

Dr M.K. GAGAN with Dr H. McGregor, Dr D. Fink and Dr E. Hodge (Australian Nuclear Science and Technology Organisation), Comparison of radiocarbon and stable isotope ratios in Holocene coral microatolls from the tropical Pacific and eastern Indian Ocean.

Prof GRÜN, Dr. I. WILLIAMS and Prof. M SPRIGGS (Archaeology and Anthropology) collaborated with a large number of international scholars on the ARC grant Microanalysis of human fossils: new insights into age, diet and migration.

Prof GRÜN collaborated with Prof. Roberts and Dr. Z. Jacobs, University of Wollongong, and Prof. G. Duller, University of Aberystwyth, on the ARC grant Out of Africa and into Australia: robust chronologies for turning points in modern human evolution and dispersal.

Prof GRÜN obtained an ARC Linkage grant Environmental Evolution of the Willandra Lakes World Heritage Area, together with Dr. E. RHODES, Prof S Webb (Bond) and Drs N Stern (La Trobe) and A. Fairbairn (UQ).

Prof GRÜN collaborates with Dr J. Field, Dept. of Archaeology, University of Sydney, on the dating of the archaeological and megafauna site of Cuddie Springs, Dr J. Dorth, Department of Archaeology, University of Sydney and Dr M Cupper, School of Earth Sciences, University of Melbourne, on the dating of the megafauna site of Lancefield, and Dr R. Wells, Flinders University, on dating a series of South Australian sites with faunal remains including Naracoorte Cave and the Rocky River Site on Kangaroo Island.

Mr R. JOANNES-BOYAU collaborates with Dr John Hellstrom, School of Earth Sciences, The University of Melbourne, Laser ablation Uranium-series dating of fossil teeth.

Dr S.D. JUPITER with Dr J. Lough (Australian Institute of Marine Science), Prof O. Hoegh Guldberg (University of Queensland), Dr G. Marion (University of Queensland), Dr N. Duke (University of Queensland), Dr S. Lewis (James Cook University).

Prof M. McCULLOCH is an Associate Director of the ARC Centre of Excellence Coral Reef Studies. The Centre, known as the ARC Centre of Excellence for Coral Reef Studies is a partnership between James Cook University (JCU), The University of Queensland (UQ) and The Australian National University (ANU). The Centre also has close collaboration with the Commonwealth Scientific Industry Research Organisation (CSIRO), the Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Institute of Marine Science (AIMS). Now in its 2nd year of operation, the Centre has a 5 year budget of approximately A\$40 million. The Centre is headquartered at James Cook University, in Townsville under the Directorship of Prof Terry Hughes and is the focus for Australia's leading research on coral reef sciences, fostering stronger collaborative links between

the major partners and 24 other leading institutions in nine countries. Collectively, the Centre creates the world's largest concentration of coral reef scientists.

Prof M. McCULLOCH collaborates with Dr. J. Lough & Dr. K. Fabricius from the Australian Institute of Marine Sciences (AIMS), as part of the Centre of Excellence, on a wide range of coral reef projects in the Great Barrier Reef.

Prof M. McCULLOCH and Dr Stacy Jupiter from RSES together with Prof Ove Hoegh-Guldberg, (UQ) and Prof Robert Dunbar (Stanford University) are chief investigators on the ARC Linkage grant entitled "Long-term records of water quality and connectivity between Coral Reefs and Mangrove Ecosystems in the Great Barrier Reef". Industry Partners include GBRMPA, Mackay City Council and The Queensland Department of Primary Industry. This project was completed in 2007.

Prof M. McCULLOCH and Prof Mike Kingsford and Dr Heather Patterson from James Cook University are continuing their collaboration on the study of the geochemistry of fish otoliths from the Great Barrier Reef.

Prof M. McCULLOCH, Dr Julie Trotter and Dr Brian Gulson from CSIRO and Macquarie University are collaborating on a medical project on the possible health hazards of zinc nano-particles in humans.

Mr I. MOFFAT collaborated with Dr N. Chang (James Cook University) and Associate Prof B. Boyd (Southern Cross University) on applying geophysical techniques to the Ban Non Wat archaeological site in North-west Thailand.

Mr I. MOFFAT collaborated with Dr B. David (Monash University), Associate Prof Bryce Barker (University of Southern Queensland) and international colleagues on the study of a wrecked Lakatoi and villages containing Motuan pottery associated with the Hiri trade in the Gulf Province, Papua New Guinea.

Mr I. MOFFAT collaborated with Dr L. Wallis (Flinders University), Dr K. Domett (JCU) and an international colleague on the application of geophysical techniques to the location of Aboriginal skeletal remains on the Coorong, South Australia.

Mr I. MOFFAT collaborated with J. Raupp (Flinders University and Department of Environment and Heritage, SA) on the attempted location of the anchor of the Casurina, a vessel that was part of Boudain's exploratory fleet using geophysical techniques.

Mr I. MOFFAT collaborated with Dr L. Wallis (Flinders University) on the application of geophysical techniques to the location of historic burials at Kensington Cemetery, South Australia.

Mr I. MOFFAT collaborated with Dr N. Chang (James Cook University) on the application of geophysical techniques to the location of historic burials at Selheim Cemetery, North Queensland.

Mr I. MOFFAT collaborated with Dr A. Gorman (Flinders University) and Dr H. Burke (Flinders University) on the geophysical investigation of the location of an air raid shelter, Adelaide.

Prof B.J. PILLANS with Dr M. Wallace (University of Melbourne), on the magnetostratigraphy of Quaternary deposits in the Murray Basin, Australia.

Prof B.J. PILLANS with Prof R.G. Roberts (University of Wollongong), on luminescence dating of aboriginal rock art.

Dr P.C. TREBLE with Dr R DRYSDALE & Dr J MCDONALD (University of Newcastle), Dr J Hellstrom (University of Melbourne), Dr B.C. Bates & Dr E Campbell (CSIRO Land & Water), WA Indian Ocean Climate Initiative, and Caveworks.

Earth Materials & Processes

Prof S.F. COX is collaborating with Assoc Prof D. Cooke (University of Tasmania) on aspects of the development of fracture-controlled flow systems in intrusion-related hydrothermal ore systems. This collaboration forms part of the activities of the ARC Centre for Excellence in Ore Deposits.

Dr K. EVANS collaborates with Prof R. Powell (University of Melbourne).

Dr J.D. FITZ GERALD collaborates with Dr I.E. Grey and Dr M.L. DeVries (CSIRO) on the crystallography of ilmenite reduction.

Dr J.D. FITZ GERALD collaborates with Dr J. Keeling (Primary Industries and Resources, South Australia) on crystallography and defect structures in antigorite.

Dr M. FORSTER collaborates with Thermochronology and Noble Gas, Geochemistry and Geochronology Organisation (TANG30), including Prof P. Vasconcelos (University of Queensland), Dr D. Phillips (The University of Melbourne), Prof M. McWilliams (John de Laeter Centre, West Australia), Dr F. Jourdan (Western Australian Argon isotope facility, Curtin University of Technology).

Prof D.H. GREEN collaborates with Dr Trevor Falloon and Dr Leonid Danushevsky of School of Earth Sciences, University of Tasmania.

Prof I. JACKSON collaborates with Dr. Z. Stachurski (Department of Engineering, ANU).

Prof G. LISTER, is collaborating with Prof W. Collins (James Cook University) in submission of a Linkage project associated with an AuScope seismic transect.

Dr J. MAVROGENES collaborates with Prof M. Barley and Dr M. Fiorrentini at University of Western Australia on Ni and PGE deposits of Western Australia.

Dr S. MICKLETHWAITE is collaborating with Dr H. Sheldon (CSIRO) on the relationship between damage mechanics, earthquake stress changes and gold mineralization.

Dr S. MICKLETHWAITE collaborates with the minerals exploration teams of Harmony Limited (New Celebration goldfield, Western Australia), Newcrest Limited, Newmont Limited, Barrick Limited, Goldfields Limited (St Ives and Agnew goldfields, Western Australia) and formerly Placer Dome Limited (now part of

Barrick), on the exploration potential of stress-transfer modeling in fault-related mineral deposits, examining mesothermal, epithermal and carlin-type gold deposits in Australia and North America.

Prof H. O'NEILL continued his collaboration with Prof B. J. Wood (Macquarie University) on high-pressure research.

Prof H. O'NEILL collaborates with Dr M.I. Pownceby (CSIRO) on Mg-Fe²⁺ exchange between minerals.

Dr R.P. RAPP with Ringwood Superabrasive Pty., Prof B. Wood (Macquarie University/Oxford University, UK), and Prof H. O'NEILL (RSES, ANU), in a project that aims to extend the working range of the multi-anvil apparatus to pressures in excess of 30 GPa (into the lower mantle), through the use of polycrystalline synthetic diamond (PCD) anvils in combination with superhard, specialty tool steel guide blocks.

Dr S. RICHARDS, with Prof G. LISTER, in collaborative research with De Beers Exploration.

Dr S. RICHARDS collaborates with Prof W. Collins (James Cook University) on orogenesis and evolution of the eastern Lachlan Fold Belt.

Earth Physics

Dr C.E. BARTON collaborates with Prof Dan Baker, Dr W.K. Peterson, and Dr E. CoBabe Amman (Laboratory for Atmospheric and Space Physics, University of Colorado) and with Peter Fox (National Center for Atmospheric Research, Boulder) on the Electronic Geophysical Year project; also with Prof A. Gvishiani (Geophysics Center, Russian Academy of Science) on ICSU's Committee on Data for Science and Technology (CODATA).

Dr A. DUTTON collaborates with Dr C. Woodroffe (University of Wollongong), Dr S. Smithers (James Cook University) on constraining rates and magnitudes of Holocene sea level change along the Australian coastline.

Dr A. DUTTON collaborates with Dr T. Esat (ANSTO) on development of U-series measurement methodology and on U-series dating of submerged speleothems from the Mediterranean and of last interglacial corals from Western Australia.

Dr F. FONTAINE with Prof B.L.N. Kennett (Australian National University), Dr Malcolm Sambridge (Australian National University), Dr H. Tkalcić (Australian National University), Dr N. Rawlinson (Australian National University), Dr P. Arroucau (Australian National University), Dr. D. Love (Geoscience Australia).

Australian National Seismic Imaging Resource (ANSIR)

Prof B.L.N. KENNETT is Director of ANSIR which continues as a National Research Facility, as a joint venture between The Australian National University and Geoscience Australia linking to the Earth Imaging component of AuScope. RSES supports the portable seismic instrument. Until mid 2007 RSES had responsibility for the reflection equipment and vibrator sources, but these have now been sold. The ANSIR portable equipment is available via a competitive proposal scheme with support in 2007 for broadband instruments in Western and Southern Australia and short-period experiments in NSW and Tasmania. A large reflection experiment was carried out from June–September 2007 in North Queensland from Mt Isa through the Georgetown Inlier to Charters Towers (nearly 1200 km in all), supplemented by 200 km spur from Mt Surprise to Mareebawith AuScope funding.

Dr R.C. KERR with Dr C. Meriaux (Monash University) on the gravitational instability of strongly sheared mantle plumes.

Prof K. LAMBECK led the successful multi-institutional bid for NCRIS funding for the geospatial science component within AuScope. He chairs the Geospatial Subcommittee of AuScope and is a member of the AuScope Executive Committee.

Dr N. RAWLINSON collaborates with Dr. Michael Roach and Dr. Anya Reading (University of Tasmania).

Mr. D. ROBINSON collaborates with members of the Risk Research Group at Geoscience Australia

Dr. W. P. SCHELLART continued collaboration with Prof B. Kennett (RSES, Seismology group) to investigate the tomography of the Southwest Pacific region in order to locate potential remnants of subducted slabs in the upper and lower mantle.

Dr. W. P. SCHELLART further collaborated with Dr. J. Freeman (RSES, Seismology), Dr. D. Stegman (Monash University, Melbourne) and A/Prof Louis Moresi (Monash University, Melbourne) working on three-dimensional numerical simulations of subduction.

Dr H. TKALCIC embarked on a collaboration with Geoscience Australia (Dr. A. Gorbatov, Mr. P. Ivanov), on the construction of synthetic seismograms for the implementation of earthquake source parameters inversion in Australia.

Dr H. TKALCIC collaborates with Dr A. Reading, University of Tasmania, on studying the lowermost mantle from core-sensitive seismic waves recorded at the SSCUA stations in Antarctica, installed by Dr Reading..

Dr P. TREGONING collaborated with Prof R. Coleman and Dr C. Watson (The University of Tasmania) and Dr M. Leblanc (James Cook University).

PRISE

Dr R.A. ARMSTRONG collaborates with Dr J. Greenfield (Geological Survey of NSW) on isotope characterisation of the Koonenberry Belt, NSW.

Dr R.A. ARMSTRONG collaborated with Dr I. Graham (Australian Museum and University of NSW) on dating of zircon megacrysts from basaltic terrains in Germany.

Dr R.A. ARMSTRONG collaborated with M. van Dongen (Monash University) on SHRIMP U Pb dating and oxygen isotope analysis of zircons from Ok Tedi mine, PNG.

Dr R.A. ARMSTRONG works in collaboration with Dr K. Sircombe (Geoscience Australia) on testing and development of SHRIMP data reduction software.

Dr R.A. ARMSTRONG is collaborating with Dr L. Shewan (University of Sydney) on isotope and chemical analyses of human remains and environments of ancient Cambodia.

Mr C.M. FANNING collaborates with Dr S. Boger (University of Melbourne) on geochronology of Madagascar.

Mr C.M. FANNING collaborates with Mr H. Reichardt (Monash University) in a study seeking to place time constraints on melt formation, segregation, magma ascent and granite emplacement in transcurrent shear zones.

Mr C.M. FANNING collaborated with the Geological Survey of South Australia and Mr G. Teale (Teale and Associates) on a geochronological framework for the Gawler Craton, South Australia.

Dr M.D. NORMAN works in collaboration with Prof Barry Kohn (University of Melbourne) on the tectonothermal evolution of southern Mexico.

Dr M.D. NORMAN collaborates with Dr. Grant Douglas (CSIRO) and Parsons-Brinckerhoff (Sydney) on groundwater tracing.

Dr M.D. NORMAN is collaborating with Prof Patrick DeDecker (DEMS-ANU) on environmental evolution of eastern Australia.

Dr G.M. YAXLEY is collaborating with AMIRA International, on development of new techniques for interpreting diamond indicator minerals.

Dr G.M. YAXLEY and K. Kiseeva collaborate with Prof D. Kamenetsky (CODES, University of Tasmania) on petrogenesis of kimberlites.

INTERNATIONAL COLLABORATION

Earth Chemistry

Dr C. ALLEN collaborates with Dr M. Palin (University of Otago, NZ), on dating zircons from the two youngest caldera-forming ignimbrites of the Yellowstone volcanic field, using the laser ablation ICP-MS.

Dr C. ALLEN collaborates with Prof P. Reiners (Yale University, USA), on double-dating [U/Pb and (Th + U)/He] of detrital zircons in sedimentary provenance studies.

Dr C. ALLEN collaborates with Prof P. Clift (University of Glasgow, UK), on double dating zircons from Southeast Asian Rivers.

Dr C. ALLEN collaborates with Prof C. Bailey (College of William and Mary, USA) and Prof K. Eriksson (Virginia Polytechnic Institute, USA), on dating detrital zircons from Appalachian sediments.

Mrs. J.N. AVILA collaborates with Prof E. Zinner, Dr. S. Amari and Mr. F. Gyngard (Laboratory for Space Sciences, Washington University), on the study of light and heavy elements on presolar silicon carbide grains.

Dr V. C. BENNETT collaborates with Dr A. Brandon (NASA-Johnson Space Center, Houston), on determining the timing of early planetary processes through the high precision measurement of extinct nuclide isotopic compositions in ancient rocks from the Earth and Moon.

Dr V. C. BENNETT collaborates with Dr A. Nutman and Dr. Y. Wan (Chinese Academy of Geological Sciences, Beijing) on the comparative geochemistry of the oldest terrestrial rocks of Australian, Greenland and China.

Dr J.J. BROCKS collaborates with Ms C. Jones and Prof J. Banfield (UC Berkeley), Microbiology and Metagenomics of saline Lake Tyrrell.

Dr J.J. BROCKS collaborates with Dr P. Schaeffer (University of Strasbourg, France), Carotenoids of the Palaeoproterozoic Barney Creek Formation.

Dr J.J. BROCKS collaborates with Ms M. Bausch, Dr E. Schefuss, Prof K.-U. Hinrichs (University of Bremen, Germany), and Dr G. Allison and Prof P. de Deckker (ANU), Biomarkers of Desert Crusts and Dust in Australia.

Dr J.J. BROCKS collaborates with Dr P. Wynn (University of Lancaster, UK), Molecular indicators of biomass burning in stalagmites.

Dr. I.S. BUICK collaborates with Dr. S. Kasemann (University of Edinburgh, UK), on in situ lithium isotope geochemistry of cordierite and garnet.

Dr. I.S. BUICK collaborates with Prof E. Grew and Dr. M. Yates (University of Maine, USA), Dr. Thomas Armbruster (Universität Bern, Switzerland), Dr. Olaf Medenbach (Ruhr Universität Bochum, Germany) and Prof Gray Bebout (Lehigh

University, USA), on the crystal chemistry and petrogenesis of the mineral boromullite.

- Dr. I.S. BUICK collaborates with Dr. G. Bebout (Lehigh University, USA), on nitrogen elemental and isotope geochemistry during crustal anatexis.
- Dr. I.S. BUICK collaborates with Prof G. Stevens and Mr A. Villaros (University of Stellenbosch, South Africa), on LA-ICP-MS mineral trace element constraints on the petrogenesis of S-type granites in the Cape Granite Suite, South Africa.
- Dr. I.S. BUICK collaborates with Dr. M. Pandit (University of Rajasthan), on the evolution of the Aravalli-Delhi Orogenic Belt, NW India.
- Dr. I.S. BUICK collaborates with Dr. S. Kumar (Shizuoka University, Japan), on trace element partitioning between garnet and orthopyroxene in granulite-facies metapelites and felsic orthogneisses, and on real rock constraints on Li diffusivity in high-temperature ferromagnesian minerals.
- Prof I.H. CAMPBELL collaborates with Dr M. Palin (University of Otago, NZ), on dating zircons from the two youngest caldera-forming ignimbrites of the Yellowstone volcanic field, using the laser ablation ICP-MS.
- Prof I.H. CAMPBELL collaborates with Prof P. Reiners (Yale University, USA), on double dating [U/Pb and (Th + U)/He] of detrital zircons in sedimentary provenance studies.
- Prof I.H. CAMPBELL collaborates with Prof P. Clift (University of Glasgow, UK), on double-dating zircons from Southeast Asian Rivers.
- Prof I.H. CAMPBELL collaborates with Prof C. Bailey (College of William and Mary, USA) and Prof K. Eriksson (Virginia Polytechnic Institute, USA), on dating detrital zircons from Appalachian sediments.
- Dr M. HONDA collaborates with Dr J. Harris (University of Glasgow, UK), continuation of collaboration on noble gas studies in diamonds.
- Prof T.R. IRELAND continues to collaborate with Dr S. Weaver (University of Canterbury, New Zealand); Prof E. Zinner (Washington University, USA); and Prof K. McKeegan (UCLA).
- Dr D. RUBATTO collaborates with Prof M. Engi, Dr A. Berger and Dr E. Janots, University of Bern, Switzerland, on the behavior of LREE accessory minerals during prograde metamorphism and the timing of anatexis in the Central Alps.
- Dr D. RUBATTO collaborates with Prof O. Müntener (University of Lausanne, Switzerland) and Dr M.-A. Kaczmarek (University of Neuchatel, Switzerland), on the geochronology of the Lanzo Massif, Western Alps, and on fluid-induced recrystallization of zircon.
- Dr D. RUBATTO collaborates with Prof O. Müntener (University of Lausanne, Switzerland) and Dr O. Jagoutz (University of Bern, Switzerland), on the timing of rifting in the Northern Atlantic.

- Dr D. RUBATTO with Dr A. Korsakov and Prof N.L. Dobrestov (Russian Academy of Sciences), on the diachronous UHP metamorphism in the Kokchetav massif and the stability of monazite at high pressure.
- Dr D. RUBATTO collaborates with Dr A. Azor (University of Granada, Spain), on the geochronology of mafic magmatism in the South Iberian Suture.
- Dr D. RUBATTO collaborates with Dr. P. H. Leloup and Miss C. Sassier (Ecole Normale Supérieure de Lyon, France), on the duration of deformation along the Ailao-Shan - Red River Shear Zone, China.
- Dr D. RUBATTO collaborates with Prof S. Chakraborty (Ruhr Universität Bochum, Germany), on the rates of metamorphism in the Sikkim region in the Himalayas.
- Dr D. RUBATTO collaborates with Dr R. Anczkiewicz (Polish Academy of Sciences, Poland), on the composition and age of highly differentiated melts from Vietnam.
- Dr D. RUBATTO collaborates with Prof R. Compagnoni and Mr I. Gabudianu-Rudulescu (University of Torino, Italy), on the stability of allanite and monazite at high pressure and the age of high-pressure metamorphism in the Gran Paradiso Massif, Western Alps.
- Dr D. RUBATTO collaborates with Prof R. Compagnoni, Dr B. Lombardo and Dr S. Ferrando (University of Torino, Italy), on the age and composition of zircon in high pressure granulites from the Argentera Massif, Western Alps.
- Dr R. SALMERON collaborates with Prof A. Konigl and Dr C. Tassis (University of Chicago, USA), on dust dynamics and planet formation in protostellar discs.
- Mr R. SCHINTEIE collaborates with Dr N. Butterfield (Cambridge University, UK), on fossil bearing Neoproterozoic and Cambrian sedimentary rocks.
- Dr I.S. WILLIAMS and Prof R.W.R. RUTLAND with Dr J. Kousa (Geological Survey of Finland), The evolution of the Svecofennian orogen.
- Dr I.S. WILLIAMS with Dr J. Wiszniewska and Mrs E. Krzeminska (Polish Geological Institute, Poland), The evolution of the basement beneath the East European Platform in Poland.
- Dr I.S. WILLIAMS with Prof Oh Chang Whan and Dr Kim Sung Won (Chonbuk National University, South Korea), The timing of thermal events in South Korea and South China.
- DR I.S. WILLIAMS with Dr Kim Jeongmin, Mr Yi Keewook and Mr Kim Yoonsup (Korea Basic Science Institute and Seoul National University, South Korea), The chronology of thermal events in South Korea.
- Dr I.S. WILLIAMS with Dr H. Kaiden (National Institute for Polar Research, Japan), Isotopic analysis by SHRIMP ion microprobe.

Dr I.S. WILLIAMS with Dr K. Sato (Universidade de São Paulo, Brazil), Isotopic analysis by SHRIMP ion microprobe.

Earth Environment

M. AUBERT collaborates with Dr Dirk Huyg, Royal Museums of Art and History, Belgium, on the study of rock art in Egypt.

Dr L. K. AYLIFFE with Dr T.E. Cerling (University of Utah), Dr B. H. Passey (CALTECH).

Dr S. EGGINS collaborates with Prof. H. Spero and Dr A. Russell, University of California, Davis, on the temperature, light and carbonate ion controls upon trace element incorporation in laboratory cultured planktic foraminifera.

Dr S. EGGINS collaborates with Dr L. Skinner, University of Cambridge, on the distribution of trace metals in benthic foraminifera.

Dr S. EGGINS collaborates with Prof. S. Troelstra and Ms E Versteegh, Vrije Universitat, Amsterdam, on the trace metal proxies for environmental change in various European mollusks.

Dr S. EGGINS and Dr M. ELLWOOD collaborate with Dr M. Kelly Troelstra (NIWA, NZ), on the trace metal and B isotopes composition of siliceous sponges.

Dr M.J. ELLWOOD collaborates with Dr. Michelle Kelly (NIWA, NZ) on Understanding the growth habits of deep sea sponges, with Dr. Philip Boyd (NIWA, NZ) and Dr. Cliff Law (NIWA, NZ) on Trace element cycling in the Tasman Sea, with Dr Derek Vance (University of Bristol, UK) on Zinc isotope fractionation in diatoms.

Dr. S.J. FALLON collaborates with Dr. B. Roark, Prof. R. Dunbar (Stanford University) and Dr. T. Guilderson (Lawrence Livermore National Laboratory) on climate records from North Pacific Deep Sea Corals. Dr. Luke Skinner on ocean overturning from deep sea sediment cores.

Dr K.E. FITZSIMMONS collaborates with Prof. G.H. Miller (University of Colorado, Boulder) on comparison of aridity proxies (with Dr J.W. Magee, ANU); also monsoon influence on the north Australian arid zone.

Dr K.E. FITZSIMMONS collaborates with Dr M.W. Telfer (Oxford University) on assessing palaeoenvironmental records in the southern hemisphere arid zones.

Dr K.E. FITZSIMMONS (as research assistant to Dr E.J. Rhodes, formerly ANU, now Manchester Metropolitan University) collaborates with Assoc. Prof. S. Holdaway (University of Auckland) (western NSW archaeology program); Dr R.H. Tedford (American Museum of Natural History) (arid zone palaeoenvironmental reconstruction).

Dr M.K. GAGAN, Dr. L.K. AYLIFFE and Mr. D. QU with Dr W. Hantoro and Dr D. Natawidjaja (Indonesian Institute of Sciences), Prof. Z. Liu (University of Wisconsin – Madison), and Prof. K. Sieh (California Institute of Technology),

Partner investigators on ARC Discovery Grant DP0663227 (2006–2010): The Indian Ocean Dipole, Australasian drought, and the great-earthquake cycle: Long-term perspectives for improved prediction.

Dr M.K. GAGAN, Dr L.K. AYLIFFE and Ms S. BRETHERTON with Dr W. Hantoro (Indonesian Institute of Sciences) and Dr G. Schmidt (NASA Goddard Institute for Space Studies), Partner investigators on ARC Discovery Grant DP0663274 (2006–2008): Monsoon extremes, environmental shifts, and catastrophic volcanic eruptions: Quantifying impacts on the early human history of southern Australasia.

Dr M.K. GAGAN and Ms R. BERDIN with Dr F. Siringan (University of the Philippines), PhD dissertation on Late Quaternary climatic histories from raised coral terraces in the Philippines.

Dr M.K. GAGAN with Dr H. Kawahata (Tohoku University) and Dr A. Suzuki (National Institute of Advanced Industrial Science and Technology), Geochemical tracers in corals from the Philippines and Indonesia as proxies of past climate change and the history of marine pollution.

Dr M.K. GAGAN with Dr N. Abram (British Antarctic Survey), Seasonal characteristics of the Indian Ocean Dipole during the Holocene.

Prof R. GRÜN collaborated with Prof. C. Falgueres, Dr. J.J. Bahain and other staff members of the the Département de Préhistoire du Musée National d'Historie Naturelle, Paris, on the further development of dating techniques, he co supervises Mr M. Duval, who visited the ANU to carry out ESR and isotopic measurements for his PhD work and collaborates with Drs D. Grimaud-Hervé and M.H. Moncel on the application of new isotopic systems on Neanderthal remains.

Prof R. GRÜN collaborates on development of dating techniques with Dr. B. Maureille, Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1, on the site of Les Predelles, where Ms T KELLY carried out her Honours project.

Prof R. GRÜN collaborates with many international scholars on the timing of modern human evolution. He has collected hominid samples from the anthropological sites Cave of Hearths, and Hutjiespunt, South Africa (Prof V.A. Tobias, Dr L. Berger, Dept of Anatomy, Medical School, University of the Witwatersrand, Prof J. Parkington, Dept of Archaeology, Cape Town University), Skhul, Qafzeh, Tabun, Kebara and Amud, Israel (Prof Y. Rak, Department of Anatomy, Haifa University, Prof C.B. Stringer, Natural History Museum, London), Banyoles, Spain (Prof J. Maroto, Area de Prehistoria, Universitat de Girona), Irhoud, Sale and Thomas Quarry, Morocco (Prof J.J. Hublin, Max Planck Institute for Evolutionary Anthropology, Leipzig).

Prof R. GRÜN collaborates with Dr J. Brink, Bloemfontein, on the dating of a range of sites in South Africa, including the newly discovered human site of Cornelia. For the dating work in Africa, he collaborates with Prof. S. Brandt (University of Florida), Prof. M. Rodrigo (University of Madrid), Prof. J. Richter (Universität zu Köln), Prof. G. Barker (University of Cambridge)

Prof R. GRÜN continues collaboration with Dr A. Pike, Department of Archaeology, University of Bristol, on uranium uptake of bones and Prof T. de Torres, Escuela Tecnica Superior de Ingenieros de Minas de Madrid, on the calibration of amino acid racemisation in bones, cave bear evolution.

Mr. R. JOANNES-BOYAU collaborates with Pr C. Stringer, Department of Palaeontology, Natural History Museum, London, UK, on the study of the CO₂-defect for ESR dating of tooth enamel from Broken Hill.

Mr. R. JOANNES-BOYAU collaborates with Dr M-H. Moncel, Département de Préhistoire, Muséum National d'Histoire Naturelle, Paris, France, High resolution analysis of uranium and U-series isotope distributions in a Neanderthal tooth from Payre.

Dr S.D. JUPITER with Dr M. Field and Dr. C. Storlazzi of the U.S. Geological Survey on coral records of sediment influx to the south Molokai reef

Prof M.T. MCCULLOCH is collaborating with Prof Claudio Mazzoli (Dipartimento di Mineralogia e Petrologia, Università di Padova , Italy), and Dr. Paolo Montagna and Dr. Sergio Silenzi (Istituto Centrale di Ricerca Applicata al Mare – ICRAM, Rome , Italy) in assessing the impacts of climate change on shallow water coral reefs in the Mediterranean.

Prof M.T. MCCULLOCH is collaborating with Dr Marco Taviani, and Dr Alessandro Remia (ISMAR-CNR, Bologna, Italy) and Dr Paolo Montagna (Istituto Centrale di Ricerca Applicata al Mare – ICRAM, Rome, Italy), on Deep Sea Corals in the Mediterranean.

Prof M.T. MCCULLOCH is continuing collaboration with Prof Robert Dunbar and Dr Brendan Roarck (Department of Geological and Environmental Sciences, Stanford University, California, USA) on Deep Sea corals in the Pacific Ocean.

Prof M.T. MCCULLOCH is collaborating with Dr J. Blichert-Toft and Prof F. Albarede (Laboratoire des Sciences de la Terre, Ecole Normale Supérieure de Lyon, France), on Lu-Hf isotopes in ancient zircons.

Prof M.T. MCCULLOCH is continuing collaboration with Dr Juan Pablo Bernal (Septo.Geoquímica, Instituto de Geología, Universidad Nacional Autónoma de México, México) on the Terrestrial impacts on Coral reef in the Caribbean and speleothem deposits in Mexico.

Prof M.T. MCCULLOCH is collaborating with Prof Thierry Correge (Departement de Geologie et Oceanographie, Université de Bordeaux I, France) on U-series dating of modern corals from New Caledonia.

Prof M.T. MCCULLOCH is collaborating with Dr Dominik Fleitmann (Institute of Geological Sciences University of Bern) on speleothem research as well as coral reefs from Kenya.

Prof M.T. MCCULLOCH and Dr S.D. JUPITER are collaborating with Dr M. Field & Dr C. Storlazzi, U.S. Geological Survey, and Dr M. D'Iorio, William Lettis & Associates (CA, USA) on linkages between land use and water quality changes on Molokai, Hawaii.

Mr I. MOFFAT collaborated with N. Araho and A. Kuaso (PNG National Museum and Art Gallery) and Australian colleagues on the study of a wrecked Lakatoi and villages containing Motuan pottery associated with the Hiri trade in the Gulf Province, Papua New Guinea.

Mr I. MOFFAT collaborated with Dr M Hounslow (Lancaster University) and Australian colleagues on the application of geophysical techniques to the location of aboriginal skeletal remains on the Coorong, South Australia.

Prof B.J. PILLANS with Prof J. Ogg (Purdue University, USA) on the status of the Quaternary in the International Geological Time Scale

Dr P.C. TREBLE collaborates with Prof I.J. FAIRCHILD, University of Birmingham, on understanding the climatic controls on cave drip water geochemistry for her sites in southwest Western Australia.

Dr Dr M. WILLE is a part Agouron-Griqualand Paleoproterozoic Drilling Project (AGPDP). In collaboration with Prof. Nicholas Beukes, University of Johannesburg, South Africa, and Prof, Jan Kramers and Prof Thomas Nagler, University of Bern reconstructing paleoredox conditions between 2.7 and 2.5 Ga with Mo isotope systematics.

Dr Dr M. WILLE is in collaboration exists with Prof. Thomas Meisel, University Leoben, Austria, for measuring PGE and Re-Os in black shales.

Dr Dr M. WILLE is in cooperation with the University of Bern and Prof. Bernd Lehmann, University of Clausthal-Zellerfeld, Germany exist by trying to reconstruct redox changes at the Precambrian-Cambrian boundary

Dr Dr M. WILLE is in cooperation with the University of Bern and Dr. Anja Reitz, Geomar, Kiel, Germany exist by reconstructing Mo scavenging mechanism in Mediterranean sapropels

Earth Materials & Processes

Prof S.F. COX continued a collaboration with Dr N. Mancktelow (Eidgenössische Technische Hochschule (ETH) Zürich), Dr A.-M. Boullier (Universite Joseph Fourier, Grenoble), Dr Y. Rolland (Universite de Nice) and Dr G. Pennachioni (Universita di Padova) on fluid flow in Alpine shear zones.

Prof S.F. COX collaborates with Mr C. Barrie, Dr A. Boyle and Prof D. Prior (University of Liverpool) in the application of EBSD techniques to determine detailed deformation mechanisms in experimentally deformed pyrite.

Dr K. EVANS collaborates with Prof M. Bickle (University of Cambridge), Dr B.R. Frost (University of Wyoming, USA) and R. Gordon (Advanced Photon Source, Chicago, USA).

- Dr J.D. FITZ GERALD collaborates with Prof I Parsons (Grant Institute, University of Edinburgh) and Dr U. Golla-Schindler (Universität Münster) on feldspar exsolution.
- Dr J.D. FITZ GERALD collaborates with Dr A.K. Engvik (Geological Survey of Norway), Prof A. Putnis (Institut für Mineralogie, Universität Münster) and Prof H. Austrheim (Institute of Geosciences, University of Oslo) on Albitisation of granitoids.
- Dr J.D. FITZ GERALD collaborates with Dr A. Camacho (University of Manitoba) and Dr J.K. Lee (Queens University) on defect structures in phlogopite.
- Dr J.D. FITZ GERALD recently collaborated with Prof C.R. Barnes (University of Victoria, British Columbia) on conodont microstructures.
- Dr J.D. FITZ GERALD collaborated with Prof J. Shen (Harbin Institute of Technology) on bulk metallic glass.
- Dr M. FORSTER collaborates with Dr T. Ahmad (Delhi University, New Delhi, India) on the structure, tectonics and geochronology along major tectonic boundaries and a UHP dome of NW Himalaya.
- Dr M. FORSTER collaborates with Prof R. Compagnoni and Ms. C. Groppo, (Università degli Studi di Torino, Dip. di Scienze Mineralogiche e Petrologiche, Torino, Italy) on the structure, tectonics and geochronology of the PT path of High-Pressure Belt, Sifnos, Greece.
- Dr M. FORSTER collaborates with Prof R. Hall and Dr M. Cottam, (Southeast Asia Research Group, Royal Holloway University of London) on the timing and exhumation of Mt. Kinabalu region, NW Borneo.
- Dr M. FORSTER collaborated with Dr U. Ring (Uni of Canterbury, NZ) and Prof B. Wernicke (Caltech), to host the Post-Conference Fieldtrip on the Ios Metamorphic Core Complex in Central Greece, in association with the GSA Penrose Conference on Naxos.
- Prof D. H. GREEN collaborates with Dr F. Chalot-Prat of Dept of Mineralogy and Petrology, CRPG-CNRS and University of Nancy, Nancy, France; and with Dr Kiyooki Niida, Dept of Mineralogy and Petrology, University of Hokkaido, Sapporo, Japan
- Dr J. HERMANN collaborates with Prof M. Scambelluri and Dr N. Malaspina (University of Genova, Italy), Prof T. Pettke and Dr C. Spandler (University of Berne, Switzerland) on constraints on subduction zone fluids from high-pressure ultramafic rocks.
- Dr J. HERMANN collaborates with Dr A. Berry (Imperial College London, UK) and Dr A. Walker (Cambridge University, UK) on water incorporation in olivine.
- Dr J. HERMANN collaborates with Dr A. Hack (ETH-Zurich, Switzerland) on phase relations in solid-water systems.

- Dr J. HERMANN collaborates with Dr A. Korsakov (Novosibirsk, Russia) on coesite and diamond facies metamorphism in the Kokchetav Massif.
- Dr J. HERMANN collaborates with Dr M. Marocchi (University of Bologna, Italy) on trace element variations in hydrous minerals in mantle wedge peridotites and implications for mantle metasomatism.
- Dr J. HERMANN collaborates with Prof M. Engi and Dr A. Berger (University of Berne, Switzerland) on barrovian metamorphism in the Central Alps.
- Dr J. HERMANN collaborates with Prof B. Cesare (University of Padova, Italy) and Dr A. Acosta Vigil (University of Granada, Spain) on partial melting in crustal xenoliths of the South Spanish volcanic province.
- Dr J. HERMANN collaborates with Dr M.T. Gomez Pugnaire and Mr. J.A. Padron (University of Granada, Spain) on dehydration of antigorite in subducted serpentinites.
- Dr J. HERMANN collaborates with Dr M. Satish-Kumar (Shizuoka University, Japan) on monitoring volatile and trace element contents of fluids in high-grade marbles from Antarctica.
- Prof I. JACKSON collaborates with Prof R. Liebermann and colleagues (Stony Brook University, USA), Prof G. Gwanmesia (Delaware State University, USA), Prof J. Kung (National Cheng-Kung University, Taiwan) and Dr. S. Antao (Argonne National Laboratory, USA) in measurement and interpretation of high temperature elastic properties of minerals.
- Prof I. JACKSON collaborates with Prof U.H. Faul (Boston University, USA), Prof S. Morris (University of California, Berkeley), Dr. Y. Aizawa (Japan Manned Space Systems Corporation, Japan) and Prof A. Kishimoto (University of Hiroshima, Japan) in studies of high-temperature viscoelastic relaxation.
- Mr. I. KOVACS collaborates with Dr. Erik Hauri (Carnegie Institute, Washington D.C.) on SIMS-FTIR cross-calibration.
- Prof G. LISTER collaborates with Prof R. Compagnoni (University of Torino, Italy) and Prof Jean-Pierre Burg, (ETH, Zurich) in a study of tectonic shuffle zones.
- Dr J MAVROGENES is collaborating with Dr J. Mungall (University of Toronto) on PGEs in arc magmas.
- Emeritus Prof I. MCDOUGALL maintains a close collaboration with Prof F.H. Brown (University of Utah, Salt Lake City, USA) in relation to geochronological studies on the Turkana Basin sedimentary sequence in northern Kenya and southern Ethiopia in east Africa.
- Dr S. MICKLETHWAITE collaborates with Dr Z. Shipton (The University of Glasgow, UK) and Dr R. Lunn (Strathclyde University, UK) on observational and theoretical aspects of fault mechanics and fault-influenced fluid migration.
- Prof H. O'NEILL collaborates with Prof H. Palme and Dr G. Witt-Eickschen (University of Cologne, Germany) on chalcophile element concentrations in the mantle.

- Prof H. O'NEILL collaborates with Prof T. Irifune (Ehime University, Japan) on experimental petrology at very high pressures.
- Prof H. O'NEILL collaborates with Dr. A. J. Berry (Imperial College, London, UK) on oxidation states of cations in silicate melts.
- Prof H. O'NEILL collaborates with Dr Xi Liu (University of Western Ontario, Canada) on the influence of minor elements on mantle melting.
- Prof H. O'NEILL works in collaboration with Dr. A Walker (Cambridge University, UK) on water substitution mechanisms in olivine.
- Mr C. PIRARD collaborates with Dr F. Hatert (University of Liège, Belgium) on the mineralogy and metallogeny of Cu-Co-U-Se deposits of Katanga, D.R. Congo.
- Mr C. PIRARD collaborates with Prof A.-M. Fransolet and Dr F. Hatert (University of Liège, Belgium) on the effect of Na-metasomatism in phosphates-bearing pegmatitic systems.
- Dr R.P. RAPP collaborates with Profs H. Martin and D. Laporte (Laboratoire Magmas et Volcans, Université de Blaise Pascal, Clermont-Ferrand, France) on an experimental study of origin of Earth's early continental crust, and slab-mantle interactions in subduction zones.
- Dr R.P. RAPP collaborates with Prof Tetsuo Irifune (Geodynamics Research Center, Ehime University, Japan) on technological advances in high pressure techniques in the multi-anvil apparatus.
- Dr R.P. RAPP collaborates with Prof J-F. Moyen (University of Stellenbosch, South Africa), on the tectonic evolution of the Barberton granite-greenstone belt in South Africa.
- Dr R.P. RAPP collaborates with Prof Nobu Shimizu (Woods Hole Oceanographic Institution, USA) on developing new analytical techniques for the ion microprobe and their application to very small, ultra-high pressure experimental samples.
- Dr R.P. RAPP collaborates with Prof S. Foley (Institut für Geowissenschaften, Universität Mainz, 55099 Mainz, Germany) on an experimental study of the melting relations of volatile-bearing mantle peridotite.
- Dr S. RICHARDS collaborates with Dr Grahame Oliver (St Andrews University, Scotland) on Buchan and Barrovian metamorphism in Scotland.

Earth Physics

- Dr D.R. CHRISTIE collaborates with Dr P. Campus, Comprehensive Nuclear-Test-Ban Treaty Organization, United Nations, Vienna, Austria on infrasound monitoring of volcanoes and CTBT verification activities.

- Mr J. DAWSON collaborates with Mr M. Baessler, Institut für Planetare Geodäsie, Technische Universität Dresden, on application of interferometric synthetic aperture radar for surface deformation and topography estimation.
- Dr A. DUTTON collaborates with Dr F. Antonioli (ENEA, Rome, Italy), Dr C. Monaco (University of Catania, Italy), and G. Scicchitano, (PhD candidate, University of Catania, Italy) on constraining the tectonic uplift of the Siracusa coastline in Sicily.
- Dr A. DUTTON collaborates with Dr F. Antonioli on reconstructing sea level change in the Mediterranean over the past several glacial-interglacial cycles using U-series ages of submerged speleothems.
- Dr A. DUTTON collaborates with Dr T. Bralower (Pennsylvania State University, USA) and Dr P. Pearson (Cardiff University, UK) on identifying and quantifying diagenesis of tropical planktonic foraminifera from ancient greenhouse climates.
- Dr A. DUTTON collaborates with Dr M. Malone (Integrated Ocean Drilling Program, TAMU, USA) on the geochemistry of diagenetic signatures in foraminiferal calcite.
- Ms G. ESTERMANN collaborates with Guillaume Ramillien, LEGOS - Observatoire Midi Pyrenees, Toulouse, France, on changes in gravitational potential of the orbits as a result of mountain deglaciation.
- Dr F. FONTAINE collaborates with Dr G. Barruol (CNRS, France), Prof G. Bokelmann (Université Montpellier II, France) and Dr D. Reymond (LDG CEA, French Polynesia) on the structure of the crust and upper mantle beneath Australia and French Polynesia. He also worked with Dr D. Mainprice (CNRS, France), Dr D. Neuville (IP Paris, France) and Dr B. Ildefonse on seismic attenuation and viscosity of basalts
- Prof R.W. GRIFFITHS and Dr G.O. HUGHES, with Prof J.R. Lister (University of Cambridge, UK), and Drs J.C. Mullarney (Dalhousie University, Canada) and W.H. Peterson on 'horizontal convection'.
- Prof R.W. GRIFFITHS continued collaboration with Prof C. Kincaid (University of Rhode Island, USA) on the flow in mantle subduction zones and the interaction of mantle plumes with subduction, funded by an ARC International Linkage grant.
- Dr A.McC. HOGG with Prof W.K. Dewar (Florida State University, USA) and P. Berloff (Woods Hole Oceanographic Institution, USA and University of Cambridge, UK) on the dynamics of ocean gyres.
- Dr A.McC. HOGG with Dr. M.P. Meredith (British Antarctic Survey, UK), Dr. C. Wilson (Proudman Oceanographic Laboratory, UK) and Mr J.R. Blundell (National Oceanography Centre, UK) on eddy heat flux in the Southern Ocean.
- Prof B.L.N. KENNETT continues to collaborate with Dr E. Debayle, University of Strasbourg, France, Dr K. Priestley, University of Cambridge, UK, Dr S Fishwick, University of Leicester, UK, and Dr K. Yoshizawa, University of Hokkaido, Japan on surface wave tomography.

Prof B.L.N. KENNETT has collaborated with Dr T. Furumura at the Earthquake Research Institute, University of Tokyo, Japan on a variety of issues in seismic wave propagation, particularly the propagation of high frequency waves from the Indonesian subduction zone into stations in northern Australia.

Dr R.C. KERR with Prof J.R. Lister (University of Cambridge, UK) on the horizontal deflection of mantle plumes.

Prof K. LAMBECK collaborates with Dr F. Antonioli, ENEA, Rome, and Dr M. Anzidei, Istituto Nazionale di Geofisica e Vulcanologia, Rome, on sea-level change in the Mediterranean Sea.

Prof K. LAMBECK collaborates with Dr C. Sparrenbom, Swedish Geotechnical Institute, Prof Svante Björck, GeoBiosphere Science Centre, Lund University, and Dr Ole Bennike, Department of Environment History and Climate Development, Geological Survey of Denmark and Greenland on ice sheet evolution and sea-level changes in southern Greenland.

Prof K. LAMBECK collaborates with Prof G. Bailey, Department of Archaeology, University of York, UK, and Prof C. Vita-Finzi, The Natural History Museum, London, on an EFCHED project relating to archaeology in the Red Sea Basin.

Prof K. LAMBECK collaborates with members of the Steering Committee for the World Climate Research Programme Workshop "Understanding Sea-level Rise and Variability" on the publication arising from this workshop.

Prof K. LAMBECK, Member of Executive Committee, InterAcademy Panel on international issues.

Prof K. LAMBECK led the Australian delegation to Beijing for the fourth annual China Australia Symposium on Sustaining Global Ecosystems, Beijing, 8-10 August 2007.

Prof K. LAMBECK attended the Federation of Asian Scientific Academies and Societies (FASAS) Council Meeting, Bangkok, 27-29 November, 2007.

Dr N. RAWLINSON collaborates with: Prof Greg Houseman, University of Leeds, on teleseismic tomography; Dr. Sebastian Rost, University of Leeds, on seismic array analysis of core phases; and Yanlu Ma, Graduate School of the Chinese Academy of Sciences, on imaging the core-mantle boundary.

Mr. D. ROBINSON collaborates with Prof Roel Snieder, Center for Wave Phenomena, Colorado School of Mines, and Dr Kim Olsen, Department of Geological Sciences, San Diego State University, and Dr Jim Rutledge, Geophysics Group, Los Alamos National Laboratory, and Dr Daniel O'Connell, Geophysics, Paleohydrology, and Seismotectonics Group, U.S. Bureau of Reclamation.

Dr M. SAMBRIDGE with Dr. T. Baba (JAMSTEC, Japan), Methods for choosing hyper parameters in Earthquake slip inversion.

Dr M. SAMBRIDGE with Prof K. Gallagher (Univ. of Rennes, France), Monte Carlo inversion and reversible jump algorithms for nonlinear inversion.

- Dr M. SAMBRIDGE with Dr. E. Debayle (Univ. of Strasbourg, France), Coupled surface and body wave inversions for mantle seismic structure.
- Dr M. SAMBRIDGE with Prof J. Tromp (California Inst. Of Technology, USA), Inversion algorithms for adjoint gradient methods in seismology.
- Dr. W. P. SCHELLART started collaboration with Prof W. Spakman (Utrecht University, Netherlands) and M. Amaru (Chevron, USA), primarily working seismic tomography of the Southwest Pacific region.
- Dr. W. P. SCHELLART started collaboration with Dr Randell Stephenson (Free University, Netherlands) working on the tectonic evolution of the Black Sea.
- Dr. W. P. SCHELLART started collaboration with Dr Keith Martin (Repsol YPF, Dubai) working on the opening of the Weddell Sea and the break-up of Gondwana.
- Dr H. TKALCIC has collaborated with with Prof Doug Dreger, University of California at Berkeley, Prof Gillian Foulger, University of Durham and Dr. Bruce Julian, USGS, on anomalous seismic radiation earthquakes in the Bárðarbunga area of Iceland.
- Dr H. TKALCIC continues to collaborate with Ph.D. candidate D, Villagomez and Prof D, Toomey, University of Oregon, USA, on lithospheric structure under the Galápagos Islands from teleseismic receiver functions and surface waves;
- Dr H. TKALCIC continues to collaborate with Dr Y. Chen, Multimax, Inc., USA, on studying lithospheric structure under the southern China region from teleseismic receiver functions and surface waves;
- Dr H. TKALCIC continues to collaborate with Prof M. Herak, Dr. S. Markusic and Ph.D. candidate J. Stipcevic, on studying lithospheric structure under Croatia and the Adriatic Sea from teleseismic receiver functions;
- Dr H. TKALCIC collaborates with Ph.D. candidate A. Fichtner, University of Munich, Germany, on using a spectral element code that he has developed to study the propagation effects under Australia and Iceland;
- Dr H. TKALCIC collaborates with Dr. S. Chevrot, on studying anomalous travel times of core-sensitive seismic phases recorded in Alaska.
- Dr P. TREGONING collaborated with Dr G. Ramillien and Dr J-M. Lemoine on the analysis of GRACE satellite data. He also continued collaboration with Prof T. Herring and Drs R. King and S. McClusky on the development of the GAMIT GPS software.

PRISE

Dr R.A. ARMSTRONG collaborates with Prof M. Macambira (Federal University of Pará, Belem, Brazil) on the crustal growth history of the Amazonian Craton,

Dr R.A. ARMSTRONG collaborates with Prof N. Beukes and Dr S. Schroeder (University of Johannesburg, South Africa) on the chronostratigraphy of the Palaeoproterozoic sequences of the Kaapvaal Craton and the Agouron-Griqualand Proterozoic Drilling Project.

Dr R.A. ARMSTRONG collaborates with Dr E. Roberts (Witwatersrand University) on provenance and age of detrital zircons from the Rukwa Rift Basin, Tanzania.

Dr R.A. ARMSTRONG collaborates with K.H. Hoffmann (Geological Survey of Namibia) on determining the ages of Neoproterozoic glaciations in Namibia.

Dr R.A. ARMSTRONG collaborates with Dr A. Cocherie (BRGM, France) on SHRIMP characterization of a potential monazite standard.

Dr R.A. ARMSTRONG collaborates with Dr P. Mendonides (Vaal University of Technology, South Africa) on the geochronology of granites from southern KwaZulu-Natal.

Dr R.A. ARMSTRONG collaborates with Prof E. Dantas and Prof M. Pimentel (University of Brasilia, Brazil) on U-Pb-Hf geochronology and isotope geochemistry on various sequences in Brazil.

Dr R.A. ARMSTRONG collaborates with Prof M. Heilbron and S. de Souza (Rio de Janeiro State University, Brazil) on SHRIMP U-Pb geochronology of the Ribeira Belt, Brazil.

Dr R.A. ARMSTRONG collaborates with Dr G. de Kock (Council for Geoscience, South Africa) on the geochronology of Ghana.

Dr R.A. ARMSTRONG collaborates with Dr Geoff Grantham (Council for Geoscience, South Africa) on a regional mapping and geochronological study of the Mozambique Belt.

Dr R.A. ARMSTRONG collaborates with Dr Paul Macey (Council for Geoscience, South Africa) on the geochronology of western Madagascar.

Dr R.A. ARMSTRONG collaborates with Dr Ken Ludwig (Berkeley Geochronology Center, California, USA) on development and testing of SHRIMP data reduction software.

Mr C.M. FANNING continued his collaboration with Prof P.K. Link, Idaho State University on the provenance and time of deposition of Neoproterozoic sequences in Utah and Idaho.

Mr C.M. FANNING collaborated with Dr J. Goodge (University in Minnesota, Duluth) on the geochronology and provenance of sequences in the central Transantarctic Mountains.

- Mr C.M. FANNING continued his collaboration with Prof F. Hervé (Universidad de Chile) and Dr R.J. Pankhurst (British Geological Survey) on the geochronological and tectonic evolution of the Patagonia, Tierra del Fuego and the Antarctic Peninsula.
- Mr C.M. FANNING is collaborating with Dr M. Babinski (Universidade de Sao Paulo) on the geochronology of Marinoan sequences in Brazil and Uruguay.
- Mr C.M. FANNING continued his collaboration with Prof C. Rapela, (Universidad Nacional de La Plata, Argentina) and Dr R.J. Pankhurst (British Geological Survey) on the geochronological and tectonic evolution of the north Patagonian massif and adjacent cratons/terrains of Argentina.
- Mr C.M. FANNING collaborated with Dr C. Casquet and Dr C. Galindo (Universidad Complutense, Madrid) on the geochronological and tectonic evolution of NW Argentina and western Peru.
- Mr C.M. FANNING continued his collaboration with Dr J.N. Aleinikoff (United States Geological Survey) on SHRIMP II U-Pb analyses of zircon and xenotime.
- Mr S.S.M. HUI collaborates with Prof R.P. Harvey, (Case Western Reserve University, Ohio, USA) on analysis of cosmic spherules from the Lewis Cliff, Antarctica
- Dr M.D. NORMAN collaborates with Mr. F. Keppie (McGill University, USA) on the tectonothermal evolution of southern Mexico.
- Dr M.D. NORMAN collaborates with Profs M. Garcia (University of Hawai'i, USA), M. Rhodes (University of Massachusetts, USA), D. Weis (University of British Columbia, USA), and A. Pietruszka (San Diego State University, USA) on the magmatic evolution of Hawaiian volcanoes.
- Dr M.D. NORMAN collaborates with Drs L. Nyquist, D. Bogard, and A. Brandon (NASA Johnson Space Center, USA) on the composition and evolution of the Moon.
- Ms A. ROSENTHAL collaborates with Dr. Heidi Hoefler and Prof Alan B. Woodland, Universität Frankfurt, obtaining measurements of Fe³⁺/Fe in garnets from Norwegian peridotites and garnet-clinopyroxenites using the electron microprobe "flank method" (Hoefler & Brey, 2007) and Mossbauer spectroscopy to establish the oxidation state of the Norwegian peridotite body and to develop standards for Fe³⁺/Fe in garnets.
- Dr G.M. YAXLEY collaborates with Prof Steven Foley, University of Mainz, on partial melting of peridotite+H₂O+CO₂ at 4.0 - 6.0 GPa.
- Dr G.M. YAXLEY, and A. Rosenthal collaborate with Prof A.V. Sobolev (Vernadsky Institute, Russia) on high pressure partial melting of garnet pyroxenite.
- Dr G.M. YAXLEY with Dr A. Camacho, University of Manitoba, on kinetics of the reaction albite = jadeite + quartz.

Cooperation with government and industry

Earth Chemistry

Dr J.J. BROCKS with Dr E. Grosjean and G.E. Logan (Geoscience Australia), The use of polyethylene byproducts to determine the permeability of rock.

Dr J.J. BROCKS with Mr. R. Schinteie (ANU) and Dr G. Ambrose (Central Petroleum Ltd.), Petroleum Potential in the Centralian Superbasin, Australia.

Prof T.R. IRELAND continues to collaborate with Australian Scientific Instruments and Geoscience Australia.

Ms D. VALENTE and Prof I.H. CAMPBELL with Phelps Dodge, on the geochemistry, geochronology and evolution of the El Abra porphyry copper deposit in Northern Chile.

Ms D. Valente with El Abra S.C.M., Chile (subsidiary of Freeport Ltd.), PhD studies support.

Dr I.S. WILLIAMS holds a 25% appointment as Chief Scientist at Australian Scientific Instruments Pty. Ltd., a subsidiary of ANU Enterprise, where he works on SHRIMP development, marketing, testing and operator training.

Dr I.S. WILLIAMS provided SHRIMP technical and scientific advice to the Geological Survey of Canada (Ottawa, Canada), Hiroshima University (Hiroshima, Japan), The National Institute of Polar Research (Tokyo, Japan), The Chinese Academy of Geological Sciences (Beijing, China), the All Russian Geological Research Institute (St. Petersburg, Russia), the Korea Basic Science Institute (Daejeon, South Korea) and the University of São Paulo (São Paulo, Brazil).

Dr I.S. WILLIAMS provided on-site scientific and technical training in secondary ion mass spectrometry to scientists from laboratories that have purchased SHRIMP ion microprobes: Dr H. Kaiden (National Institute for Polar Research, Japan), Dr Kim Jeongmin, Mr Yi Keewook and Mr Kim Yoonsup (Korea Basic Science Institute and Seoul National University, South Korea) and Dr K. Sato (Universidade de São Paulo, Brazil).

Earth Environment

Prof R. GRÜN collaborates with the Department of Environment and Conservation, NSW, and the Three Traditional Tribal Groups in the ARC Linkage grant Environmental Evolution of the Willandra Lakes World Heritage Area.

Prof. M.T. McCULLOCH and Dr S.D. JUPITER from RSES continued their collaboration with the Great Barrier Reef Marine Park Authority, the Mackay Whitsunday Natural Resource Management Group and the Mackay City Council, in long-term changes in Mackay Whitsunday water quality and connectivity between coral reefs and mangrove ecosystems.

Prof. M.T. McCULLOCH together with Jon Brody from JCU and Dr Fabricius from AIMS are collaborating with the Commonwealth Department of Environment and Heritage in The Marine and Tropical Sciences Research Facility (MTSRF) which is part of the Commonwealth Environmental Research Facilities Program (CERF), an initiative of the Australian Government to invest in world-class public good research over the next four years. Prof McCulloch is involved in a project to support the conservation and sustainable use of the Great Barrier Reef and the connecting coastal regions, focusing on the highly intensive land-use catchments of the Townsville to Cairns region.

Mr I. MOFFAT collaborated with J. Raupp (Flinders University and Department of Environment and Heritage, SA) on the attempted location of the anchor of the Casurina, a vessel that was part of Baudan's exploratory fleet.

Mr I. MOFFAT assisted the Major Crime Squad, South Australia by performing geophysical survey as part of two murder investigations in Adelaide, South Australia.

Prof B.J. PILLANS with Woodside Energy, regolith and rock art on the Burrup Peninsula, Western Australia.

Prof B.J. PILLANS with Newmont Australia. Geochronology of landscape evolution in the Tanami region, Northern Territory

Dr P.C. TREBLE with Land & Water Australia, Drs M FISCHER & E Hodge (Australian Nuclear Science and Technology Organisation (ANSTO)), WA Department of Conservation and Land Management, Naracoorte Caves World Heritage Area, and NSW Department of Environment and Conservation (Yarrangobilly Caves)

Earth Materials & Processes

Prof S. F. COX and Dr S. Micklethwaite are collaborating with a consortium of minerals industry sponsors, via AMIRA International, in an ARC Linkage project "Exploration potential of stress transfer modelling in fault-related mineral deposits".

Prof S.F. COX is collaborating with Gold Fields Australia Limited in a PhD project "Deformational Controls on Dynamics of Fluid Flow, Hydrothermal Alteration and Ore Genesis, Argo Gold Deposit, WA". This project is jointly funded by Gold Fields Australia Limited and an ARC Linkage grant.

Dr M. FORSTER cooperates with Dr L. Wyborn (Geoscience Australia) in regard to telechronology, discussion and resources for automation and data storage in geochemistry and geochronology and as a national assessment.

Dr M. FORSTER collaborates with Dr Nigel Wood, Australian Nuclear Science and Technology Organisation (ANSTO) Lucas Heights, Sydney in respect to 'fast neutron rig' for argon irradiation facility in OPAL reactor.

Dr J. MAVROGENES and Dr C McFARLANE collaborated with Randgold Resources Limited on a study of the Morila Au mine in Mali.

Dr S. MICKLETHWAITE collaborates with T. Beardsmore, L. Gauthier, C. Weakly, and P. Dobak (Barrick Limited), A. Hawkins, B. Davis, J. Essman, and R. Reid (Newmont Limited), S. Shakesby, B. Spence, and F. Maccorquodale (Newcrest Limited), S. Cooke, and I. Pegg (Gold Fields Limited). Three major industry reports have been produced this year: Dr S. MICKLETHWAITE and Dr S.F. COX, (2007) Cracow epithermal goldfield, SE Queensland, Australia (Field Study Report), AMIRA International P718A, p. 10; Dr S. MICKLETHWAITE and Dr S.F. COX, (2007) Cracow epithermal goldfield, SE Queensland, Australia (Field and Modelling Results), AMIRA International P718A, p. 23; Dr S. MICKLETHWAITE (2007) Golden Mile: P718 Update, p. 10.

Dr S. RICHARDS collaborates with Dr Heilke Jelsma (DeBeers Exploration) on structural controls on kimberlite magmatism.

Earth Physics

Dr D.R. CHRISTIE with Dr D.J. Brown (Geoscience Australia) on matters related to verification of the Comprehensive Nuclear-Test-Ban Treaty.

Dr F. FONTAINE and Prof B. Kennett with T. Aravanis (Rio Tinto Exploration) realized a short seismic experiment in Shannons Flat to get constraints about the subsurface structure using the seismic noise.

Prof B.L.N. KENNETT has continued to provide support to the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organisation in Vienna through the operation of the Warramunga Seismic and Infrasound Research Station near Tennant Creek in the Northern Territory. The seismic and infrasound arrays have been very ably supported by Scott Savage as station manager at Warramunga. Very high reliability has been achieved with data transmitted continuously to the International Data Centre in Vienna via satellite link

Prof K. LAMBECK, as President of the Australian Academy of Science, was a member of the Prime Minister's Science Engineering and Innovation Council.

Prof K. LAMBECK, as President of the Australian Academy of Science, was a jury member for the L'Oréal Australia Inaugural 2007 For Women in Science Fellowships.

Prof K. LAMBECK was Science Advisor to the National Geospatial Reference System, Geoscience Australia.

Dr N. RAWLINSON collaborates with Dr. Marthijn de Kool (Geoscience Australia) on seismic wavefront propagation in complex 3-D media, and with Dr. Dave Robson (NSW Geological Survey) on teleseismic tomography in NSW.

Dr M. SAMBRIDGE with Dr. P. Cummins (Geoscience Australia), Robust and rapid Earthquake slip inversion for the Australian Tsunami Warning System.

Dr P. TREGONING with Dr P. Cummins (Geoscience Australia) on earthquake deformation in the Southwest Seismic Zone. Dr P. Tregoning with Mr G. Johnston on the establishment and rollout of the Geospatial component of AuScope.

PRISE

Dr R.A. ARMSTRONG and Dr C. McFARLANE are working with G. Cameron and P. Heidstra (Randgold Resources Limited) on SHRIMP sulphur isotope characterization of the Morila gold deposit, Mali.

Dr R.A. ARMSTRONG collaborates with Dr Hielke Jelsma (De Beers) on the geochronology of Angola and diamond exploration.

Dr M.D. NORMAN collaborates with S. Roy and M. Grummet (Amerada Hess) on diagenesis and fluid migration in the El Gassi oil field, Algeria.

Staff activities 2007

Conferences and outside studies
Editorial responsibilities
Outreach and workshops
Teaching activities
Honours supervision
Other matters

Conferences and outside studies

Earth Chemistry

Dr C.M. ALLEN attended the Geological Society of America meeting in Denver Colorado, USA to present a paper on dating detrital rutile grains; she also gave seminars at Texas Tech University and University of Wyoming.

Mrs. J.N. AVILA, First SINS Summer School on Nuclear Astrophysics & Nucleosynthesis, Monash University, Melbourne, Australia, 8-19 January.

Mrs. J.N. AVILA, Mass Spectrometry Course, The Australian National University, Canberra, Australia, 19 February – 02 March.

Mrs. J.N. AVILA, SHRIMP Stable Isotope Workshop, The Australian National University, Canberra, Australia, 10-11 September.

Mrs. J.N. AVILA, The Workshop on the Chronology of Meteorites and the Early Solar System, Hawaii, USA, 5-7 November, presented a poster entitled "Chronology of Presolar Silicon Carbide: Assessing the Viability of the U-Th-Pb System".

Mrs. J.N. AVILA, post-meeting field trip to the Big Island, Hawaii, The Workshop on the Chronology of Meteorites and the Early Solar System, Hawaii, USA, 8-9 November.

Dr V. C. BENNETT was a visiting scientist at the Lunar and Planetary Institute and NASA Johnson Space Center, Houston, Texas, USA from 20 October to 6 December.

Dr V. C. BENNETT, 17th Goldschmidt Conference, 19-24 August, Cologne Germany, was a keynote speaker and presented a paper entitled: "Crust- mantle dynamics in the early Earth: The ^{142}Nd - ^{143}Nd and ^{176}Hf isotopic perspective".

Dr V. C. BENNETT, 38th Lunar and Planetary Science Conference, 12-16 March, Houston Texas, presented a paper entitled "Coupled ^{142}Nd , ^{143}Nd and ^{176}Hf isotopic data from 3.6 -3.9 Ga rocks: New constraints on the timing and composition of early terrestrial chemical reservoirs".

Dr J.J. BROCKS, Opening Lecture for Series A, Centre of Macroevolution and Macroecology, 7 February The Australian National University, "Extremely Ancient Molecules".

- Dr J.J. BROCKS, 17th Annual V. M. Goldschmidt Conference, 24 August, Plenary Lecture 'Molecular Fossils and Early Life on Earth', Cologne, Germany.
- Dr J.J. BROCKS, 17th Annual V. M. Goldschmidt Conference, 22 August, session co-chair with Dr. E. Javaux of 'Early evolution of life and the hydro- and atmosphere', Cologne, Germany.
- Dr J.J. BROCKS, invited seminar presentation 'Extremely ancient molecules and the early evolution of eukaryotes', 14 March, University of Adelaide.
- Dr J.J. BROCKS, invited seminar presentation "Extremely ancient molecules and the early evolution of eukaryotes", 20 April, University of Queensland.
- Dr J.J. BROCKS, presentation "Molecular Fossils and Early Life on Earth", 27 September, University of Sydney.
- Dr J.J. BROCKS with Prof A. Cooper (University of Adelaide), conducted field work in Naracoorte Cave to collect sediment and bone samples to study molecular indicators of DNA damage, 15 March 2007.
- Dr J.J. BROCKS with Prof J. Banfield (Berkeley), Prof E. Allen (UC San Diego) and Prof K. Heidelberg (U. of Southern California), conducted field work at Lake Tyrrell, Victoria, to collect samples for biomarker analysis and environmental genomics, 18 to 28 January.
- Dr J.J. BROCKS with Prof J. Banfield, Ms C. Jones (Berkeley), Prof E. Allen (UC San Diego) and Prof K. Heidelberg (U. of Southern California), 2007, conducted field work at Lake Tyrrell, Victoria, to collect samples for biomarker analysis and environmental genomics, 5 to 12 August.
- Dr I.S. BUICK undertook collaborative analytical work at Lehigh University (USA) and the University of Edinburgh (UK), and attended the Frontiers in Mineral Science meeting at the University of Cambridge in June.
- Prof I.H. CAMPBELL visited the Institute for Study of Earth's Interior at the University of Okayama in Misasa, Japan for six weeks.
- Ms T.A. EWING, 2007 EURISPET (European Intensive Seminars of Petrology) School on "State-of-the-art analytical and imaging techniques in petrology", Paris, France, 20-28 October.
- Ms T.A. EWING conducted field work in the Ivrea-Verbano Zone (Western Alps) from 13 - 19 October.
- C. J. GREGORY, Geological Society of Australia SGTSG Conference "Deformation in the Desert", Alice Springs, Australia, 9-13 July, presented a paper entitled "The timing of prograde metamorphism and partial melting during the Petermann Orogeny".
- Mr J. HIESS, 17th Annual V.M. Goldschmidt Conference, Cologne, Germany, 20-24 August, presented a paper entitled "In situ Hf and O isotopic data from Archean zircons of SW Greenland."

- Mr J. HIESS, SHRIMP Stable Isotope Workshop, RSES, ANU, Canberra, Australia, 10-11 September, presented a paper entitled "Insights to Crustal Petrogenesis - In situ O and Hf isotopic data from Archean zircons of SW Greenland."
- Dr M. HONDA, Earth Dynamics 2007, Canberra, 5-7 November, presented a paper entitled "Automation of Noble Gas Extraction Line with Remote Access at ANU".
- Mr R. ICKERT, 2nd Biennial Conference of the Specialist Group in Geochemistry, Mineralogy, and Petrology, Geological Society of Australia, Dunedin, NZ, 14-19 October, presented a paper entitled "Correlated, In-Situ Analysis of U/Pb, ^{180}O and eHf in Zircon from Siluro-Devonian Granite in the Eastern Lachlan Orogen: Constraints on Juvenile Additions to the Continental Crust".
- Mr R. ICKERT, 1st European Intensive Seminar of Petrology, Paris, France, 20-28 October, presented a paper entitled "Constraints on granite petrogenesis in SE Australia from in situ isotope ratio measurements"
- Prof T.R. IRELAND, "SIMS in the Space Sciences - the Zinner Impact" Conference, 29 January - 6 February, St Louis USA.
- Prof T.R. IRELAND, Lunar and Planetary Sciences Conference, 10-18 March, Houston USA.
- Prof T.R. IRELAND, Chronology of Meteorites Conference, 4-11 November, Hawaii USA.
- Dr C.H. LINEWEAVER, American Astronomical Society Meeting, Seattle, USA, 6-12 January and presented a paper entitled "The Metallicities of Stars with Close Companions"
- Dr C.H. LINEWEAVER, Bioastronomy 2007, San Juan, Puerto Rico, 15-20 July and presented a paper entitled "The Chemical Composition of Other Earths".
- Mr. S. J. MCKIBBIN, Workshop on the Chronology of Meteorites and the Early Solar System, 5-7 November, presented a poster entitled "Solar System Isotopic Heterogeneity from ^{53}Mn - ^{53}Cr ".
- Dr D. RUBATTO, AMAS IX Symposium, Brighton, Victoria, 14-16 February 2007, presented an invited paper entitled "The impact of microanalysis on geochronology and the study of accessory minerals".
- Dr D. RUBATTO, 17th Goldschmidt Conference, Cologne, Germany, 19-24 August 2007, presented a paper entitled "Migmatization in the Central Alps lasting 10 m.y.".
- Dr D. RUBATTO, workshop on "Accessory minerals in-situ: microanalytical methods and petrological applications", Krakow, Poland, 15-16 September 2007, presented an invited paper entitled "A microanalytical study of fluid-induced zircon and allanite recrystallization".
- Dr R. SALMERON, Nuclear Astrophysics and Nucleosynthesis Workshop, Stellar and Planetary Astrophysics, Monash University, 14-18 January.

Dr R. SALMERON, Origin of Solar Systems, Gordon Research Conference, Boston, 8-13 July, presented a poster entitled "Magnetorotational instability in protoplanetary disks".

Dr R. SALMERON, Chronology of Meteorites and the Early Solar System, University of Hawaii, 5 – 7 November, poster presentation entitled "Jets and Outflows in Protoplanetary Disks".

Ms D. VALENTE presented a two-day seminar/field-trip based on the results of her PhD studies for El Abra S.C.M staff in Chile during the period 11-12 September.

Dr I.S. WILLIAMS, 17th Annual V.M. Goldschmidt Conference, Cologne, Germany, 14-24 August, represented Australian Scientific Instruments at their exhibition booth, including demonstrating SHRIMP remote analysis.

Dr I.S. WILLIAMS, study leave at the Polish Geological Institute, Warsaw, preparing work carried out in collaboration with Dr J. Wiszniewska and Mrs E. Krzeminska for publication, 25-31 August.

Dr I.S. WILLIAMS, invited lecture at Earth Dynamics 2007, Australian Academy of Science, Canberra, entitled "Telegeochronology: Remote operation of the SHRIMP ion microprobes", 7 November.

Dr I.S. WILLIAMS, invited lecture on the commercialisation of the products of university research at the Annual General Meeting of the Australian Academy of Technological Sciences and Engineering, Perth, entitled "Bridging the Divide", 18 November.

Dr X. ZHANG, Earth Dynamics 2007, Canberra, 5-7 November, presented a paper entitled "Automation of Noble Gas Extraction Line with Remote Access at ANU".

Earth Environment

Mr M. AUBERT, XVII INQUA Congress, 28 July – 3 August 2007, Cairns, Australia, "High resolution elemental and isotopic distribution in fossil teeth: Implications for diet and migration", Abstract 0880, Quaternary International 167-168, 17-18.

Dr L. AYLIFFE attended INQUA 2007, Cairns, Australia, 28 July – 3 August, and presented two papers entitled "Speleothems from Flores, Indonesia tropical archives of climate and environmental change throughout the past two glacial cycles." And "Changes in the $^{234}\text{U}/^{238}\text{U}$ of sea water over the past 50ka as reflected in corals from the central and western Pacific."

Dr L. AYLIFFE conducted fieldwork on the island of Flores, Indonesia from 20 May – 24 June.

Dr L. AYLIFFE visited Dr J. Hellstrom at The University of Melbourne in October to perform U-Th dating of micro-carbonate samples from Liang Bua, Flores, Indonesia.

- Ms S.C BRETHERTON, attended 17th International Union for Quaternary Research Congress, Cairns, Australia, 28 July – 3 August.
- Dr S. EGGINS, American Geophysical Union Fall meeting, San Francisco, USA, 9-14 December, contributed an oral presentation entitled "Controls on Mg/Ca variation in planktonic foraminifera – new insights from microanalysis of laboratory cultured *Orbulina universa*".
- Dr S. EGGINS, Geological Society of New Zealand Conference, Tauranga, USA, 26-29 November, contributed an oral presentation entitled "Temperature and carbonate ion effects on Mg/Ca incorporation in planktonic foraminifera".
- Dr S. EGGINS, Workshop on Laboratory Culture of Planktonic Foraminifera, Wrigley Institute for Environmental Studies, Catalina Island, USA, 3 August, presented a seminar entitled "Compositional variability in planktonic foraminifera".
- Dr S. EGGINS, Marine Science Workshop, ANU, 14 September, presented a talk entitled "Fabulous Forams – new open marine carbonate system proxies and improving seawater temperature proxies"
- Dr M.J. ELLWOOD, Ncycle and COST voyages data workshop, NIWA, Wellington, NZ, 18-20 April, presented a paper entitled "Trace metal cycling in the Tasman Sea" and "Results from beak-board incubation experiments".
- Dr. S.J. FALLON attended the XVII INQUA congress in Cairns, Jul. 28- Aug. 3, 2007 and presented a paper entitled "Natural Variability and Anthropogenic Influence on Climate: Surface Water Processes in the Indonesian Seas"
- Dr. S.J. FALLON attended the 3rd International Conference on the Mechanisms of Organic Matter Stabilisation and Destabilisation in soils and Sediments in Adelaide, 23-26 Sept. 2007.
- Dr K.E. FITSZIMMONS, 17th International Quaternary Association Congress, Cairns, 28 July – 3 August 2007, presented papers entitled "The timing of late Quaternary linear dune activity in the central Australian deserts" and "Australasian INTIMATE: Late Quaternary environmental change in central Australia" (with Dr E.J. Rhodes and Dr J.W. Magee).
- Dr K.E. FITSZIMMONS attended the Cooperative Research Centre for Landscape Environments and Mineral Exploration Regolith Symposium, Hahndorf, November 2006, and presented a paper entitled "Regional landform patterns in the Strzelecki Desert dunefield: dune migration and mobility at large scales".
- Dr M.K. GAGAN, 17th INQUA Congress, Cairns, Australia, 28 July to 3 August, presented an invited keynote paper entitled "Abrupt shifts and mega-droughts during the Holocene evolution of tropical Australasia".
- Dr M.K. GAGAN, 17th INQUA Congress, Cairns, Australia, 28 July to 3 August, presented a paper entitled "Coral chemo-geodesy: long-term perspectives for improved prediction of great submarine earthquakes".
- Dr M.K. GAGAN, 17th INQUA Congress, Cairns, Australia, 28 July to 3 August, presented a paper entitled "New archaeological finds below Liang Bua, Flores: a split-level home for the Hobbit?".

- Dr M.K. GAGAN, 9th International Conference on Paleoceanography, Shanghai, China, 3-7 September, presented an invited plenary paper entitled "Ocean-atmosphere interactions, abrupt shifts and patterns of drought during the Holocene climatic evolution of tropical Australasia".
- Dr M.K. GAGAN led a speleothem collecting expedition to the Liang Bua area on the island of Flores, Indonesia, from 20 May to 23 June.
- Prof. R. GRÜN was member of the organising Committee of the XVII INQUA Congress. 28 July - 3 August 2007, Cairns, where he chaired Plenary Session 4 Origins and dispersal of pre-modern humans and Session 18.5 Other Quaternary Sites and was invited to give a review on Advances in ESR dating.
- Mr R. JOANNES-BOYAU, 17th INQUA Congress, Cairns, Australia, 28-3 August 2007, "Two species of CO₂ threaten the fundamentals of ESR", Abstract 0151, p.195, Quaternary International 167-168
- Miss T. E. KELLY, XVII INQUA Congress, 28 July - 3 August 2007, Cairns, Australia, "Sr isotope tracing at the Neanderthal site of Les Pradelles, Charante, France., Abstract 397, Quaternary International 167-168, 203.
- Prof. M.T. McCULLOCH, continued his research program on Mediterranean coral reef during a visit to Italy in August.
- Prof. M.T. McCULLOCH, attended 2007 Goldschmidt Conference in Cologne, Germany 19-25 August and presented a paper entitled "Coral reefs and global change: the roles of increasing ocean acidity, ocean temperatures, sea-levels and direct human impacts"
- Prof. M.T. McCULLOCH, attended 2007 INQUA Conference July 28-August 4 and presented a paper entitled "Coral Reefs: The Silent Sentinels of Global Change"
- Prof. M.T. McCULLOCH, Coral Reef Society Conference, Perth, Western Australia, 8-12 October, presented a paper entitled "Coral Reefs: will they survive catastrophic climate change"?
- Mr I. MOFFAT was the principal author and presenter of a conference presentation to the International Union for Quaternary Research Conference in Cairns entitled "Geophysical Prospection for Late Holocene Skeletal Remains, Coorong, South Australia" with co-authors Dr LA Wallis (Flinders University), Dr K. Domett (James Cook University) and G. Trevorrow (Coorong Wilderness Lodge).
- Mr I. MOFFAT was the second author with Mr J. Raupp (Flinders University) of a conference presentation to the Society of Historical Archaeology Conference in Williamsburg Virginia entitled "Size Does Matter: Multi-technique Geophysical Investigations of Port Elliot".
- Prof. B.J. PILLANS, XIIth International Union for Quaternary Research (INQUA) Congress, Cairns, 28 July - 3 August, presented a keynote address "Defining the Quaternary".

Prof. B.J. PILLANS, Kalgoorlie'07 Conference on mineral exploration, gave an invited paper "Dating the regolith – implications for landscape evolution".

Dr M. WILLE et al., European Geosciences Union San Francisco, General Assembly 2007, Vienna, Austria, 15 – 20 April 2007, presented a paper entitled "Deep water upwelling and its implication for the Precambrian Cambrian boundary. Evidences from Molybdenum isotopes in black shales".

Dr M. WILLE et al., Goldschmidt Conference 2007, Cologne, Germany, August 19 - 24, 2007, presented a paper entitled "Massive H₂S release to surface waters at the Precambrian-Cambrian (PC-C) boundary: Evidence from Mo isotopes"

Dr M. WILLE et al., ANU fall meeting 2007; San Francisco, USA, will present a paper entitled "Mo Isotopes Record Destabilization of a Stratified Ocean at the Precambrian-Cambrian Boundary"

Earth Materials & Processes

Dr M. BELTRANDO, 16th Deformation mechanisms, Rheology and Tectonics (DRT) Conference, Milan, Italy, 27 September – 2 October, presented a poster entitled "Dating microstructures by the ⁴⁰Ar/³⁹Ar step-heating technique: Deformation pressure-temperature-time history of the Penninic units of the Western Alps".

Prof S.F. COX, Geological Society of America Annual Conference, Denver, 28-31 October, presented an invited lecture and gave the Society of Economic Geologists 2007 Distinguished Lecture. He also presented two invited lectures at the Colorado School of Mines.

Prof S.F. COX, Deformation, Rheology and Tectonics conference, Milan, 27 September – 2 October, presented a lecture entitled "Paths to failure: the application of failure mode diagrams in pore fluid factor ~ differential stress space for analysing fluid pressure and stress states during rock failure".

Prof S.F. COX, Meeting of the Geological Society of Australia's Specialist Group in Tectonics and Structural Geology, Alice Springs, 8-14 July, presented a talk.

Dr J.D. FITZ GERALD, 31st Annual Condensed Matter and Materials Meeting, Wagga Wagga, 6-9 February, co-presented four posters with ANU College of Science colleagues.

Dr J.D. FITZ GERALD, visited the Institut für Mineralogie, Westfälische Wilhelms Universität, Münster, April – May for collaborative work on electron microscopy in minerals.

Dr J.D. FITZ GERALD, Festkolloquium on Metasomatism (in honour of Prof H. Austrheim), 25 April, presented a paper "Permeability and Porosity Evolution of Hydrothermal Fault Gouges".

- Dr M. FORSTER, Geological Society of London Peach and Horne Memoir Conference: Continental Tectonics and Mountain Building, Ullapool, Scotland, 12-19 May, presented a talk entitled "Orogenic Sequence Diagrams".
- Dr M. FORSTER, 16th Deformation mechanisms, Rheology and Tectonics (DRT) Conference, Milan, Italy, 27 September – 2 October, gave an oral presentation entitled "Seismogenic strain rates during ductile deformation – the example of the South Cyclades Shear Zone, Ios, Cyclades, Greece".
- Dr M. FORSTER, Geology Society of America Penrose conference: Extending a Continent: Architecture, Rheological Coupling, and Heat Budget, Naxos Island, Greece, 7–12 October, presented a poster entitled "Extension of the Aegean lithosphere initiated at the Eocene-Oligocene transition".
- Dr J. HERMANN, 17th V.M. Goldschmidt Conference, Cologne, Germany, 19-24 August, presented a paper entitled "Accessory phase control on the trace element signature of subduction zone fluids" and was co-author on three other contributions.
- Dr J. HERMANN conducted field work in the Western Alps from 29-30 August; in the Central Alps from 13-14 September and in New Caledonia from 4-14 November.
- Dr J. HERMANN presented a seminar at the University of Berne, Switzerland, on 4 September and at ETH-Zurich, Switzerland on 5 September.
- Prof. I. JACKSON, 31st Condensed Matter and Materials Meeting (Wagga Wagga, NSW, February) and IUGG XXIV General Assembly (Perugia, Italy, July), presented papers.
- Prof. I. JACKSON visited and lectured at the University of Utrecht and Shell International Exploration and Production in The Netherlands and the Ecole Normale Supérieure in Paris (June).
- Mr. I. KOVACS, AGU Spring Conference, Acapulco Bay, Mexico, 22-25 May, presented two talks entitled "Water solubility in forsterite and enstatite: a key for understanding mantle rheology" and "Quantitative IR spectroscopy with unpolarized light".
- Mr. I. KOVACS, Petrological evolution of the European lithospheric mantle from Archean to present day, Ferrara, Italy, 29-31 August, presented a poster entitled "Middle Miocene volcanism in the vicinity of the Middle Hungarian zone: evidence for an inherited enriched mantle source" and was co-author in two talks entitled: "A quartz-bearing orthopyroxene-rich websterite xenolith from the Pannonian Basin, Western Hungary: Evidence for release of Si-oversaturated melts from the subducted slab" and "Silicate melt inclusions in amphibole-bearing spinel peridotites xenoliths from the Bakony-Balaton Highland Volcanic Field (Western Hungary)".
- Mr. I. KOVACS, XIX European Current Research on Fluid Inclusions (ECRFI), Bern, 17-20 July, was a coauthor in two presentations entitled "Primary carbonatite melt inclusions in apatite and in K feldspar from clinopyroxene-rich mantle xenoliths from Hungarian lamprophyres: implications for generation and

evolution of carbonatite melts in the Earth's upper mantle" and "Silicate melt inclusion study in peridotite xenoliths from Pannonian Basin, Hungary".

Prof G. LISTER, International meeting organized by the Académie des Sciences, Paris, France at the Institut Océanographique "Ocean Continent Transition", 19–21 September, was an invited keynote speaker, giving a talk entitled "The nature and origin of detachment faults in the context of the geodynamical evolution of passive continental margins".

Prof G. LISTER was the Umbgrove Lecturer 2007 at the Instituut voor Aardwetenschappen, Universiteit Utrecht, The Netherlands, 24–25 September, presenting a talk entitled "The nature of orogenesis".

Prof G. LISTER, Geology Society of America Penrose conference: Extending a Continent: Architecture, Rheological Coupling, and Heat Budget, Naxos Island, Greece, 7–12 October, presented an invited keynote lecture entitled "The nature and origin of detachment faults and their relation to extensional shear zones".

Prof G. LISTER, 16th Deformation mechanisms, Rheology and Tectonics (DRT) Conference, Milan, Italy, 27 September – 2 October, presented two talks entitled "Structural analysis of aftershock sequences from the 2004–2005 Great Sumatran Earthquakes" and "Are textural and chemical transformations episodic?".

Mr. G. MALLMANN, Workshop on the Chronology of Meteorites and the Early Solar System, Kauai-Hawaii, USA, 5–7 November and the Post-conference Field trip, Big Island, Hawaii, USA, 8–9 November.

Mr. G. MALLMANN, 2007 AGU Fall Meeting, San Francisco, USA, 11–14 December, presented a paper entitled "Vanadium partitioning and mantle oxidation state: New experimental data".

Dr J. MAVROGENES presented an invited lecture at the Geological Association of Canada – Mineralogical Association of Canada (GAC-MAC) conference in Yellowknife, Canada, in the Unusual Ore Deposit Session.

Dr J. MAVROGENES presented an invited lecture at the AMIRA Exploration Managers Conference, Barossa Valley.

Dr J. MAVROGENES presented a keynote lecture at the Goldschmidt Conference in Cologne, Germany, in the New Frontiers in Fluid Inclusion Analysis Session and an invited lecture in the Fluid Properties at High pressures and Temperatures Session.

Dr S. MICKLETHWAITE, was invited to speak at the Kalgoorlie'07 Conference, Old Ground New Knowledge, Kalgoorlie, WA, 25–27 September. He presented a paper entitled "Structural processes – which ones are critical for targeting?".

Dr S. MICKLETHWAITE, visited The University of Glasgow and Strathclyde University from 10–30 June to work with the Faults and Fluid Flow research group, funded by an international travel fellowship.

Dr S. MICKLETHWAITE conducted field work in Nevada, USA, from 12-26 March, 6-27 August and 10-14 December; in Cracow, Queensland from 23-27 April; in Agnew, Western Australia from 28 September to 5 October.

Prof. H. O'NEILL attended and gave papers at the European Geosciences Union meeting in Vienna, 24-29 April, the 17th Annual V.M. Goldschmidt Conference, Cologne, 19-24 August, and a Royal Society Discussion Meeting on "Origin and differentiation of the Earth: past to present", 13-14th September, London.

Mr C. PIRARD, Granitic Pegmatite : the State of the Art (PEG2007), Porto, Portugal, 6-12 May, presented a poster entitled "Alteration sequences of aluminium phosphates from Montebras pegmatite, Massif Central, France".

Mr C. PIRARD conducted field work in New Caledonia archipelago from 4 November – 1 December.

Dr R.P. RAPP, 17th International Goldschmidt Conference, Cologne, Germany, 19-24th August, presented an invited paper entitled "A new, comprehensive set of bulk distribution coefficients (D's) governing partial melting of hydrous metabasalt".

Dr R.P. RAPP, Sixth Hutton Symposium on the Origin of Granitic Rocks, Stellenbosch, South Africa, 3-6 July, presented a paper entitled "Comprehensive trace element characteristics of experimental TTG and sanukitoid melts".

Dr R.P. RAPP, State-of-the-Arc (SOTA) 2007 Meeting, Termas de Puyehue, Chile, 28 January - 2 February, presented a paper entitled " Primary high magnesian andesites from adakite-metasomatized peridotite: insights from melting hybridization-assimilation experiments at 1.5-4.0 GPa.

Dr S. RICHARDS, Specialist Group in Tectonics and Structural Geology (SGTSG): Deformation in the Desert conference, Alice Springs, Northern Territory, 9-13 July, presented a paper entitled "Virtual Earth: 4D evolution of the Indo Australian Plate" and a poster entitled "Buchan Metamorphism during Extension."

Mr D.R. VIETE, Continental Tectonics and Mountain Building: 'The Peach and Horne Meeting', Ullapool, Scotland, 12-19 May 2007, presented a paper entitled "Synchronous development of the Barrovian and Buchan metamorphic facies series as the result of lithosphere-scale extension during orogenesis".

Mr D.R. VIETE conducted fieldwork in the Scottish Highlands from 19-24 May.

Mr D.R. VIETE, Specialist Group in Tectonics and Structural Geology: 'Deformation in the Desert', Alice Springs, Northern Territory, 9-13 July 2007, presented a poster entitled "Heat sources for Barrovian regional metamorphism".

Earth Physics

- Dr C.E. BARTON, National Academies Forum symposium entitled 'A celebration of the history, culture, science and technology of Recherche Bay', Hobart, Tasmania 27-28 January 2007, presented a paper entitled "From geomancy to geodynamo magnetism and the Earth Sciences".
- Dr C.E. BARTON, WIPS (Western Interior Paleontology Society), Denver, 3-4 March 2007, presented a paper entitled "Magnetic dating, stratigraphy, and tracing".
- Dr C.E. BARTON, visited the Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 2-25 March 2007, to work on the Electronic Geophysical Year (eGY) project.
- Dr C.E. BARTON, chaired the eGY General Meeting, NCAR, Boulder, 13-14 March 2007.
- Dr C.E. BARTON, "Envisioning a National Geoinformatics System for the United States", Denver Federal Center, Denver, 14-15 March 2007, presented a paper entitled "The Electronic Geophysical Year, 2007-2008".
- Dr C.E. BARTON, visited Moscow courtesy of the Russian Academy of Science, 22-28 June 2007. Presented invited lecture to the RAS Geophysics Center entitled "The International Science Years and the Electronic Geophysical Year, 2007-2008"; presented invited lecture to IZMIRAN (Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation) entitled "The Electronic Geophysical Year, 2007-2008 - towards an Earth and space science information commons"; visited the Institute of Physics of the Earth, palaeomagnetism group; discussions with the Head of the RAS Earth Science Division, Yuri Leonov about Russian-Australian collaboration in Earth and space science.
- Dr C.E. BARTON, IUGG General Assembly, Perugia, 30 June-13 July 2007, presented a paper entitled "eGY - towards an Earth and space science information commons", and an invited lecture at the official launch of the Electronic Geophysical Year entitled "The importance of the eGY and a vision for universal data access".
- Dr C.E. BARTON, International Science Years Workshop, New Delhi, India, 2-4 October 2007, presented invited paper "eGY - a 21st Century approach to issues of data".
- Dr C.E. BARTON visited National Geophysical research Institute, Hyderabad, 5-7 October 2007, presented invited lecture entitled "The nature and applications of the Earth's magnetic field"
- Dr C.E. BARTON visited Indian Institute of Geomagnetism, Mumbai, 8-9 October 2007, presented three invited lectures entitled "Frontiers in geomagnetism research" "The nature and applications of the Earth's magnetic field", and "The Electronic Geophysical Year, 2007-2008".
- Dr C.E. BARTON, IHY-Africa Space Science Workshop, Addis Ababa, Ethiopia, 12-16 November 2007, presented a paper entitled "eGY - an opportunity to improve

access to Earth and space science data"; launched eGY-Africa , an Electronic Geophysical Year initiative to advocate better cyber-infrastructure for science in Africa.

Dr D.R. CHRISTIE, 29th Monitoring Research Review Symposium, Denver, Colorado, 25-27 September, presented a paper entitled "Advances in infrasound technology with application to nuclear explosion monitoring".

Dr D.R. CHRISTIE, attended the Infrasound Technology Workshop, Tokyo, Japan, 13-16 November and presented two papers entitled "Recent progress in wind noise reduction at infrasound monitoring stations" and "Optimum array design for the detection of distant atmospheric explosions: Influence of the spatial correlation of infrasonic signals".

Mr J. DAWSON, Geophysical Union Conference, San Francisco, USA, 8-14 December 2007, presented a paper entitled "Shallow earthquakes in Western Australia observed with seismic and InSAR data".

Dr A. DUTTON, INQUA Congress 2007, Cairns, Australia, 28 July - 3 August, was session chair for "Chronologies of sea level change from 0 to 500 ka" which included a paper of hers on "Global Sea Level During the Last Interglacial."

Dr A. DUTTON, Geological Society of America Annual Meeting, Denver, CO, USA, 28 October- 31 October, presented a paper on "Evaluating diagenesis in Eocene tropical planktonic foraminifera."

Dr A. DUTTON was a co-author on a paper presented at the International Conference on Paleoceanography, Shanghai, China, entitled, "Interlaboratory comparison study of calibration standards for foraminiferal Mg/Ca thermometry."

Dr A. DUTTON conducted field work at Cape Range and Ningaloo NP near Exmouth, WA to collect fossil coral samples for research on sea level of the last interglacial.

Ms. G. Estermann, "Bringing Science Together" conference, ANU, Canberra, December 11th, 2006, oral presentation entitled "Relative sea-level changes due to recent mountain deglaciation"

Ms G. Estermann, European Geosciences Union (EGU) conference, Vienna, 15-20 April 2007, oral presentation entitled "Geodetic signals from numerical modelling of recent mountain deglaciation"

Dr F. FONTAINE conducted field work in the Murray Basin from 11-22 February; in the North of Canberra from 25-27 July and 6, 9-10 August; in Shannons Flat from 30th August to 14th September and in South Australia from 22nd October to 3rd November.

Ms M. A. COMAN, ANU Marine Science Forum, 12 September 2007, presented a talk "Surface buoyancy and the overturning circulation".

Dr. G.F. DAVIES presented a paper "Dynamical and chemical evolution of the mantle" at the Geological Association of Canada "NUNA" conference "The pulse of the Earth and planetary evolution", Sudbury, Ontario, June 2007.

Dr. G. F. DAVIES presented a paper "Episodic layering of the early mantle by the basalt barrier mechanism" at the Fall Annual Meeting of the American Geophysical Union, San Francisco, December 2007.

Prof. R. W. GRIFFITHS, XV Summer School on Fundamental Problems in Geophysical and Environmental Fluid Mechanics, Ocean-atmosphere convection in the context of climate change, Aosta, Italy, June 2007, gave a series of three invited seminars on "Horizontal convection". He also attended the annual American Physical Society – Division of Fluid Dynamics meeting in Salt Lake City, USA, and delivered a dinner speech at a workshop on the occasion of the 60th birthday of Prof P. F. Linden, University of California, San Diego.

Prof. R. W. GRIFFITHS visited the Graduate School of Oceanography, University of Rhode Island, July – September, for research on flow in mantle subduction zones and ocean circulation. During this period he also visited and lectured at the Department of Oceanography, Dalhousie University, Canada, and participated in a workshop on the Cascadia subduction zone, Carnegie Institution, Washington DC, USA.

Dr A.McC. HOGG, Australian Meteorological and Oceanographic Society 14th Annual Conference, Adelaide, 5-8 February 2007, presented a paper entitled "Southern Ocean response to Variations in the Southern Annular Mode".

Dr A.McC. HOGG, Understanding Nature's Fury, Canberra, 5–7 November 2007, presented a paper entitled "Positive feedbacks and the CO2 cycle".

Dr G.O. HUGHES, XV Summer School on Fundamental Problems in Geophysical and Environmental Fluid Mechanics, Aosta, Italy, June 2007, gave an invited seminar on "Horizontal convection and the ocean overturning circulation".

Prof B.L.N. KENNETT attended the European Geosciences Union meeting in Vienna in April, where he received the Gutenberg Medal in Seismology. He made a brief visit to Japan in May and attended part of the Japanese Earth Sciences Meeting. In September he gave an invited presentation at the Bicentennial Meeting of the Geological Society of London, and then attended a Heraeus Workshop on the nature of the Earth's Interior in Bavaria, for which he was an organiser. He also attended the Fall Meeting of the American Geophysical Union with an invited talk on structure in the Lithosphere.

Prof K. LAMBECK, Nobel Laureates Beijing Forum 2007: Energy and Environment, Beijing, China, 10-14 September 2007, presented papers entitled "The Climate-Energy Nexus: the transition from vicious circle to virtuous circle" <http://www.science.org.au/events/11september07.htm> , and "The utilization and promotion of new energy sources in Australia" <http://www.science.org.au/events/14september07.htm> as well as several presentations to Chinese Academy of Science Institutes.

Ms M.J. O'BYRNE, Australian Meteorological and Oceanographic Society 14th Annual Conference, Adelaide, 5–8 February 2007, presented a paper entitled "The effects of perturbed incident flow on island and headland wakes".

- Ms M.J. O'BYRNE, ANU Marine Science Forum, 12 September 2007, presented a talk "Wake flows in coastal oceans: an experimental study of topographic effects".
- Dr. N. RAWLINSON, 24th General Assembly of IUGG, Perugia, Italy, 2-13 July, presented a paper entitled "Seismic imaging of the lithosphere beneath southeast Australia using data from multiple array deployments".
- Dr. N. RAWLINSON conducted fieldwork in Tasmania from 24 January -1 February, 5-12 June and 21-30 August; and in NSW from 11-22 February, 16-25 April, 13-22 September, 14-20 November, 5-14 December.
- MR D. ROBINSON, Australian Earth Science Convention, Melbourne, 2-6 July 2006, presented a paper entitled "Coda wave interferometry and constraints on relative earthquake locations "
- Dr. M. SAMBRIDGE, American Geophysical Union Conference, San Francisco, USA, 10-14 December, presenting papers on Seismic wavefront tracking methods and coda wave interferometry jointly with co-authors Dr. N. Rawlinson, and RSES students Mr. J. Hauser and Mr. D. Robinson.
- Dr. M. SAMBRIDGE, attended the joint CIG/SPICE/IRIS Seismology Workshop held in October 9-11th, 2007, in Jackson, NH, USA and presented a paper entitled "Cross validation in inverse problems".
- Dr. W. P. SCHELLART presented a poster Prospecting the Southwest Pacific mantle for fossil slabs by using regional tectonic reconstructions, surface geology and seismic tomography at the EGU general assembly, Vienna, Abstract EGU2007-A-00652, 2007. (with B.L.N. Kennett)
- Dr. W. P. SCHELLART presented a talk Slab width as the dominant factor in determining trench migration velocity and subduction zone curvature at the EGU general assembly, Vienna, Abstract EGU2007-A-00646, 2007. (with J. Freeman, D.R. Stegman, L. Moresi and D. May)
- Dr. W. P. SCHELLART presented a poster Global trench-migration velocities in different "absolute" reference frames: Geodynamic constraints to find the optimal reference frame. EGU general assembly, Vienna, Abstract EGU2007-A-00648 2007.
- Dr. W. P. SCHELLART presented a talk Three-dimensional subduction-induced flow patterns in the mantle: Insight from fluid dynamic modelling EGU general assembly, Vienna, Abstract EGU2007-A-00650, 2007. (with R.W. Griffiths)
- Dr. W. P. SCHELLART presented a talk Orogenesis above a subduction zone: Explaining the formation of the Andes at the Geological Society Arthur Holmes Meeting Continental tectonics and mountain building, Ullapool, Scotland, 2007. (with D.R. Stegman, and J. Freeman)
- Dr. W. P. SCHELLART was second author on a talk from Moresi et al. Slab width as the dominant factor in determining trench migration velocity and subduction zone curvature presented at the AGU joint assembly, Acapulco, Mexico, May, 2007.

- Dr. W. P. SCHELLART was third author on a talk from Stegman et al. The Effect of Trench Width on the Evolution and Diversity of Subduction Zones and Slab Morphology in the Upper Mantle presented at the Subduction zone geodynamics conference, Montpellier, France, 2007.
- Dr. W. P. SCHELLART presented a talk Orogenesis above a subduction zone: Explaining the formation of the Andes at the SGTSG Conference Deformation in the desert, Alice Springs, Australia, 64, 2007. (with D.R. Stegman, J. Freeman, L. Moresi, and D. May)
- Dr. W. P. SCHELLART presented a poster Trench migration velocities in different "absolute" global reference frames: Geodynamic constraints to find the optimal reference frame at the SGTSG Conference Deformation in the desert, Alice Springs, Australia, 90, 2007.
- Dr. W. P. SCHELLART presented a poster Locating fossil slabs in the Southwest Pacific mantle with tectonic reconstructions, surface geology and mantle tomography at the SGTSG Conference Deformation in the desert, Alice Springs, Australia, 89, 2007. (with B.L.N. Kennett, and S. Richards)
- Dr. W. P. SCHELLART was second author on a talk from R. Stephenson The Cretaceous Black Sea back-arc basin compared with modern analogues presented at the East Asia Geoscience Society 4th Annual Meeting, Bangkok, Thailand, 2007.
- Dr H. TKALCIC, The American Geophysical Union Fall Meeting 2007 in San Francisco, USA, December 9-14, presented two papers entitled "New estimate of the inner-outer core density ratio from previously unobserved steep-incidence inner core reflections" by H. Tkalcic and B.L.N. Kennett and "Detailed seismic imaging of the Australian lithosphere using a dense rolling array of seismometers" by N. Rawlinson, B.L.N. Kennett and H. Tkalcic.
- Dr H. TKALCIC conducted field work in Western Australia (CAPRA seismic deployment pullout) for two weeks in May/June, and in Tasmania (SETA array pullout) for one week in August.
- Dr P. TREGONING, attended the Cryosat II Calibration Validation and Retrieval Team 1st Meeting in Noordwijk 18-19 October, 2007.
- Dr P. TREGONING, attended the Geodesie et Geophysique meeting, Grenoble, France, 21-23 November and presented a paper entitled "GRACE en Australie: la secheresse et les signaux oceaniques".
- Dr D. ZWARTZ conducted GPS field work in Australian Antarctic Territory from 6 December 2006 to 1 Apr 2007 and in Papua-New Guinea.

PRISE

Dr R.A. ARMSTRONG, 7th International Symposium on Applied Isotope Geochemistry, Stellenbosch, South Africa, 10-14 September, presented a keynote talk entitled "Exploring new avenues with in-situ isotope analysis".

Dr R.A. ARMSTRONG, 1st Workshop on Problems in Western Gondwana Geology, Gramado, Brazil, 27-29 August, presented an invited paper entitled "A summary of the geochronology and Precambrian crustal architecture of southern Africa, and possibilities for correlations with South America"

Mr C.M. FANNING, 10th International Symposium on Antarctic Earth Sciences, Santa Barbara, USA, 26-31 August, was a co-author on six presentations.

Mr C.M. FANNING, 2007 Geological Society of America Annual Meeting & Exposition, Denver, USA, 28 – 31 October, was a co-author on eight presentations.

Mr C.M. FANNING, GEOSUR 2007, A conference on the Geology and Geophysics of the Southern Hemisphere, Santiago de Chile, 18-20 November, presented a poster entitled "Detrital zircon ages from the cover rocks of the northern flank of Cordillera Darwin: further evidence for an extended pre Middle Jurassic hiatus in the magmatic record of southern Patagonia" and co-authored a further seven presentations.

Mr C.M. FANNING conducted fieldwork in the Flinders Ranges, South Australia from 7-15 March, in Peru from 8-14 August and in Chile from 21 November – 7 December.

Mr S.S.M. HUI, 7th Australian Space Science Conference, Sydney, 24-27th September, presented a talk entitled "Analysis and Classification of Cosmic Spherules from the Lewis Cliff, Antarctica"

Dr M.D. NORMAN, 7th Australian Space Science Conference, Sydney, 24-27th September, presented an invited keynote talk entitled "Planetary Science in Australia", and a contributed talk entitled "Lifting the Veil on the Lunar Cataclysm: A 4.2 Billion Year Old Impact Event on the Moon".

Dr M.D. NORMAN, 38th Lunar and Planetary Science Conference, Houston, USA, 11-16 March, presented a talk entitled "Early Impacts on the Moon: Crystallization Ages of Apollo 16 Melt Breccias".

Ms A. ROSENTHAL, 17th V.M. Goldschmidt Conference, Cologne, Germany, 19-24 August, presented a paper entitled "Phase and melting relations of a residual garnet clinopyroxenite".

Dr G.M. YAXLEY, Geological Association of Canada – Mineralogical Association of Canada Meeting (GAC-MAC), Yellowknife, Canada, 23-25 May, presented a paper entitled "A new experimental calibration of Ni-Mg exchange between garnet and olivine at upper mantle pressures – implications for Ni in garnet thermometry."

Dr G.M. YAXLEY, 17th V.M. Goldschmidt Conference, Cologne, Germany, 19-24 August, presented a key-note talk entitled "The influence of minor elements on melting of eclogite in the mantle".

Editorial responsibilities

Earth Chemistry

Dr V. C. BENNETT, Co-editor with M. van Kranendonk, and H. Smithies of "Earth's Oldest Rocks" Elsevier Press, Sept. 2007.

Dr J.J. BROCKS, Associate Editor, *Palaios*, a Journal of the Society of Sedimentary Geology. Dr I.S. Buick, Co-editor in Chief, *Lithos*.

Dr I.S. BUICK, Associate Editor, *Gondwana Research*.

Prof I.H. CAMPBELL, Co-editor *Chemical Geology Special Issue on Mantle Plumes*.

Dr M. HONDA, Associate Editor, *Geochemical Journal*.

Dr C.H. LINEWEAVER, Co-editor, *Proceedings of the 5th Stromlo Symposium Disks, Winds and Jets: from Planets to Quasars*, (2008) Dordrecht: Kluwer, 500 pages, in press.

Dr D. RUBATTO, Associated Editor, *Lithos*.

Dr D. RUBATTO, Editorial Review Board, *Journal of Metamorphic Geology*.

Earth Environment

Dr S. EGGINS, Editorial Board, *Quaternary Geochronology*.

Dr S. EGGINS, Editorial Board, *Geostandards and Geoanalytical Research* (to Sept 2007).

Dr K.E. FITZSIMMONS, Editor, *Quaternary Australasia*.

Prof. R. GRÜN is the Editor in Chief of *Quaternary Science Reviews* and member of the Editorial Boards of *Quaternary Science Reviews* and *Radiation Measurements*

Mr I. MOFFAT, Associate Editor, *Exploration Geophysics*.

Prof. B.J. PILLANS, Editorial Board, *Quaternary Science Reviews*.

Earth Materials & Processes

Prof S.F. COX continued as a member of the Editorial Advisory Boards of Journal of Structural Geology and Geofluids.

Dr J.D. FITZ GERALD, Editorial Board, Physics and Chemistry of Minerals and coordinating editor of the special volume, Proceedings of the 31st Annual Condensed Matter and Materials Meeting, Wagga Wagga.

Dr J. HERMANN, Associate Editor, LITHOS.

Prof. I. JACKSON, Editorial Boards of Earth and Planetary Science Letters, Physics of the Earth and Planetary Interiors.

Prof. H. O'NEILL, Advisory Editorial Board of Earth and Planetary Science Letters, Editorial Board of Chemical Geology, Advisory Board of Elements and Associate Editor, eEarth.

Earth Physics

Prof. R.W. GRIFFITHS served as Associate Editor, Journal of Fluid Mechanics, and as a member of the Editorial Committee for the Annual Review of Fluid Mechanics.

Prof B.L.N. KENNETT, Member of Advisory Editorial board for Physics of the Earth and Planetary Interiors and Earth and Planetary Science Letters.

Dr. N. RAWLINSON is an editorial board member of Tectonophysics

Mr. D. ROBINSON, Book Review Editor Preview Magazine

Dr. W.P. SCHELLART served as Associate Editor for Journal of Geophysical Research-Solid Earth.

Dr. W.P. SCHELLART served as Associate Editor for Journal of Geodynamics.

Dr. W.P. SCHELLART served as Associate Editor for Journal of the Virtual Explorer.

Dr P. TREGONING, Associate Editor, Journal of Geophysical Research-Solid-Earth

PRISE

Dr R.A. ARMSTRONG, Editorial Board, Journal of African Earth Sciences.

Dr M.D. NORMAN, Editorial Board, Open Mineralogy Journal.

Outreach and workshops

Earth Chemistry

Dr J.J. BROCKS was interviewed on 22 August by the major German radio channel 'Deutschlandfunk' about 'Proterozoic Purple Oceans'
<http://www.dradio.de/dlf/sendungen/forschak/661111/>

Dr J.J. BROCKS gave a Plenary Lecture in the series 'Making the Earth in Five Days' at the Goldschmidt Conference in Cologne, accessible at
<http://www.goldschmidt2007.org/plenary.php>

Prof T.R. IRELAND visited the Cowra Primary School to talk to students about meteorites.

Prof T.R. IRELAND, invited speaker, 25-29 October, at Curtin University, Perth.

Dr C.H. LINEWEAVER was interviewed by Klaus Toft on Space-Based Solar Power for the ABC science show, "Catalyst", recorded on 7 and 9 November, to be broadcast Australia-wide on a Thursday in December 2007 or January 2008, 8 pm, approx. 5 minute segment, estimated audience 881,000.

Dr C.H. LINEWEAVER was interviewed by Graham Phillips on "The Future of the Space Elevator" for the ABC science show Catalyst recorded 16 August, broadcast Australia-wide 8:11 pm, Thursday, 11 October.

Dr C.H. LINEWEAVER was interviewed by Graham Phillips on "The Future of Living on Mars" for the ABC science show Catalyst, recorded August 16, broadcast Australia wide 8:14 pm, Thursday, 4 October, 6 minutes, estimated audience 881,000.

Dr C.H. LINEWEAVER was interviewed by Graham Phillips on the new NASA spacecraft STEREO and on coronal mass ejections "The Sun in Stereo" for the ABC science show Catalyst, broadcast Australia-wide Thursday, 26 July, 8:17 pm, 4 minute interview, estimated audience 881,000.

Dr C.H. LINEWEAVER was interviewed by Mike Welsh for Mike Welsh's Drive Show, Capitol Radio, 2CC 5:51 to 5:56 pm, 8 November, on the Astrophysical Journal Paper: "The Metallicity of Stars with Close Companions".

Dr C.H. LINEWEAVER was interviewed 23 October by Jennifer Macey for ABC Radio National on the new Pentagon plan for geostationary arrays of solar panels, broadcast Australia-wide.

Dr C.H. LINEWEAVER was interviewed by Loretta Foo Xue Ling, 5 November of Radio Singapore International (English Service) on the recent detection of a 5 Earth mass planet around the M dwarf Gliese 581 in the habitable zone; see also
<http://www.rsi.sg/english/frontiers/view/2007050815212/1/.html>.

- Dr C.H. LINEWEAVER was interviewed and cited on a ABC Radio National report on Mars and global warming by Mark Colvin and Jennifer Macey; available on-line at <http://www.abc.net.au/pm/content/2007/s1891367.htm>.
- Dr C.H. LINEWEAVER was interviewed by Marilyn Head on 1 June for ABC Science Online story about terrestrial planets.
- Dr C.H. LINEWEAVER was interviewed by Stuart Gary, ABC Radio National, Star Watch on 19 March; available at <http://www.abc.net.au/newsradio/audio/20070317starstuff.asx>.
- Dr C.H. LINEWEAVER participated in a ABC Radio National, Science Week Discussion: "The Biggest Questions of the Universe" Broadcast 28 January and repeated 30 January; ABC Science hosts Bernie Hobbs and Paul Willis.
- Dr C.H. LINEWEAVER's lecture on astronomy was written up in The Champion Post, Parkes, NSW Regional Newspaper, "The Big Bang and Fascinating Questions" by John Sarkissian, 5 October.
- Dr C.H. LINEWEAVER and Dr D. Grether's research was written up in <http://www.physorg.com/news113756127.html> and <http://www.sciencealert.com.au/news/20070911-16561.html>.
- Dr C.H. LINEWEAVER gave a lecture to the ANU National Youth Science Forum Lecture to Year 12 Students on 19 January, entitled "Are We Alone?"
- Dr C.H. LINEWEAVER gave a lecture at Narrabundah College, ACT, Teachers Orientation Seminar Lecture, 30 January entitled "Worlds without Water".
- Dr C.H. LINEWEAVER gave a lecture to the North Sydney Astronomical Association, on 23 February entitled "The CMB, Exoplanets and the 2006 Nobel Prize for Physics".
- Dr C.H. LINEWEAVER gave a lecture at BrisScience, Brisbane on 19 March organized by Jennifer Dodd, entitled "Are We Alone?"
- Dr C.H. LINEWEAVER gave the ANU Black Hole Society Inaugural Lecture on 15 May entitled "Black Holes: the most legitimate Weirdness Known".
- Dr C.H. LINEWEAVER gave a lecture to the Theiss Environmental Division, Coolangatta Retreat Workshop, June 18 organized by Ravi Prasad: "The Origin of Water on Earth".
- Dr C.H. LINEWEAVER gave a lecture at ANU Burton and Garran College on 17 August entitled "Are We Alone?"
- Dr C.H. LINEWEAVER gave a lecture to the Sutherland Astronomical Society Greenpoint Observatory, 6 September entitled "Cosmology and the CMB".
- Dr C.H. LINEWEAVER gave a lecture to the Central West Astronomical Society of New South Wales, Parkes Observatory, Visitors Centre, NSW, 5 October entitled "Misconceptions about the Big Bang".

Dr C.H. LINEWEAVER and Dr J. ROBLES' research was written up in "Studying extrasolar planets 'on the cheap'" by ABC journalist Marilyn Head, available at <http://www.abc.net.au/science/news/stories/2007/1933544.htm>

Dr R. SALMERON, Visiting Fellow at Monash University, Melbourne.

Dr R. SALMERON, Speaker, Centre for Stellar and Planetary Astrophysics, Monash University, "Are magnetic fields dynamically important in protostellar disks".

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students attending the National Youth Science Forum, 4 and 18 January.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory 2-4 March by representatives of the Chinese Research Institute of Petroleum Exploration and Development, Petrochina: Professor Luo Ping, Chief Geologist of the Central Laboratory, Director of the Key Laboratory for Oil and Gas Reservoirs; Professor Chen Jianping, Chief, Petroleum Geochemistry; Wang Hitong, Chief, Laboratory of Organic Analysis, and Luo Zhong, Engineer.

Dr I.S. WILLIAMS, Eurogranites 2007 Workshop, Poland, 1-6 September, co-authored presentations with Dr J. Wiszniewska and Mrs E. Krzeminska on the geochronology of the basement rocks of northern Poland.

Earth Environment

Dr S. EGGINS participated in an NSF funded workshop on the laboratory culture of planktonic foraminifera at the University of Southern California's Wrigley Institute for Environmental Studies, Catalina Island, July 4-August 10.

Dr M.J. ELLWOOD was interviewed on radio about the growth of sponges in the deep ocean. Approximately 3 minute interview with Leigh Hatcher, ABC Radio Canberra, broadcast at 4.30 pm 26 July.

Dr. S.J. FALLON hosted two students from the CSIRO Student Research Scheme as well as participating in Science Week as part of a forensic investigation.

Dr K.E. FITZSIMMONS was Joint Field Trip Coordinator, Pre-Conference field trip for International Quaternary Association (INQUA) Congress, with Prof.essor Gerald Nanson (University of Wollongong): Quaternary fluvial, lacustrine and Aeolian activity, Lake Eyre Basin, Central Australia.

Dr K.E. FITZSIMMONS is a regular contributor on the Fuzzy Logic Popular Science radio show, 2XX FM.

Dr M.K. GAGAN was interviewed in January for television, radio, newspaper, and web-site postings regarding a publication in Nature (v. 445: 299-302, 2007) entitled Seasonal characteristics of the Indian Ocean Dipole through the Holocene.

Dr M.K. GAGAN was interviewed in February by Science magazine ("Hobbit" finders to return, v. 315, p. 1065, 2007) and for newspaper and web-site postings

regarding exploration of a cave-chamber below Liang Bua on the island of Flores, Indonesia.

Dr S.D. JUPITER and Prof. M. McCULLOCH hosted an international workshop on Coral Reef Indicators of Land-Based Pollution in Mombasa, Kenya, from 1-5 Oct.

Dr S.D. JUPITER ran a public workshop to present the results of a catchment to reef study, funded by an ARC Linkage Grant, to the industry partners, stakeholders and citizens of Mackay, 1 June. Results of the study were additionally presented to members of the Mackay Conservation Group, 5 June, and to the Mackay City Council, 6 June. Results from the study generated 13 media stories, including newspaper articles in the Sydney Morning Herald and The Age, radio interviews on ABC Rural Report, and TV interview on Channel 7 News Mackay.

Prof. M. McCULLOCH and Dr S.D. JUPITER hosted an international workshop on Coral Reef Indicators of Land-Based Pollution in Mombasa, Kenya, from 1-5 October.

Prof. M. McCULLOCH contributed to a public workshop coordinated by Dr S.D. JUPITER to present the results of a catchment to reef study, funded by an ARC Linkage Grant, to the industry partners, stakeholders and citizens of Mackay, 1 June. Results of the study were additionally presented to members of the Mackay Conservation Group, 5 June, and to the Mackay City Council, 6 June. Prof. M. McCULLOCH presented a paper at the workshop, "Long-term changes to Mackay Whitsunday water quality and connectivity between terrestrial, mangrove and coral reef ecosystems". Results from the study generated 13 media stories, including newspaper articles in the Sydney Morning Herald and The Age, radio interviews on ABC Rural Report, and TV interview on Channel 7 News Mackay.

Prof. M. McCULLOCH together with Prof. R. Dunbar (Stanford University) and Dr Janette Lindesay (Fenner School of Environmental Science, ANU) instigated a Public forum at the ANU, Canberra entitled "Debunking The Great Global Warming Swindle". The forum critiqued the claims aired in The Great Global Warming Swindle televised on ABC TV. Prof. Malcolm McCULLOCH, ANU Research School of Earth Sciences and Deputy Director for the Centre of Excellence for Coral Reef Studies presented key points and discussion on Why we should Avoid Dangerous Climate Change: Risks, Thresholds and Mitigation. July 13.

Prof. McCULLOCH responded to and was cited in 14 media stories (both radio and newspaper articles) throughout Australia regarding global warming awareness and issues raised at the Public Forum at the ANU, Canberra entitled "Debunking The Great Global Warming Swindle".

Prof. M. McCULLOCH was an invited speaker at ICOMOS Public forum in Cairns, on 19 July focusing on Heritage and Climate Change and gave a presentation entitled "Coral Reefs: Will they survive Rapid Environmental-Climate change?" This generated local media interest with a major article appearing in the Cairns Post

Prof. M. McCULLOCH attended a planning meeting in Bungendore to contribute toward "Sustainable Development Science Policy" 5-6 May

Prof. M. McCULLOCH attended a Deep Sea Coral Workshop held at Stradbroke Island. He presented a paper to the workshop which is part of the "Deep Down Under" ARC Linkage proposal based at UQ and led by Prof., Justin Marshall.

Prof. M. McCULLOCH attended a Public workshop Understanding Nature's fury at the academy of science and presented a paper "Catastrophic collapse of Ice Sheets".

Prof. M. McCULLOCH attended and chaired the Catchments to Reefs: Integrated Planning, management and Governance Session at the Centre of Excellence Forum at the Academy of Science, Canberra 18-19 October.

Prof. M. McCULLOCH presented a paper entitled "Acid trip to Australia's future: Ocean acidification and coral reefs" at the Centre of Excellence Forum and as an outcome to his presentation at the Forum responded to and was cited in 8 media stories (radio, television, magazine and newspaper articles) on ocean acidification and current global warming issues under media consideration.

Mr I. MOFFAT appeared on television as part of an investigation by the major crime squad filmed for "Missing Persons Unit" on Channel Nine aired at 8:30 pm on Channel Nine on 29/11/07.

Mr I. MOFFAT appeared in the "Eastern Courier Messenger" in a photograph associated with an article entitled "Can you dig it?" appearing on 25/7/07 about geophysical survey and archaeological excavation of the Repatriation Hospital in Adelaide.

Mr I. MOFFAT presented a paper in the Centre for Archaeological Research seminar series at the Australian National University entitled "Applications of Geophysical Techniques to Australian Indigenous Archaeology".

Mr I. MOFFAT was the second author on a paper presented by Dr L. Wallis in the Department of Archaeology seminar series at Flinders University entitled "Geophysical Prospection in Australian Indigenous Archaeology: Case studies from Northwest Queensland and the Coorong".

Mr I. MOFFAT presented a paper entitled "Geophysical Prospection for Late Holocene Skeletal Remains, Coorong, South Australia" in the Centre for Archaeological Research's Contemporary Challenges in the Archaeology and Natural History of the Asia-Pacific Region workshop at The Australian National University, 2007.

Dr P. TREBLE presented three external seminars during 2007: "Reconstructing southwest Australia's natural rainfall variability using speleothems" at the offices of Land & Water Australia, Canberra on 14/3/07; and "Paleo-rainfall records from speleothem O isotopes" at the University of Birmingham on 1/11/07 and the University of Bristol on 29/11/07.

Earth Materials & Processes

Dr M. FORSTER was co-ordinator for the Thermochronology and Noble Gas, Geochemistry and Geochronology Organisation (TANG30) workshop in July.

Dr M. FORSTER co-ordinated the Earth Dynamics workshop for Thermochemistry and Noble Gas, Geochemistry and Geochronology Organisation (TANG30) in November. Workshop discussions: a) Is telechronology a reality yet? b) Visions for the future of the Virtual Facility.

Dr J. HERMANN was interviewed on radio SBS (in Italian) about the investigation of exposed mantle rocks at mid-ocean ridges by a submarine.

Dr J. HERMANN coordinated two visits of students participating at the National Youth Science Forum at RSES.

Mr. I. KOVACS was a guest speaker on unpolarized infrared spectroscopy at the University of Boston, May.

Prof. G. LISTER organized and coordinated Earth Dynamics 2007, with sessions on "AuScope" and "Understanding Nature's Fury".

G.S. LISTER collaborated with Dr U. Ring (Uni of Canterbury, NZ) and Prof B. Wernicke (Caltech) to run the Post-Conference Fieldtrip on the Ios Metamorphic Core Complex in Central Greece, in association with the GSA Penrose Conference on Naxos.

Dr J. MAVROGENES presented a series of lectures at Marist College as part of the Scientists in School program of CSIRO.

Dr S. MICKLETHWAITE ran a workshop for industry sponsors on 15 February.

Dr S. RICHARDS had a one-page article in the Canberra Times, 24 November, discussing the highlights of the Virtual Earth Project.

Dr S. RICHARDS appeared on WIN News, WIN Canberra, 24 November and had an article in the Canberra Times, 24 November, the Adelaide Advertiser, 25 November and the Australasian Science Magazine (November/December 2007) and a report in the ANU Reporter magazine (Winter 2007) discussing the highlights of the Virtual Earth Project.

Dr S. RICHARDS organized and ran an industry workshop for DeBeers exploration (December 2006)

Earth Physics

Dr A. DUTTON participated in the ANU Climate Initiative Dialogue Event (28-29 June) where she delivered a presentation on paleoclimate research at the ANU.

Dr A. DUTTON prepared a lecture for high school students attending the John Curtin School of Medical Research Open Day on climate change.

Dr A. DUTTON participated in the Marine Science Forum held on 12 September.

- Dr F. FONTAINE was interviewed on television about his recent award called: young talent 2007 of France's overseas department. Approximately 1 minute interview with Radio France Outre Mer (RFO TV), broadcast at 13 pm 13 November.
- Drs A. McC. HOGG, R.C. KERR and Mr T. Prastowo introduced participants in the National Youth Science Forum, held in Canberra, to the variety of research undertaken in the Geophysical Fluid Dynamics Laboratory.
- Dr A. McC. HOGG gave a presentation to the Current Affairs group of the Belconnen branch of the University of the 3rd Age entitled "Ocean Circulation and Climate: SurPRISEs in the Earth System" (21st March 2007).
- Prof B.L.N. KENNETT, Member of Advisory Editorial board for Physics of the Earth and Planetary Interiors and Earth and Planetary Science Letters.
- Prof K. LAMBECK, as President of the Academy of Science, has provided a number of interviews on television, radio and print during 2007. This included the televised National Press Club address on 26 September 2007 entitled "Roadmap for a prosperous Australia in a competitive world" <http://www.science.org.au/events/npc2007.htm> and Radio National's The Science Show on 10 November 2007 <http://www.science.org.au/events/10november07.htm>
- Prof K. LAMBECK, Deakin University Graduation Ceremony, Victoria, 27 April 2007, presented the occasional address to graduands of the Faculty of Science and Technology and the Faculty of Health, Medicine, Nursing and Behavioural Science.
- Prof K. LAMBECK, 2007 Gentilli Memorial Lecture, Perth, Western Australia, 16 October 2007, entitled "Sea Level Change through the Ages: Learning from the past to understand the future".
- Prof K. LAMBECK, Australian-French Association for Science and Technology ACT Lecture, Canberra, ACT, 23 October 2007, entitled "Sea-level through the Ages: Learning from the past to understand the future".
- Prof K. LAMBECK As President of the Australian Academy of Science, participated in several Conferences and Symposia including the National Academies Forum Symposium, Recherche Bay, Tasmania, 26-28 February, Science and Engineering: Skills for Australia's Future, Sydney, 28-29 June and the High Flyers Think Tank on Extreme Natural Hazards, Melbourne, 30 October 2007.
- Dr. N. RAWLINSON was featured in an extensive article on his observational work in the centrefold of the Times2 supplement (pages 6-7) of the April 30, 2007 edition of the Canberra Times.
- Dr M. SAMBRIDGE gave lectures on 'What can you do with mathematics in the Earth Sciences' to year 10-12 students at Canberra Girls Grammar School, ACT, in June.
- Dr M. SAMBRIDGE gave presentations on earthquake generation during Science week activities at Lyneham Primary School, ACT in August.

Dr. W. SCHELLART Research related to subduction zones and the Andes mountain belt appeared in several Australian newspapers (The Canberra Times, The Age, Sydney Morning Herald, Daily Telegraph, Daily Advertiser) and overseas newspapers (NRC Handelsblad (national Dutch newspaper) and De Volkskrant (national Dutch newspaper)). The work also appeared on numerous Australian and international websites (e.g. News@Nature, Physics Web, PhysOrg, Malaysia Sun, Daily India), and featured in several Australian and international magazines (Physics World, Australasian Science, Monash Magazine, ANU Reporter, Natuurwetenschap en Techniek (national Dutch science magazine), and Aarde Nu (national Dutch geoscience magazine)).

Dr. W. P. SCHELLART gave a live radio interview on ABC Sydney-Canberra-NSW-ACT radio on 15 March 2007 about subduction zones and the Andes mountains.

Dr. W.P. SCHELLART published a letter in The Australian Geologist on "Plate tectonics explains the New Britain trench-arc-backarc system", volume 143, pages 31-33, June

Dr H. TKALCIC participated in the workshop "Managing Waveform Data and Related Metadata for Seismic Networks' Kuala Lumpur", Malaysia, October 21-26, 2007. He gave a talk to the participants of the workshop, which was an overview of the RSES Seismology Group activities related to the collection and the scientific use of seismic data.

Dr H. TKALCIC gave a seminar at the RSES, entitled: „The Earth's core: seismological perspective“.

PRISE

Dr R.A. ARMSTRONG was invited to participate in the 1st Workshop on Problems in Western Gondwana Geology with the theme "South America–Africa correlations: du Toit revisited" in Gramado, Brazil from 27 – 29 August and presented a talk on the Precambrian geochronology and crustal architecture of southern Africa.

Teaching activities

Earth Chemistry

Dr J.J. BROCKS taught 'Early evolution of life on Earth (and other planets?)' in Geol3022 Planetary Science at the Department of Earth and Marine Sciences, ANU.

Dr J.J. BROCKS taught the 'Carbon Cycle' as part of the 'Global Cycles' course Geol3022 at the Department of Earth and Marine Sciences, ANU.

- Dr J.J. BROCKS lectured on 'Studying molecular remains of extremely ancient life, an introduction to organic mass spectroscopy' for the RSES Mass Spectroscopy course, 19 February – 02 March.
- Prof T.R. IRELAND taught Planetary Geology (GEOL3022) in the second semester at the Department of Earth and Marine Sciences, ANU.
- Prof T.R. IRELAND lectured at the SINS Summer School "Nuclear Astrophysics and Nucleosynthesis" program, 15–18 January, Monash University, Melbourne.
- Prof T.R. IRELAND gave lectures for the RSES Mass Spectroscopy course, 19 February – 02 March.
- Dr C.H. LINEWEAVER convened and taught the RSAA Honours course in Planetary Science 1–12 August.
- Dr C.H. LINEWEAVER gave a guest lecture in Astronomy 1001 (convenor P. Francis), 15 August.
- Dr C.H. LINEWEAVER gave a Planetary Science Institute Seminar on "Super Earths and Rocky Planet Compositions", 12 September, at RSES.
- Dr C.H. LINEWEAVER lectured at RSAA to visiting Monash Undergraduates (convenor H. Jerjen), 13 September entitled "Exoplanets and Habitability".
- Dr C.H. LINEWEAVER gave a guest lecture in Planetary Geology (Geology 3022, convenor T.R. Ireland) at the Department of Earth and Marine Sciences, 25 September.
- Dr C.H. LINEWEAVER gave a Planetary Science Institute Seminar on "Making of a Habitable Planet", 3 October, at RSAA.
- Dr C.H. LINEWEAVER organised a Planetary Science Institute Research Workshop in honour of David Stevenson, the Jaeger-Hales 2006 lecturer, 24 October.
- Dr C.H. LINEWEAVER convenor of the RSAA Summer Scholarship Program November 20 2006 – Feb 3.
- Dr C.H. LINEWEAVER convenor of the RSAA Summer Scholarship Program November 20 2007 – February 3 2008.
- Dr C.H. LINEWEAVER supervised Physics final year project of ANU 4th year Physics student Mr T. Rutherford, whose topic is "Extending the Concept of a Circumstellar Habitable Zone" (completed June 2007)
- Dr C.H. LINEWEAVER supervised the RSAA Summer Research Scholar Aditya Chopra (University of Western Australia) on the topic "What was the Chemical Composition of the Last Universal Common Ancestor?" (Dec 2006–Feb 2007)
- Dr D. RUBATTO taught (50%) and coordinated "Chemistry of Earth and Oceans", a second year undergraduate course (GEOL2015) at the Department of Earth and Marine Sciences, ANU.

Dr D. RUBATTO coordinated a postgraduate block course in Mass Spectrometry, 19 February – 02 March.

Dr D. RUBATTO taught "Geochronology by ion microprobe" at the EURISPET international postgraduate school, Paris, 21-28 October.

Dr I.S. WILLIAMS lectured on vacuum systems and secondary ion mass spectrometry for the RSES Mass Spectrometry short course, 19 February – 02 March.

Earth Environment

Dr S. EGGINS and Dr M. ELLWOOD taught the 3rd year Marine Biogeochemistry (GEOL 3014) course.

Dr S. EGGINS taught a unit on Marine Chemistry within the 1st year Blue Planet course (GEOL 1002).

Dr S. EGGINS supervised summer student Michelle Linklaker (University of Wollongong)

Dr M.J. ELLWOOD coordinated and taught the Department of Earth and Marine Sciences third year course Marine Biogeochemistry (GEOL 3023).

Dr M.J. ELLWOOD taught the Department of Earth and Marine Sciences third year course Special Topics (GEOL 3050).

Dr M.J. ELLWOOD supervised the three summer students: Mr Hugh DOYLE (University of Otago), Ms Kelly Michelle JAMES (RMIT, Melbourne), and Ms Rebecca NORMAN (ANU)

Dr K.E. FITZSIMMONS gave a guest lecture and laboratory tour for the Centre for Archaeological Research workshop for Honours and Masters students.

Dr M.K. GAGAN serves as external supervisor (2006-2008) for Ms E. St Pierre, ARC Postgraduate Research Scholar with Dr J.-x. Zhao and Assoc. Prof. S. Golding at the University of Queensland, and for Mr M. Griffiths, ARC Postgraduate Research Scholar with Dr R. Drysdale at the University of Newcastle.

Prof. R. GRÜN taught the complete course Scientific dating techniques for archaeology and palaeoanthropology (BIAN 3010) at the Dept. of Archaeology and Anthropology, ANU.

Prof. M. McCULLOCH supervised summer student Aimee Komugabe (UTS)

Mr I. MOFFAT taught "Introduction to Archaeological Geophysics" (ARCH 8307) to coursework masters students enrolled in the graduate programs in archaeology and cultural heritage management and external short course students, Department of Archaeology, Flinders University.

Mr I. MOFFAT taught the two day short course "Geophysics for Archaeologists" to external short course students, Department of Archaeology, Flinders University.

Mr I. MOFFAT taught the archaeology geophysics components of "Archaeological Field Methods" (ARCH2201) to second year undergraduate students, Department of Archaeology, Flinders University.

Mr I. MOFFAT taught the sedimentology and stratigraphy components of "Quaternary Paleoecology" (ARCH2103) and "Archaeological Science" (ARCH3009) to second and third year undergraduate students, Department of Archaeology, Flinders University.

Prof. B.J. PILLANS was co-convenor of the course GEOL3026 "Environmental and Regolith Geoscience".

Prof. B.J. PILLANS gave lectures in SRES3026 "Geomorphology".

Dr P. TREBLE supervised RSES Summer Research Scholar Ms Islay Laird on reconstructing the O isotope record of a 17.5-14 ka speleothem from the Flinders Ranges, SA.

Earth Materials & Processes

Prof S.F. COX taught GEOL2012, Introduction to Structural and Field Geology, GEOL3002, Structural Geology and Tectonics, and portions of GEOL1004 and GEOL3005 in the Department of Earth & Marine Sciences as part of his joint appointment at the Department of Earth & Marine Sciences and RSES.

Dr M. FORSTER taught at the 3rd year Structural Mapping Course at Broken Hill.

Dr J. HERMANN taught the course Magmatism and Metamorphism (GEOL3024) totaling 22 hours of lectures, 36 hours of practicum and one day of excursion.

Dr J. HERMANN taught one hour at the course Chemistry of Earth and Oceans (GEOL2019).

Prof. I. JACKSON co-taught a new third year undergraduate physics course Physics of the Earth (PHYS3070) and supervised three Ph. B. Advanced Study projects.

Prof. G. LISTER with Dr M. FORSTER and Dr S. RICHARDS, organized and taught the ANU undergraduate geology field mapping course at Broken Hill, NSW.

Dr J. MAVROGENES co-coordinated and presented 50% of SRES1004, Australia's Environment.

Dr J MAVROGENES coordinated and taught GEOL3007, Economic Geology.

Dr S. RICHARDS ran the Kialoa Field Trip (September), a field trip to localities along the SE coast of NSW for PhD candidates at ANU.

Mr N. TAILBY tutored the undergraduate Earth Science course SRES1004, Australia's Environment, Faculty of Science (first semester) and was an Associate lecturer,

under the SWAP scheme, in undergraduate Earth Science course, GEOL3007, Economic Geology.

Mr D.R. VIETE helped demonstrate in the first year Earth Sciences course, first semester 2007 (SRES1004).

Mr D.R. VIETE helped demonstrate in the Broken Hill mapping course, July (GEOL 2012).

Earth Physics

Dr A. DUTTON was an invited lecturer for the Greenhouse Science & Policy Course. she provided advice to a graduate student working on seismic attenuation.

Dr. G. F. DAVIES taught PEAT 8001 Masters Course (Plate Tectonics and Mantle Dynamics).

Dr. G. F. DAVIES taught two weeks of GEOL 3027 (Global Cycles and Paleooceanography).

Prof Dr F. FONTAINE taught one practice on seismic anisotropy (PEAT 8002 - Seismology).

R.W. GRIFFITHS and Drs A.McC. HOGG, R.C. KERR and G.O. HUGHES taught PHYS3034 (Physics of Fluid Flows).

Dr A.McC. HOGG taught GEOL1006 (The Blue Planet).

Prof B.L.N. KENNETT – "Research Methods and Management", a component of the Masters Course in Physics of the Earth and Online Course: "Imaging the Earth's Interior"- delivered to Honours and Masters students.

Dr. N. RAWLINSON ran a two week intensive short course in seismology (PEAT8002) as part of the RSES Earth Physics Masters course.

Dr M. SAMBRIDGE taught the Physics of the Earth Honours and Master course Introduction to inverse problems (PEAT 8012 and PEAT8036).

Dr M. SAMBRIDGE gave a component of the Physics of the Earth undergraduate course (PEAT 3070).

Dr H. TKALCIC taught the Physics of the Earth undergraduate course with Prof I. Jackson and Dr P. Tregoning (PHYS 3070), Faculty of Science (second semester).

Dr H. TKALCIC helped with teaching activities for the Masters course Seismology (PEAT 8002), Faculty of Science (first semester).

Dr P. TREGONING was the convener of the Physics of the Earth Honours programme at RSES during 2007. He was also the convener of the Master of Science (specializing in Earth Physics) programme, and taught one third of the 3rd year undergraduate physics course (PHYS3070) entitled "Physics of the Earth". He

also supervised a PhB student undertaking an ASC in analyzing GRACE data and a MSc student undertaking a research project in assessing leakage effects in GRACE analysis into the Australian region from geophysical signals elsewhere in the world.

Honours supervision

Earth Chemistry

Prof T.R. IRELAND and Dr P. Holden are supervising Ms J. Thorne in her Honours project on Hadean zircons.

Dr C.H. LINEWEAVER supervised Honours student Ms E. Jones on Identifying Targets Within the Potential Biosphere of Mars Through a Study of Gullies and Rampart Craters (completed November 2007).

Dr C.H. LINEWEAVER supervised Honours student Mr S. Williams with Prof R. Arculus (Department of Earth and Marine Sciences) on the formation of the Earth from Enstatite Chondrites.

Earth Environment

Prof. R. GRÜN supervised the honours project of Ms T. Kelly on Sr isotope tracing in animal teeth from the Neanderthal site of Les Predelles, France.

Prof. B. J. PILLANS supervised the honours project of Mr James Hughes on regolith geochronology and landscape evolution.

Earth Materials & Processes

Prof. G. LISTER supervised one Honours student (Andrew Barker)

Dr J. MAVROGENES supervised the honours project of Rikki Bailey on Arnhemland Uranium exploration.

Earth Physics

Dr G.O. HUGHES and Prof R.W. GRIFFITHS supervised the Honours project of Mr K. Stewart on "Horizontal convection incorporating a two- or three-dimensional sill".

Dr H. TKALCIC supervised the Ph.B. project of Jessica Hudspeth, on studying the deep earth structure using seismic body waves.

PRISE

Dr M.D. NORMAN supervised the honours projects of Ms. K. Bermingham on the petrology and geochemistry of eucrite meteorites, and of Ms. J. Roberts on the mineralogy and geochemistry of metal in lunar impact breccias.

Other matters

Earth Chemistry

Dr. V.C. BENNETT continues as a member of the Petrology and Geochemistry Earth Sciences review panel for the U.S. National Science Foundation.

Dr V.C. BENNETT, Member, International Program Committee, 2008 Goldschmidt Conference, Vancouver, Canada.

Dr V.C. BENNETT served as student presentation judge at the Dec. 2006, American Geophysical Union Meeting.

Dr V.C. BENNETT was elected to the Board of Directors of the Geochemical Society.

Dr J.J. BROCKS, Founding Member of the 'Centre for Macroevolution and Macroecology' at The Australian National University.

Dr J.J. BROCKS, Member of the ANU College Advisory Board.

Dr J.J. BROCKS, Interim Governing Council of IODP - Australia.

Dr J.J. BROCKS, new Biogeochemistry Laboratory opened in the second floor of Jaeger 1 at RSES, two new mass spectrometers installed.

Prof I.H. CAMPBELL, Secretary General of the Commission for the Evolution of the Solid Earth, a subcommission of the International Union of Geological Sciences; co leader of the Commission for Large Igneous Provinces (LIP); and served on the advisory Committee for COE-21, Institute for Study of the Earth's Interior, University of Okayama.

Prof T.R. IRELAND attended the Noble Gas Virtual Facility meeting 25 March, Brisbane.

Prof T.R. IRELAND chaired a meeting of the UCLA Keck Center Advisory Board, 4-13 December, Los Angeles USA.

Prof T.R. IRELAND chairs the Muses-C Task Force for the Australian Academy of Science.

Dr C.H. LINEWEAVER chaired the RSAA Colloquia Committee and organized various Planetary Science Institute Lectures

Dr C.H. LINEWEAVER maintains the Planetary Science Institute website
<http://www.mso.anu.edu.au/PSI/>

Dr D. RUBATTO, Convener, Session on Rates of high-grade metamorphism, 2007 Goldschmidt Conference, Cologne, Germany.

Dr D. RUBATTO, Treasurer, Association for Research between Italy and Australasia.

Dr R. SALMERON, Reviewer, Origins of Solar Systems/Terrestrial Planets Finder Programs, NASA.

Dr R. SALMERON, Reviewer, Astrophysics & Space Science.

Earth Environment

Dr K.E. FITZSIMMONS was awarded an Australian National University College of Science Small Equipment Grant for Early Career Researchers.

Dr M.K. GAGAN is a member of the Australasian INTIMATE Project (INTEgration of Ice, MARine and TERrestrial records of the Last Glacial Maximum and Termination), which is a core program of the INQUA Palaeoclimate Commission.

Dr M.K. GAGAN is a corresponding member of the INQUA Palaeoclimate Commission (PALCOMM).

Prof. R. GRÜN supervised summer student Rebecca McMillan (Flinders' University)

Prof. M.T. McCULLOCH, is a counsel member of the Australian Coral Reef Society, and attended the meeting on 18 August 2006.

Prof. M.T. McCULLOCH is a member of the governing counsel of the Geochemical Society.

Prof. M.T. McCULLOCH, hosted the Centre of Excellence, Scientific Management Committee, Canberra meeting, in February and participated two further meetings in May (Townsville) and August (Brisbane).

Prof. B.J. PILLANS, Chair, Geological Society of Australia, Capital Territories Division.

Prof. B.J. PILLANS, President, Stratigraphy & Chronology Commission, International Union for Quaternary Research.

Prof. B.J. PILLANS, Member, Organizing Committee for XVIIth INQUA Congress, Cairns, 2007.

Prof. B.J. PILLANS, Leader, Geochronology Project, Cooperative Research Centre for Landscape Environments & Mineral Exploration (CRC LEME).

Dr P. TREBLE was on maternity leave between March and October 2007.

Earth Materials & Processes

Dr M. FORSTER is an academic representative for the OHS Committee for RSES.

Prof D. GREEN serves as a member of the Board of AUSCOPE.

Dr J. HERMANN, convener of session for 2007 Goldschmidt Conference held in Cologne, Germany.

Prof. I. JACKSON served as Chair of the Organising Committee for the 31st Condensed Matter and Materials Meeting (Wagga Wagga, NSW, February), as a member of the Australia - New Zealand Bid Committee for the 2011 IUGG General Assembly, convener of the Symposium on Physics and Chemistry of Earth Materials at the IUGG XXIV General Assembly (Perugia, Italy, July) and as Executive Committee member and Vice-President, International Association for Seismology and Physics of the Earth's Interior (IASPEI).

Mr. I. KOVACS was a reviewer for the European Journal of Mineralogy.

Prof G. LISTER is a member of the College of Science Advisory Board and of the AuScope Modelling and Simulation Committee.

Dr J. MAVROGENES was Deputy Head of the Department of Earth and Marine Sciences, ANU.

Earth Physics

Dr C.E. BARTON served as a member of the National Committee for Earth Sciences, Australian Academy of Science.

Dr C.E. BARTON served as a member of the National Committee for Space Sciences, Australian Academy of Science.

Dr C.E. BARTON served as President of the International Association of Geomagnetism and Aeronomy; also as a member of the Executive Committee of the International Union of Geodesy & Geophysics (IUGG) - both until July 2007.

Dr C.E. BARTON served as IUGG's representative to ICSU's Committee on Data for Science and Technology (CODATA)

Dr C.E. BARTON chaired the International Committee of the Electronic Geophysical Year, 2007-2008 (eGY) initiative. and also the Working Group for eGY-Africa.

Dr A. DUTTON, Committee Member, Promoting Marine Geoscience in Australia (MARGO).

Dr A. DUTTON supervised Dr J. Desmarchelier who provides technical support for U-series analyses at ANU.

Dr A. DUTTON supervised Ms E. Kent, a student who came to RSES for research experience prior to undertaking a PhD.

Dr A. DUTTON is a member of the ANU Climate Initiative.

Prof B.L.N. KENNETT, Chair, Geological Society of Australia Specialist Group in Solid Earth Geophysics.

Prof B.L.N. KENNETT, Member National Committee for Earth Sciences and Chair of Working Party on National Geotranssects.

Prof B.L.N. KENNETT, Chair of the Australian Academy of Science Committee for the Frederick White Conference Series.

Prof K. LAMBECK, President, Australian Academy of Science.

Prof K. LAMBECK, President Elect, Federation of Asian Scientific Academies and Societies.

Mr D. ROBINSON is a committee member for the ACT Branch of the Australian Society of Exploration Geophysicists

Dr H. TKALCIC shared the responsibility with PROF B.L.N. KENNETT for the managing of the seismic and infrasonic facility in Warramunga, NT since July 2007.

Dr H. TKALCIC continues serving as a peer reviewer for the international geophysical journals and the National Science Foundation.

Dr H. TKALCIC, with Dr. C Tarlowski, Mr. A. Arcidiaco and Mr. J. Li has been involved in the major seismic data reformatting, reorganisation and building the acquisition tools to access the RSES archive of seismic data.

Dr H. TKALCIC was awarded a grant from the ANU VC's Office to support a three month long visit by Professor Vernon Cormier in 2008.

PRISE

Dr R.A. ARMSTRONG acted as the external supervisor and advisor for two PhD students from Spain, one PhD student from South Africa and one PhD student from Brazil.

Dr M.D. NORMAN, Chair, Geological Society of Australia Specialist Group in Planetary Geoscience.

Dr M.D. NORMAN, Program Committee, 7th Australian Space Science Conference.

Dr M.D. NORMAN, Program Committee, 2008 Australian Earth Science Convention.

Dr M.D. NORMAN, Steering Committee and Chair of the Planetary Science Working Group for the Australian Space Science Decadal Plan, National Committee for Space Sciences, Australian Academy of Science.

Dr G.M. YAXLEY visited diamond mines Ekati (BHP-Billiton) and Diavik (Rio Tinto) in northern Canada.