Research School of Earth Sciences Annual Report 2006

"India meets China - the mountainous peaks of the Zanskar Himalaya"
Field trip to the Indus suture, NW Himalaya, G.S. Lister and M.A. Forster

THE AUSTRALIAN NATIONAL UNIVERSITY

Research School of Earth Sciences Annual Report 2006 Contents

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Director's Introduction

2006 was the year with three Directors of the Research School. Prof. Mark Harrison completed his term in at the end of March 2006, and then took leave of absence to return to the University of California, Los Angeles. Prof. Ross Griffiths then acted as Interim Director until the beginning of September, when Prof. Brian Kennett took up a three-year appointment as Director. The changes were accompanied by significant administrative upheavals as the Executive Officer, Ms Kerryn Jackson, moved to take up the position of Executive Officer to the College of Science. The new RSES Executive Officer. Mr Mike Avent, was then faced with the task of rebuilding the administrative team, following further departures to the College of Medicine and Health Sciences. By the end of the year the School structures had settled down, just as the significant changes associated with the creation of the College of Science became apparent.

The emphasis on discipline groupings within the College of Science has led to close interactions with the Department of Earth and Marine Sciences in the development of a Strategic Plan for the Geosciences and in a revision of the curriculum for 2007. RSES will henceforth be more strongly involved in undergraduate teaching; as well as starting an M.Sc course on the Physics of the Earth in 2007.

In May, Prof. K. Lambeck commenced a four-year term as President of the Australian Academy of Sciences. In the same month Prof. B. Kennett received the Murchison Medal from the Geological Society of London. Dr G. Yaxley has been awarded an Alexander von Humboldt Fellowship to work in Germany.

Many members of the School were involved in the preparation of investment plans under the National Collaborative Infrastructure Strategy (NCRIS). In particular, a workshop in RSES at the end of January launched the AuScope structure for topic 5.13 "Structure and Evolution of the Australian Continent", and there was also strong involvement in the development of plans for a National Geospatial Reference Frame. These efforts were rewarded in December 2006 with the announcement of $42.8M support over the period 2007-2011 for AuScope, of which $15.8M is designated for the geospatial component. The next step of establishing the AuScope organisation will involve significant work, but should bring major infrastructure investment into the School particularly in the area of Earth Imaging and Inversion.

The School has had months of building work as the former radiocarbon laboratories were remodelled to accommodate the installation of the Accelerator Mass Spectrometer supported by 2005 ARC LIEF funds. A total refit of laboratories on the top floor of Jaeger 2 was also commenced to provide a home for the geobiological mass-spectrometry of Dr J. Brocks which again received 2005 LIEF support.

A joint ARC LIEF bid with the University of Melbourne for new noble gas mass-spectrometers was successful in 2006. With the completion of the SHRIMP SI expected in 2007, a substantial renewal of major facilities in the geochemistry area will have occurred in a rather short time.

The equipment for joint seismic/magnetotelluric recording funded under a 2005 LIEF grant with support from Adelaide and Macquarie Universities has been commissioned with 12 full sets of magnetic coils and 15 recorders. This equipment provides the basis for systematic magnetotelluric exploration of the continent and will be supplemented with AuScope investment.

RSES continued to do quite well in the ARC funding round in 2006 with 12 funded grants (8 direct, 3 through other institutions for Discovery, and a major Linkage project), including a QEII Fellowship to Dr W. Schellart. The pattern of funding across research areas is somewhat uneven, and a challenge for the future comes in maintain the breadth in the School activities so that we are well placed to take up new challenges.

2006 saw the completion of recruitment against the new initiatives of the last few years. In Earth Sounding, Dr H. Tkalcic has been appointed as a Fellow in Observational Seismology. In the Marine Science Initiative, the complement was completed with the appointment of Dr A. Hogg as a Fellow in the area of Ocean Modelling. Further, after prolonged visa delays Dr Y. Amelin was able to accept appointment to the Planetary Sciences Institute and will bring a strong profile in cosmochemistry.

A successful Frederick White Conference sponsored by the Australian Academy of Sciences was organised by RSES in Canberra in April on "Mastering the Data Explosion in the Earth and Environmental Sciences". A diverse Audience with strong RSES participation gained insight from discussion of many topics including inverse problems and data mining from geophysical and statistical viewpoints.

Members of the School also played an important role in the organisation of the 2006 Goldschmidt conference in Melbourne in August, which secured a large attendance from the international geochemistry community.

Dr S. Eggins and Dr M.Gagan were promoted to Level D and Dr G. Hughes and Dr A. Reading to Level C. Dr Reading will not have long to enjoy her new status at RSES, since she has been appointed to a continuing position in Geophysics at the University of Tasmania from February 2007.

The breadth of the research activity of RSES is astonishing and the following pages provide an account of a fraction of the total activity.

STAFF, STUDENTS AND AWARDS 2006

Honours & Awards

Mr T. FUJIOKA was awarded the Best Student Oral Presentation Award at the 12th Australian and New Zealand Geomorphology Group (ANZGG) conference, Taipa Bay , New Zealand , 13-17 February 2006

Prof M.T. McCULLOCH was awarded Doctor of Science *honoris causa* by the Council of Curtin University of Technology, May 2006.

Prof S.F. COX was made "Distinguished lecturer - 2007" by the Society of Economic Geologists.

Prof D. H. GREEN was made a Member of the Order of Australia (AM) for services to science, science policy and education.

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 elected a Fellow of the Mineralogical Society of America.

Prof B.L.N. KENNETT received the Murchison Medal from the Geological Society of London for his work in using seismology to understand large scale geological problems.

ACADEMIC STAFF

Director and Professor

B.L.N. Kennett, Ma PhD ScD Cambridge, FRAS, FAA, FRS (from 4 September 2006)

R.W. Griffiths, BSc, PhD ANY, FAIP, FAA (2 April to 3 September 2006)

T.M. Harrison, BSc British Columbia , PhD ANU, FAA (to 1 April 2006)

Distinguished Professors:

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

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

Professors

S.F. Cox, BSc Tasmania , PhD Monash

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

R. Grün, DiplGeol, Dr.rer.nat.habil Köln, DSc ANU

T.M. Harrison, BSc British Columbia , PhD ANU, FAA

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 Oxf, PhD Manchester

B.J. Pillans, BSc PhD ANU

Senior Fellows

I.H. Campbell, BSc UWA, PhD DIC London

G.F. Davies, MSc Monash, PhD CalTech

C.M. Fanning, BSc Adelaide

M. Honda, MSc PhD Tokyo

T.R. Ireland, BSc Otago, PhD ANU

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

C. Lineweaver, BSc Munich , PhD Berkeley

M.S.Sambridge, BSc Loughborough, PhD ANU

I.S. Williams, BSc PhD ANU

Fellows

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

W.J. Dunlap, BA CarlCol, MS PhD Minnesota

S. Eggins, BSc UNSW, PhD Tasmania

M.K. Gagan, BA UCSantaBarbara, PhD James Cook

J. Hermann, Dip PhD ETH Zürich

J.A. Mavrogenes, BS Beloit, MS Missouri-Rolla, PhD VirginiaPolyTech

M. Norman, BS Colorado , PhD Harvard

A.P. Nutman, BSc PhD Exeter (to 28 February 2006)

R. Rapp, BA (Geological Sciences) State University of New York , PhD (Geology) Rensselar Polytechnic Institute

E. Rhodes , BA DPhil Oxford

D. Rubatto, BSc MSc Turin, PhD ETH

P. Tregoning, BSurv PhD UNSW

G. Yaxley, BSc PhD Tasmania

Research Fellows

L. Ayliffe, BSc (Hons) Flinders University , Graduate Dipolma (Oenology) University of Adelaide , PhD ANU (from 29 May 2006)

A.L. Dutton, BA (Mus) Massachusetts , MSc PhD Michigan

M. Ellwood, BSc (Hons) University of Otago, PhD University of Otago (from 15 June 2006)

K. Evans , MA PhD Cambridge

S. Fallon, BA University of San Diego , MS University of San Diego, PhD ANU (from 2 November 2006)

H.U. Faul, Vordiplom Ulm, PhD Oregon (to 1 September 2006)

G. Hughes, BE ME Auckland , PhD Cambridge

J. Kurtz, BSc MSc Louisiana State , PhD Arizona State

C. McFarlane, BSc Toronto, MSc Calgary, PhD Texas

A. Reading , BSc Edinburgh, PhD Leeds

C. Sinadinovski, BSc (Hons) Zagerburi University , MSc (Geology) Zagreburi University , PhD (Geotomography) Flinders University

P. Treble, BSc Woll, BSc PhD ANU

Postdoctoral Fellows:

M. Aubert

A. Barnhoorn, MSc Utrecht, PhD ETH Zürich

J.M. Desmarchelier, BSc PhD Tasmania

A.L. Dutton, BA (Mus) Massachusetts , MSc PhD Michigan (to 31 July 2006)

F. Fontaine, DEUG (Hons) University of Reunion, MSc University of Montellier II, PhD University of Montpellier II

M. Forster, BSc MSc PhD Monash

J. Freeman, BSc Curtin, PhD Monash

M. Heintz, BSc Nancy, MSc Strasbourg, PhD Montpellier (to 2 May 2006)

A.M. Hogg, BSc ANU, PhD UWA

J. Huang, BSc Peking, PhD Academy of Sciences China (from 28 February 2005)

S. Jupiter, A.B Harvard University , PhD University of California (from 29 September 2006)

S.N. McLaren, BSc PhD Adelaide (to 31 January 2006)

S. Micklethwaite, BSc PhD Leeds

N. Rawlinson, BSc PhD Monash

S.W. Richards, BSc PhD Newcastle

W.P. Schellart, BSc Amsterdam, PhD Monash

C. Spandler, BSc PhD ANU (to 2 May 2006)

E. Tenthorey, BSc McGill, MSc Florida , PhD Columbia

J. Tuff, BSc (Hons) University of Bristrol, PhD University of Cambridge

A.M. Walker, MSc (Geology) University College of London , PhD Royal Insitution of Great Britain (to 6 January 2006)

Senior Visitors

J.M.A Chappell, BSc MSc Auckland, PhD ANU, FAAS, FAA

W.Compston, BSc PhD Dsc(Hon) WAust, FAA, FRS*

D.H. Green, BSc MSc DSc, DLitt(Hon) Tas, PhD Camb, FAA, FRS*

I. McDougall, BSc Tas, PhD ANU, FAA*

J.S. Turner MSc Syd, PhD Camb, FIP, FAIP, FAA, FRS*

* Emeritus Professor

Research Officers

J.D. Fitz Gerald, BSc James Cook, PhD Monash

P. Holden, BSc Lancaster, PhD St. Andrews

H.W.S. McQueen, BSc Qld, MSc York, PhD ANU

Research Assistants

A. Arcidiaco, BAppSc GradDip SAInst

B.J. Armstrong, BSc UNISA

L. Carr, BSc (Hons) BA ANU

A. Christian, BSc (Earth and Land Science) (Hons) University of Canberra , (from 15 June 2006)

M. De Kool, CAND. Sc (Physics) University of Amsterdam , D.S.C (Astrophysics) University of Amsterdam , PhD University of Amsterdam

T. Ewing, BSc MSc Canterbury NZ (to 25 February 2006)

S. Fishwick, BSc Edinburgh, PhD ANU (from 11 April 2006)

C. W. Magee, BSc Brown, PhD ANU

M. Maldoni, BAppSc RMIT, MSc PhD UNSW (until 10 January 2006)

R.W.L. Martin, BSc ANU

P. Rickwood, BSc (Comp Sci) (Hons) UNSW

Y. Shan, BSc Wuhan Cehui Technical University , MSc Wuhan Cehui Technical University , PhD UNSW, (from 8 August 2006)

C. Tarlowski, MSc Moscow, PhD Warsaw

L. Weston, BSc Macquarie (to 19 March 2006)

J. Zhao, BEng Fuzhou, MEng Ganzhou, DEng Wuhan, PhD ANU

D. Zwartz, BSc (Hons) Victoria University of Wellington , PhD ANU (from 10 July 2006)

POST-GRADUATE STUDENTS

PhD Candidates

A. Abdulah, BE ME Institut Teknologi Bandung (ITB)

A. Aikman, BSc (Hons) Edinburgh

J. Avila , MSc Universidade Federal Do Rio Grande do Sul , Brazil

B. Ayling, BSc Wellington

S. Barker, BSc (Hons) Otago

M. Beltrando, MSc Turin

R. Berdin, BSc MSc Philippines

R. Brodie, BSc QLD

S.N. Burgess, BSc (Hons) Adelaide , MSc (Hons) Auckland

J. Celerier, BSc (Hons) Melbourne

M. Coman, BSc (Hons) ANU

A. Cross, BAppSc GDipAppSc MAppSc Canberra

R. Da Fonseca, BSc Lisbon

J. Dawson, BSc BS MSc Melbourne, Grad Cert UWS

G. Estermann, MSc Vienna

T. Fujioka, BSc MSc Osaka

R. Fraser, BTech BSc Flinders

S. Giger, Vordiplom MSc ETH Zürich

C. Gregory, BSc Monash, BSc (Hons) ANU

J. Hauser, Vordiplom BS MS, ETH

J. Hiess, BSc (Hons) Canterbury

R. Ickert, MSc (Hons) Simon Fraser University

F. Jenner, BSc (Hons) Oxf Brookes

R.C. Joannes-Boyau, MSc University-Bordeaux , France

A. Kallio, MSc Helsinki

N. Keller, MSc ETH

I. Kovacs, MSc Eötvös

K. Lilly, BSc (Hons) ANU

A. Lyman, BSc MSc Arizona State

G. Mallman, BA MS Brazil

I. McCulloch, BSc UNSW, GradDip ANU

M. Miller, BA Whitter, MSc Columbia NY , MEng Cornell NY

M. O'Byrne, BSc (Hons), Grad Dip ANU

T. Prastowo, BSc ITS, MSc ITB

D. Qu, Petroleum Inst Jianghan, MSc Academy of Sciences China

D. Robinson, BSc (Hons) Flinders, Grad Cert UWS

A. Rosenthal, MSc, University in Freiberg , Germany

A. Sadekov , BC MG Moscow State

E. Saygin, BSc Istanbul Technical

M. Smith, BSc UNSW

P.J. Smythe, BSc, University of Wollongong

H. Sparks, BSc UBC, BSc (Hons) ANU

N. Tailby, BSc (Hons) ANU

J. Trotter, BSc MSc Macquarie

D. Valente, BSc (Hons) La Trobe

D. Viete, BSc BE (Hons) Monash

G. Webb, BSc (Hons) Adelaide

D. Wood, BSc Monash

Y. Zhou, BSc MSc Chengdu Inst Tech

MPhil Candidates

I. Itikarai, BSc UPNG Papua New Guinea

Honours Students

C. Mexted-Freeman

A. Papuc

R. Ruddick

PhD THESES SUBMITTED

B. Ayling – Seasonal Paleoclimates of the MIS 5E, 9 and 11 Interglacials, Using Geochemical Proxies in Porites and Tridacna. Supervisor: Prof M. McCulloch. Advisors: Prof B. Pillans, Dr P. Hearty, Dr M. Gagan, Prof J. Chappell.

T. Fujioka – Development of In-situ Cosmogenic 21Ne Exposure Dating, and Dating of Australian Arid Landforms by Combined Stable and Radioactive In-situ Cosmogenic Nuclides. Supervisor: Prof J. Chappell, Dr M. Honda. Advisor: Prof L.K. Fifield, Dr F. Fabel, Dr T. Barrows.

F. Jenner – The Geochemistry of early Archean basic and ultrabasic rocks from southern west Greenland : Tectonic setting and mantle source evolution. Supervisor: Dr V. Bennett, Dr A. Nutman. Advisor: Dr G. Yaxley, Dr A.J. Crawford.

A. Lyman – Effects of Rheology and surface soildfication on the emplacement of channelized lava flows. Supervisor: Prof R. Griffiths, Dr R. Kerr. Advisor: Dr W. Johnson

M. Miller – Four_Dimensional Structral Evolution of the Western Pacific Convergent Margin Based on Seismic Tomography and Palaeographic. Supervisor: Prof G. Lister, Dr W.J. Dunlap. Advisor: Prof M. Harrison, Dr L. Moresi, Prof B.L.N Kennett.

M. Smith – Towards a Geochronology for Long-Term Landscape Evolution, Northwestern New South Wales . Advisor: Prof B. Pillans, Dr K.G. McQueen, Dr W.J. Dunlap, Dr S.M. Hill.

J. Trotter – Conodont Geochemistry – proxies for understanding palaeoenvironments, bioevents and geoevents of the Palaeozic. Supervisor: Prof M. McCulloch, Prof P. De Deckker, Dr S. Eggins Advisor: Dr C. Barnes, Dr R.S. Nicoll, Prof J. Chappell.

Student Scholarships and Fellowships

A.L. Hales Honours Year Scholarship: Not Awarded.

Mervyn and Katalin Paterson Fellowship: I. Kovacs

Robert Hill Memorial Prize: F. Reith

A.E. Ringwood Scholarship: R. Ickert

John Conrad Jaeger Scholarship: S. Barker

Summer Research Scholarships

H. Doyle (Otago University , New Zealand) under the supervision of Dr M. Ellwood

D. Gaetijens (The Flinders University, South Australia) under the supervision of Prof M. McCulloch, Dr S. Eggins.

M. Laird (University of Canterbury , New Zealand) under the supervision of Prof J. Chappell, Dr P. Treble.

H. Rogers (University of Canterbury , New Zealand) under the supervision of Prof G. Lister, Dr V. Bennett, Dr T. Ireland

K. Stewart (Australian National University , Canberra) under the supervision of Dr A. Hogg, Dr G. Hughes.

Student Internships

M. Ayling of Victoria University of Wellington . Supervisor: Dr S. Eggins

R. Bailey of Australian National University . Supervisor: Dr T. Ireland, Dr J. Mavrogenes

C. Bolton of Australian National University . Supervisor: Dr E. Rhodes

S. Hui of Australian National University . Supervisor: Dr J.A. Mavrogenes

J. Hughes of Australian National University . Supervisor: Prof J.M.A. Chappell

J. Lapwood of University of Canterbury Supervisor: Prof B.L.N. Kennett

J. Lapwood of University of Canterbury . Supervisor: Prof B.L.N. Kennett

T. Kelly of University of Tasmania . Supervisor: Prof R. Grün

J. Roberston of University of Otago . Supervisor Prof G. Lister

J. Van Jaarsveld of Technische Universiteit Eindhoven . Supervisor: Prof R. Griffiths

GENERAL STAFF

Executive Officer

Michael Avent Grad Cert Mgmnt, Grad Dip Admin, University of Canberra (from 6 February 2006)

Kerryn Jackson (to 25 February 2006)

Executive Assistant to the Director

Marilee Farrer (from 25 July 2006)

Vivien Gleeson (to 1 July 2006)

Building and Facilities Officer

Eric Ward, Cert V Frontline Management, Quest/ANU

Finance Officers

Teresa Heyne, (Operations) BComm, Deakin University (from 20 February 2006)

Lisa Pope, (Grants) BComm (MgmtSci), University of Canberra

Human Resources Officer

Jennifer Nott, B. Education, University of Canberra (from 29 May 2006)

Monica Murphy (to May 2006)

Student Officer & Human Resource Assistant

Nathalie Garrido, Cert III Tourism & Events Management, CIT (from 24 July 2006)

Jennifer Talbot (to May 2006)

Information Technology

Duncan Bolt, BSc University of Sydney

Brad Ferguson, BDesign(Phot) CIT

Receptionist & Finance Assistant

Natalie Fearon (from May 2006)

Coralie Cullen (to 7 April 2006)

Area Administrators

Earth Chemistry – Robyn Petch

Earth Environment – Susanne Hutchinson, BA, La Trobe University (from 31 July 2006)

Kristy Stubbs (to 31 May 2006)

Earth Materials – Kay Provins

Earth Physics – Denise Steele (from 6 July 2006)

Anna Osterberg (to 9 March 2006)

Jenny Nieto (to 1 April 2006 - 25 May 2006)

Danica Fouracre (Kurt Lambeck), BEnv.Des, BA (Hons), University of WA (from 10 July 2006)

School Librarian

Chris Harney, Dip CIT , BA (Communications Information) University of Canberra

Technical Officers

Charlotte Allen , AB Princeton MSc Oregon , PhD VirginiaTech

James Arnold, BSc Sydney, GradDip CCAE (to 5 October 2006)

Anthony Beasley, AssocDip CIT

Brent Butler, Cert III Mechanical Engineering Sydney Institute

Zane Bruce, BSc PhD Canterbury (to 9 July 2006)

Joseph Cali, BAppSc QIT

David Cassar (Trainee)

David Clark

Wayne Cook, Cert Geoscience (field hands) CIT, BSc ANU (from 3 July 2006)

Derek Corrigan

Joan Cowley, BSc ANU

Daniel Cummins, (Trainee)

Jingming Duan, BE DUT, MSc Murdoch

John D. Fitz Gerald, BSc James Cook, PhD Monash

Alan Forster

John Foster, BSc Sydney, MSc PhD ANU

Daniel J Hunt, Adv Diploma Mechanical Engineering (Trainee, from 4 December 2006)

Ben Jenkins, BSc UTS, PhD ANU

Damien Kelleher, AssocDip Cartog CIT

Leslie Kinsley, BSc GradDipSc ANU

Harri Kokkonen, BAppSc CCAE

Clementine Krayshek (to 30 June 2006)

Andrew Latimore

Christopher Morgan (to 18 February 2006)

Graham. Mortimer, BSc PhD Adelaide

Charles Norris, BSc ANU

Shane Paxton

Anthony Percival

Jean-Pierre Robbie (to 21 January 2006)

Craig Saint

Scott Savage

Norman Schram, Dip EIE SAIT

Dean Scott

Heather Scott-Gagan, BSc Sydney

James Shelley, MSc Canterbury (to 18 November 2006)

Stefan Sirotjuk, AssocDip TAFE

Brendan Taylor

David Thomson

Carlyle Were

Lara Weston (to 19 March 2006)

Andrew Welsh, BAppSc CCAE

Andrew Wilson

Geoffrey Woodward

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

Xiaodong Zhang, PhD LaTrobe

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.

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.

Geobiology

A new direction in Earth Chemistry is the study of organic matter and biomarker molecules extracted from sedimentary rocks by Dr Jochen Brocks. Biomarkers give information about ancient microbial ecosystems and their environments. Earth Chemistry and RSES have committed to a new laboratory facility for biomarker research including a new mass spectrometer. We were able to secure central support for the construction of a new laboratory and construction started on 21 November and will be completed by end-February 2007.

SHRIMP

This year has seen systematic improvements in our abilities to measure stable isotope ratios with SHRIMP II in negative ion mode. A combination of terrestrial-magnetic-field suppression, mount redesign, and suppression of secondary ions induced by the electron gun, had all contributed to pulling analytical errors well into the subpermil range. SHRIMP I has had a computer refit, even though the 14-year-old Apple Mac II has performed flawlessly, and a stage drive upgrade such that stage positions can be computer controlled. This allows unattended computer-controlled analyses. SHRIMP SI progresses with the ordering of many of the major components and final designs for most assemblies being carried out or completed.

Personnel

This year we welcome APF Fellow Dr Ian Buick who has moved from Monash University to continue his studies in combinations of metamorphic petrology, conventional light isotope geochemistry of carbonates (O-C) and silicate (O) rocks, U-Pb geochronology and mineral-scale trace element geochemistry.
Dr Yuri Amelin of the Canadian Geological Survey, Ottawa , has accepted a position funded by the Planetary Science Institute and is expected to arrive in early 2007. Dr Amelin's specialty is high precision geochronology, focusing on the earliest chronology of the solar system.

ARC and MEC

This year saw one ARC Discovery awarded to Dr Jochen Brocks for research into saline Lake Tyrrell mud. Further in this research, an ANU / U.C. Berkeley / Macquarie University collaboration in the Lake Tyrrell Metagenome/Biomarker project was successful with the award of US$1,920,911 from NSF to our collaborator Prof Jill Banfield (UC Berkeley) for the genome sequencing part of the project. Dr Masahiko Honda and collaborators were successful in securing ARC and MEC funding for a multicollector noble gas mass spectrometer, and Dr Jochen Brocks received MEC funding for an automated solvent extraction system.

Research Highlights

Geochronology and Ti-thermometry of eastern Himalayan granitoids	Amos B. Aikman
Opening the possibility of more multiple analytical techniques on individual zircon grains: case study of U/Pb and (U+Th)/He dating, so called "double-dating"	C.M. Allen
Signatures of extinct nuclides preserved in Earth's oldest (> 3600 Ma) rocks shed light on the "dark ages" of early planetary history	Vickie C. Bennett
Ancient steroids and the evolution of complex life	Jochen J. Brocks
Ar diffusion in muscovite	Julien Célérier
Some insights into the SHRIMP U–Pb analysis of xenotime	Andrew Cross
How chalcophile is Re? An experimental study of the solubility of Re in sulphide mattes.	Raúl O. C. Fonseca
Exploring the potential of allanite as a geochronometer of high-grade crustal processes	Courtney J. Gregory
Redesign of SHRIMP mounts to minimize geometric effects on isotopic and inter-elemental fractionation.	Joe M. Hiess
Cosmogenic 21 Ne exposure dating of young basaltic lava flows from the Newer Volcanic Province, southwestern Victoria, Australia	M. Honda
Electron-Induced Secondary Ion Emission (EISIE): An important consideration in the analysis of light isotopes in insulators	Ryan Ickert
Solar Wind Oxygen in Lunar Metal Grains	Trevor Ireland
Complex histories of melt inclusions in archean komatiites	Antti Kallio
Extrasolar Planets and the Dry Brown Dwarf Desert	Charles H. Lineweaver
What happens to zircon during subduction?	Daniela Rubatto
Marginal Basin Development in the Svecofennian orogenic province 2.30 to 1.85 billion years ago	R.W. Roye Rutland
The Geology, Geochemistry and Geochronology of the El Abra Mine, Chile, and the adjacent Pajonal-El Abra suite of intrusions	Dianne L. Valente
Further advances in measuring the oxygen isotopic compositions of granite zircon using *SHRIMP II*	Ian Williams

Geochronology and Ti-thermometry of eastern Himalayan granitoids

Amos B. Aikman[1], T. Mark Harrison[2], Peter Holden[1] & Joe Heiss[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Department of Earth and Space Sciences, The University of California Los Angeles, USA*

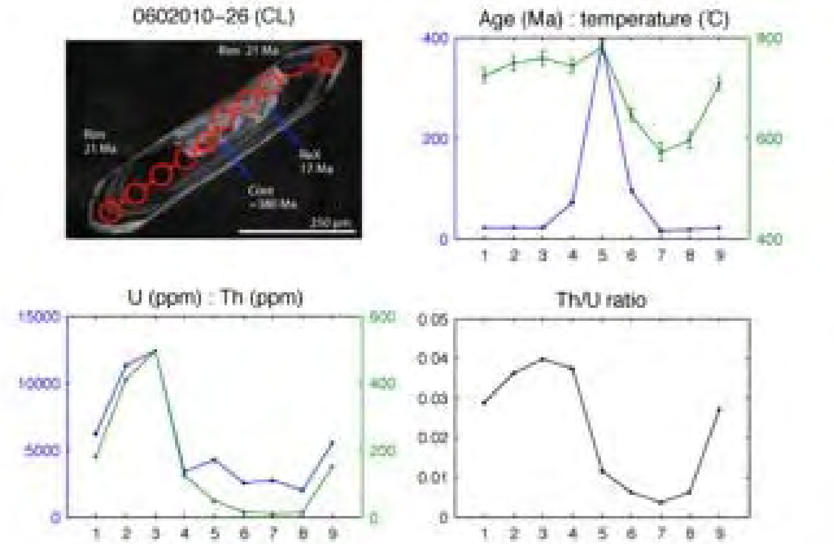
Granitoids are frequently found in regions that have experienced prolonged crustal thickening. This spatial and temporal association places significant requirements on models of orogenesis. The distribution and timing of granitoid magmatism bears on the thermal budget and locus of tectonic activity within the orogen. Their geochemistry can provide insights into the sources and distribution of protolith materials and, in some cases, the structural architecture of the orogen. The nature of granitoid formation is such that magmas naturally concentrate many trace elements that may be characteristic of their source regions and melting processes. These elements are often conveniently incorporated into neoformed accessory phases, the age of which may in some cases be determined through the use of radioactive decay schemes. This has provided a valuable tool with which to understand the evolution of modern and ancient orogenic zones.

Zircon is a mineral that is particularly valuable in studies of granitoid petrogenesis. It is ubiquitous in granitic rocks and many other crustal rocks. It not only contains sufficient quantities of radioactive U and Th to be dated using a variety of analytical techniques, but it also hosts important isotopic tracers such as Hf and O. Furthermore, it is characterized by very low diffusivities of most elements such that their concentrations and/or isotopic ratios generally retain the characteristics of the zircon's formative environment.

Recent studies have demonstrated the temperature dependency of Ti concentration in the zircon lattice (e.g. Watson and Harrison, 2005). We have developed a protocol for measuring Ti content ([Ti]) rapidly with high accuracy and precision, using the SHRIMP 2 Multi-collector (S2MC). This method also allows for high spatial resolution such that [Ti] measurements may be easily correlated with the results of conventional ion-probe U-Pb dating. This approach allows us to study the distribution of age, crystallization temperature, and trace elements (U+Th) within individual zircon grains.

The results of analyses of zircons from four granitoid sample suites yielded a spectrum of crystallization temperatures that are consistent with the processes of magma genesis inferred from bulk geochemistry. Offset temperature peaks in two anatectic samples correctly distinguish between vapor-present and vapor-absent melting, and a broad distribution skewed to higher temperatures, derived from a plutonic body, matches that predicted by fractional crystallization models.

Positive correlations of both [Th] and Th/U ratio with crystallization temperature were observed in data from all sample suites. These are attributed to co-crystallization with monazite, effectively starving the melt of Th. Similarly, core-to-rim transects through individual zircon grains, confirm the decreasing Th/U proportional to decreasing age and temperature, and increasing degree of fractional crystallization. Furthermore, these factors are also correlated with Cathodoluminescence (CL) zonation. Analyses conducted parallel to CL-zones typically yielded similar ages, temperatures, Th/U and [Th+U]. However, analyses conducted across CL-zones frequently show large temperature and trace element excursions, which are interpreted to reflect thermal and compositional instability in the zircon's growth environment, possibly associated with convection and/or magma recharge. Anomalous areas that appear to cross-cut CL zonation yielded younger ages, lower temperatures and lower Th/U. They are attributed to localized re-crystallization associated with late/post magmatic fluids.



Watson, E.B. and Harrison, T.M. (2005) Zircon thermometer reveals minimum melting conditions on earliest earth. *Science* 308, 841-844.

Opening the possibility of more multiple analytical techniques on individual zircon grains: case study of U/Pb and (U+Th)/He dating, so called "double-dating"

C.M. Allen[1], I.H. Campbell[1], and P.W. Reiners[2]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Dept. of Geology and Geophysics, Yale University, New Haven CT 06511*

The ability to U-Pb date zircon grains rough mounted on double-sticky tape opens up fields of research based on multiple geochemical analyses of individual grains, especially when the rim of the grain is of interest. In the LA-Q-ICP-MS facility, (Excimer laser plus Agilent 7500 ICP), we can ablate a small percentage of a grain, date it using the U-Pb system, and then have 99% of the grain left for other investigations such as (U+Th)/He dating, or Hf-Lu work (Figure CA-1). Thus far we have taken advantage of this analytical capability by U-Pb and (U-Th)/He dating zircons from active river sands from North America and from the Himalaya (Reiners et al., 2005; Campbell et al., 2005). Using this "double-dating method", we can date when a zircon crystallized, and when it last cooled through 200°C, i.e. approached within a few kilometres of the Earth's surface. This research has been on going for 4 years and we now have a substantial data set for North America. In this work about 20% of the U-Pb dated grains (~1100 for 6 river samples) are selected for (U+Th)/He dating. The selected grains have simple age and compositional structure.

This work, in part, has been to prove assumptions made in the first "double-dating" paper (Rahl et al., 2003) that double-dating can be used as a much more accurate provenance tool than either dating method individually. For instance, a Mississippi River zircon dated at 1100 Ma using U-Pb could have several potential sources: the Cordillera, the mid-continent rift, or the Grenville Province of Canada and the northeastern U.S. Grenville bedrock currently being eroded can be expected to have (U+Th)/He ages of about 1000-800 Ma based on region Ar-Ar work. Grains exposed in the Appalachian Mountains should have Appalachian orogenic ages, from about 430 to 220 Ma, if Triassic thermal disturbances are included in this grouping. Cordilleran rocks have 200 Ma and younger (U+Th)/He ages. What double dating signature the mid-continent rift would express is unknown. In a lower Mississippi River sand two distinct groupings of grains with U-Pb ages ranging from 1000-1200 Ma are encountered in the total age range of 3450 to 30 Ma: 1) (U+Th)/He ages of 1040 to 850 Ma, and 2) (U+Th)/He ages of 440 to 220 Ma. Although these zircons are indistinguishable from the traditional U/Pb dating method, clearly they have distinct sources, probably freshly eroded Grenville bedrock in the first case, and Appalachian sources (sediments uplifted during orogenic events, and now recycled into the modern river system) in the second. With such tools estimates of the amount of zircon recycling in modern sediments can be made.

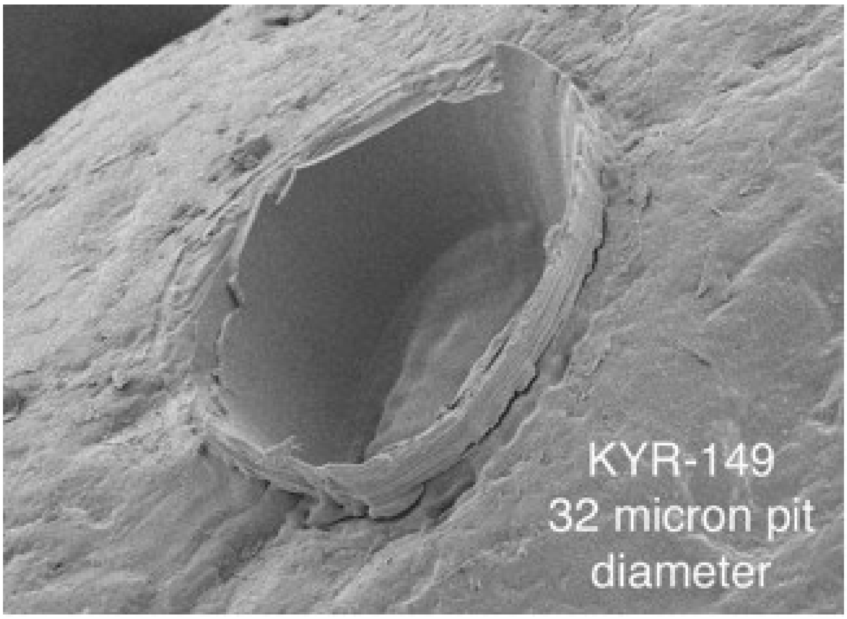


Figure 1. Whole zircon from Kentucky River sand with laser ablation pit.

Reiners, P.W., Campbell, I.H., Nicolescu, S., Allen, C.M., Hourigan, J.K., Garver, J.I., Mattinson, J.M., and Cowan, D.S., (U-Th)/(He-Pb) double dating of detrital zircons, *American Journal of Science*, 305, 259-311.

Rahl, J.M., Reiners, P.W., Campbell, I.H, Nicolescu, S., and Allen, C.M., 2003. Combined single-grain (U-Th)/He and U/Pb dating of detrital zircons from the Navajo Sandstone, Utah: *Geology*, 31, 761-764.

Campbell, I.H., Reiners, P.W., Allen,C.M., Nicolescu, S., and Upadhyay, R., 2005, *Earth and Planetary Science Letters*, 237, 402-432.

Signatures of extinct nuclides preserved in Earth's oldest (> 3600 Ma) rocks shed light on the "dark ages" of early planetary history

Vickie C. Bennett[1], Alan D. Brandon[2] and Allen P. Nutman[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] NASA Johnson Space Center, Houston, TX 77058, USA
[3] Chinese Academy of Geological Sciences, Beijing 100037, P.R. China

Revealing the mechanisms and timescales of planetary formation, including that of Earth is a major quest of 21st century science. Owing to vigorous tectonic processing the earliest history of the Earth, during the 600 myr "dark ages" between the start of planetary accretion at about 4.567 as dated by primitive meteorites and the beginning of the rock record at about 4.0 Ga is poorly understood. Yet, it is during this time period that the major chemical domains of the Earth formed, including the metallic core and silicate mantle, the growth of the first continents and the development of the oceans and atmosphere.
Here we are applying novel radiogenic isotopic approaches, the tracking of the signatures of "extinct" nuclides as preserved in the oldest rocks, to provide new types of information on Earth's early history. Extinct nuclides are radioactive isotopes with short half-lives, on the order of 1myr to 100 myr years, that were present at the time of solar system formation, but have now completely decayed into their daughter elements. Thus variations in the isotopic compositions of the daughter products of short half-life parents, if they can be found in the rock record, must record chemical events that occurred early in Earth's history while the parent isotopes were still "alive". Whilst various short half-life isotopic systems have applied to the study of meteorites, which formed and were chemical differentiated within a few 10's of millions of years of solar system history, it has proved much more difficult to use this approach on Earth. A system with potential for early Earth studies is the decay of ^{146}Sm-^{142}Nd (half-life = 103 myr).

As part of our on-going studies of early Earth history we have undertaken high precision ^{142}Nd isotopic measurements of samples of the two most extensive early Archaean terranes, the Itsaq complex, southwest Greenland and the Narryer gneiss complex, western Australia. Itsaq complex samples range in age from 3.63-3.87 Ga and include both felsic and mafic lithologies. The 3.73 Ga gneisses from the Narryer gneiss complex are the oldest rocks in the Yilgarn craton. The Itsaq samples have ^{142}Nd/^{144}Nd compositions that are 8-17 ppm higher than modern terrestrial compositions (Fig. 1); five of the oldest (ca. 3.85 Ga) gneisses yield similar values of +15ppm. The new results confirm (Bennett et al, 2006) and extend the high precision (< +/-5 ppm) data of Caro et al. (2006) and further document the existence of terrestrial ^{142}Nd variations arising from the decay of now extinct ^{146}Sm. The 3.73 Ga gneisses from the Narryer gneisses complex overlap in age with the Itsaq samples, but have distinctly lower ^{142}Nd/^{144}Nd compositions of ca. +4 ppm. The relative isotopic differences preserved in contemporaneous samples from two widely separated terranes points to the existence of early formed, chemically diverse mantle sources at 3.7 Ga. The Narryer gneisses either formed from a mantle source with a lower average Sm/Nd than the Itsaq source, or the Narryer mantle was partially remixed with a more LREE enriched source prior to 3.7 Ga, but after ^{146}Sm was largely decayed. The Sm-Nd system also contains the commonly used long half-life isotopic scheme of ^{147}Sm decaying to ^{143}Nd (106 byr half-life). Using the information from the coupled long and very short half-life Sm-Nd systems in the same rocks provides additional age controls. The combined ^{143}Nd- ^{142}Nd data from the oldest (ca. 3.85 Ga) measured terrestrial samples require formation of differentiated silicate reservoirs in the first 60 myr of Earth history, that is shortly after core formation and points to very rapid timescales for the formation and chemical differentiation of terrestrial planets including Earth.

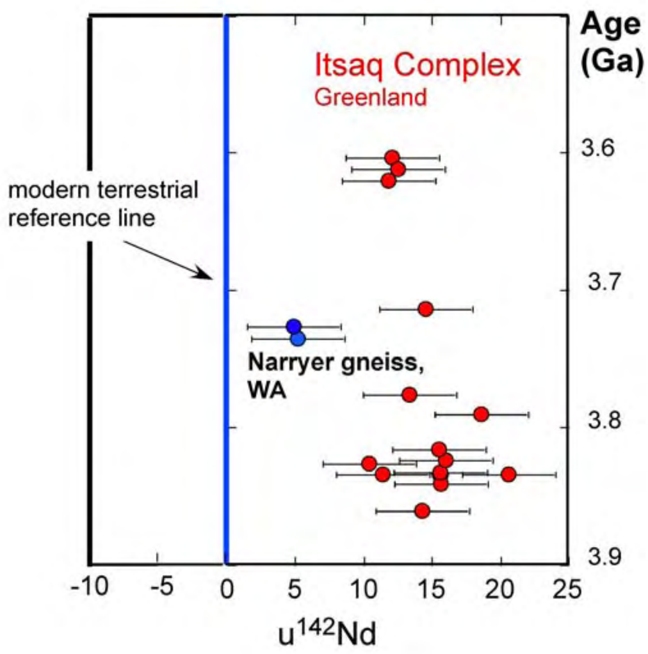


Figure 1. High precision ^{142}Nd isotopic compositions expressed as parts per million deviations from modern terrestrial samples. The crystallization ages in Ga (billions of years) are indicated on the right axis. Early Archaean samples from West Greenland show anomalous isotopic compositions; contemporaneous Narryer gneisses have smaller isotopic effects pointing to an early formed, but chemically heterogeneous mantle source. Error bars indicate +/- 3ppm measurement precision.

Bennett, V. C., Brandon, A. D., and Nutman (2006) Combined $^{142-143}$Nd Isotopic Data from 3.6- 3.87 Ga Rock Suites Document Incomplete Mixing of Early Mantle, *Eos Trans. AGU*, 87(52), Fall Meet. Suppl., V22CC-06.

Caro et al, (2006) High-precision ^{142}Nd/^{144}Nd measurements in terrestrial rocks: Constraints on the early differentiation of the Earth's mantle. *Geochimica et Cosmochimica Acta*, 70, 164-191.

Ancient steroids and the evolution of complex life

Jochen J. Brocks

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

Charles Darwin cited the apparent absence of fossils from rocks of Precambrian age (now dated at >0.542 billion years, Ga) as a valid argument against his concepts on the origin of species. One hundred years after Darwin, these concerns were resolved and petrified remains of prokaryotes (bacteria and archaea) were detected in all periods that preceded the Cambrian, dating as far back as 3.5 Ga. The oldest fossils of eukaryotes, the group of nucleated organisms that includes all animals, fungi, protists and plants, date back to at least 1.5 Ga. However, eukaryotic diversity and abundance remained low well into the Neoproterozoic (1.0 – 0.542 Ga) and the evolutionary pace to new eukaryotic forms and shapes remained more than ten times slower than in the following Phanerozoic. The first convincing evidence for animals, at this stage still mere clusters of cells, was detected in Chinese phosphorites, 600 Ma old. However, early eukaryotes were microscopic and generally lacked skeletons that are easily preserved. How do we know that the scarcity, low complexity and slow evolution of eukaryotes in the Precambrian are not an artefact of fossil preservation?

Biomarkers, or molecular fossils, provide an independent record of life in the Precambrian that can be used to test our understanding of early eukaryote evolution. Biomarkers are the hydrocarbon fossils of biological molecules such as lipids. A variety of steroid lipids are exclusively found in the cell membranes of eukaryotes, and the fossils of these steroids can be preserved in sedimentary rocks that are hundreds of millions of years old. Unfortunately, the study of minute traces of genuine Precambrian steroids is extremely difficult because of ubiquitous contamination with biomarkers from younger sources. As a consequence, published distributions of steroids in Precambrian rocks look curiously similar to steroids found in the Phanerozoic. To see a genuine Precambrian biomarker distribution, we devised a new technique (microsonication) that distinguishes between traces of Precambrian steroids and younger additions. Using the new technology, we discovered a distribution of eukaryotic biomarkers in 1.6 to 0.6 Ga old rocks from Australia, North America and China that are distinct from anything observed later in Earth history. The oldest steroids that we found are biosynthetically simple and could reflect evolutionary precursors to modern membrane lipids. The new results show that steroids remain generally rare throughout most of the Precambrian and the full range of known structures only becomes prevalent after 0.7 Ga ago. The simplicity and scarcity of steroids appears to be analogous to the rarity of eukaryotic body fossils in the Precambrian and suggests that the unusual microfossil distribution uncovered by Palaeontologists reflects ecological reality and is not simply preservational artifact.

Figure 1. An extant eukaryote growing on 1.65 Ga old braided river deposits of the Kombolgie Formation at Bardedjilidji in Kakadu National Park, Northern Territory, Australia. The early ancestors of this tree already existed when the rocks were deposited, but biomarker evidence from contemporaneous sea sediments suggests that they were still rare and probably ecologically unimportant.

Brocks J.J. (2006) Proterozoic ocean chemistry and the evolution of complex life. *16th Annual V. M. Goldschmidt Conference*. 27 August to 1 September, Melbourne, Australia.

Brocks J.J. (2006) Geochemical cycles and the late rise of complex life. *Stars to Brains Conference in Honour of Prof Paul Davies*, Canberra 20 to 21 June, 2 pages.

Brocks J.J. (2006) A revised history of steroid evolution in the Proterozoic? *Australian Organic Geochemistry Conference* , Rottnest Island , WA , 12 to 15 February, 2 pages.

Ar diffusion in muscovite

Julien Célérier[1], T.M Harrison[1,2], Jöerg Hermann[1], Amos Aikman[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[1] *Department of Earth and Space Sciences & IGPP,UCLA, Los Angeles, CA 90095, USA*

Muscovite is one of the most utilised minerals in $^{40}Ar/^{39}Ar$ geochronology and thermochronology. Despite its importance, no experimental study of the diffusion behavior of Ar in muscovite – key to assigning closure temperature – has yet been published. This is largely attributable to the narrow experimental range between temperatures high enough to effect measureable (>5%) diffusive loss whilst not exceeding the phase stability field. Instead, the thermochronological community has tended to adopt a nominal value for closure temperature (e.g. Hodges, 1991) based on empirical calibrations. In the past year of research I have been able to produce preliminary results from diffusion experiments which have enabled determination of Arrhenius parameters for Ar diffusion in muscovite; activation energy (E) ≈ 60 kcal/mol and a frequency factor (D_0) ≈ 10 cm^2/s [similar to that of phlogopite; Giletti (1974)]. These values correspond to a closure temperature (Tc) of 370°C for a grain with a 100 µm radius cooling at 10°C Ma-1.

As starting material, we use a large muscovite crystal from a pegmatite in the Harts Range, Central Australia. This sample has been analysed by the $^{40}Ar/^{39}Ar$ step-heating method revealing a uniform release pattern over >90% of the gas release (Fig. 1). We thus infer that it has been closed to loss of ^{40}Ar since 325.8±2.5 Ma. Size fractions of the starting material of 38-45 µm were loaded in gold capsules together with $AlOH_3$ to buffer Al_2O_3 and H2O activity during the experiments. The capsules were run in a piston cylinder apparatus for 1-6 weeks at temperatures ranging from 660°C to 730°C at 10 kbar pressure, ensuring that run conditions were well within the phase stability of muscovite. Treated samples were subsequently analysed by the $^{40}Ar/^{39}Ar$ method to determine f (fractional loss), in turn allowing calculation of D (diffusion coefficient).

Examination of experimental run products by transmitted light microscopy revealed that under hydrothermal run conditions, muscovite grains are undergoing grainsize reduction and/or recrystallisation. This bimodal grainsize distribution is reflected in the age spectra of the hydrothermally treated samples, which differ from that expected from outgassing of grains with a single diffusion size (blue curve, Figure 2). We have constructed a simple model which represents the effects of mixing a bimodal grainsize distribution under conditions of diffusive loss. Preliminary results indicate that the observed form of the age spectra for the experimental run products may be reproduced by varying 1) the loss parameter (Dt/r^2), 2) the mass ratio of large to small grainsize domains, and 3) the enhanced diffusion parameter resulting from reduced grainsize. Together, these results indicate that incorporation of smaller diffusion domains leads to an overestimation of fractional loss. Calculations of closure temperature assuming loss from a single domain will therefore be underestimtaed.

Take for example the model in Figure 2. Best fit modelling indicates an *f* substantially lower than the bulk loss resulting in a *D* around an order of magntitude lower than that shown in Figure 1 b. This, in turn, results in a *Tc* about 25°C higher.

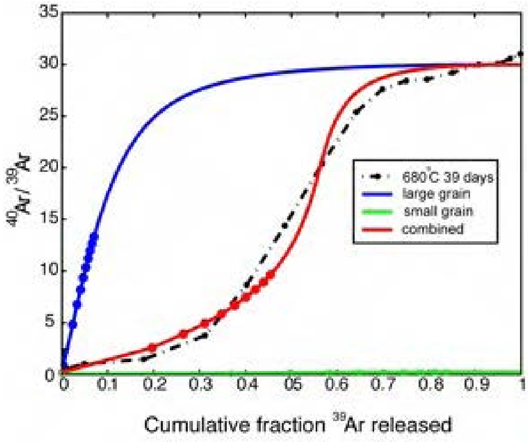


Figure 1. Figure 3. a) ^{40}Ar/^{39}Ar age spectra of the Harts Range pegmatite before and after hydrothermal treatment in a piston cylinder apparatus over a range of experimental conditions. b) Arrhenius plot of diffusion coefficients calculated from experimental data using an infinite cylinder model, against reciprocal absolute temperature. Plot assumes a single diffusion domain size.

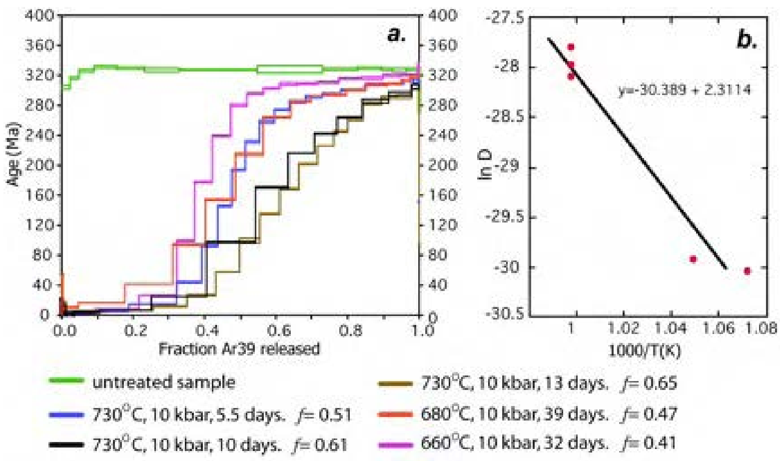


Figure 2. Observed and model age spectra for the experimental run products. Blue and green lines indicate the form of the age spectra that would be expected for the large and small grainsize domains respectively. Red lines indicates the combined age-spectra assuming a mass ratio of 17:1. Note that the model fit could be significantly improved through the incorporation of more than two grainsize domains.

Gileti B. (1974) Studies in diffusion 1: Argon in phlogopite mica. In: Geochemical transport and kinetics (ed. A.W Hoffman, B.J Giletti, H.S Yoder, Jnr & R.A Yund), pp 107-115. Carnegie Inst. Of Wash. Publ. 634.

Hodges K.V. (1991) Pressure-temperature-time paths. Ann. Rev. Earth Planet Sci 19, 207-236.

Some insights into the SHRIMP U–Pb analysis of xenotime

Andrew Cross and Ian Williams

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

Introduction

Recent years have seen the mineral xenotime (YPO_4) proven as a valuable chronometer of mineralisation, metamorphism and sediment diagensis. In these settings, xenotime is usually found as small (<20 μm) overgrowths and single grains, their small size restricting U–Pb isotopic studies to SIMS techniques. Xenotime preferentially incorporates the HREE (mainly Gd, Dy, Er Yb) and also U, Th, Ca and Si into its structure. HREE contents typically range between ~15 and 25 wt % while U and Th can range up to ~7 wt %. Chemical contrasts between standard and unknown (especially in U) can result in SHRIMP U–Pb ages that are elevated by >20%. Correcting for this is a major challenge. Fletcher et al. (2000) recognised a correlation between increasing U contents and SHRIMP U–Pb ages and proposed a method of U abundance scaling to correct for this effect. More recently Fletcher et al. (2004) proposed matrix correction factors that consider the role of U, Th and REE in xenotime SHRIMP U–Pb analysis.

Present study

As a prelude to a number of proposed xenotime SHRIMP U–Pb studies, a series of experiments were carried out to determine optimal analytical conditions. The three xenotime standards used in these investigations (MG1, BS1 and Xeno1) vary in age and also have contrasting U, Th and REE contents. Initial experiments trialed energy filtering as a technique to eliminate the U–Pb matrix effects. This was tested as energy filtering increases the proportion of high energy ions collected, which Shimizu (1978) and Shimizu and Hart (1982) have shown to be less chemically fractionated relative to the low energy ion population. Although effective in reducing scattered ions observed at the ^{204}Pb and background mass stations, energy filtering failed to reduce the U–Pb matrix effects. Experiments show that YbO/Y_2O ratios within a high U sample monitor the U–Pb fractionation. However, this effect is not consistent between samples and therefore cannot be used as a correction technique.

Xenotime U–Pb matrix correction protocols adopted for future experiments are similar to those used by Fletcher et al. (2004) and necessarily involve electron microprobe chemical determinations for U, Th and ΣREE for each spot prior to SHRIMP analysis. Corrected Pb/U ages are referenced to the primary standard MG1 which is used for the Pb/U–UO/U discrimination correction. BS1 and Xeno1 are used as secondary standards which monitor the effect of U, Th and REE on the raw Pb/U ratios. Matrix corrections are then derived from the chemical composition of each spot and the level of U–Pb fractionation relative to its reference age, via a simple least squares method. Interestingly, xenotime U–Pb matrix correction factors for U, Th and ΣREE can differ from session to session and indicate that correction factors are sensitive to machine operational conditions, in particular the strength of the primary beam and therefore the resulting secondary ion transmission. For example, the matrix effect for U (expressed as the % U–Pb ratio change for a relative abundance difference of 1 %) was ~13 % when using an O^-_2 primary beam of ~2 nA and kohler aperture of 70 μm on SHRIMP II. In contrast to this, a session using SHRIMP RG employing an O^- primary beam of ~0.9 nA and kohler aperture of 30 μm resulted in a matrix correction for U of ~10 %. Both of these results are quite different to those of Fletcher et al. (2004), who obtained a correction for U of ~7 % using different operating conditions. The matrix correction factors for U, Th and ΣREE for the above sessions indicate that the percentage effect that U has on the U–Pb ratios, increases with increasing secondary ion transmission. These results also indicate that the reproduceabilty of xenotime matrix correction factors for U, Th and ΣREE may need to be monitored on a session-by-session basis.

Fletcher, I.R., McNaughton, N.J., Aleinikoff, J.A., Rasmussen, B. and Kamo, S.L. (2004). Improved calibration procedures and new standards for U–Pb and Th–Pb dating of Phanerozoic xenotime by ion microprobe. *Chem. Geol.* 209, 295–314.

Fletcher, I.R., Rasmussen, B., and McNaughton, N.J. (2000). SHRIMP U-Pb geochronology of authogenic xenotime and its potential for dating sedimentary basins. *Aust. J. Earth Sci.* 47, 845–859.

Shimizu, N (1978). Analysis of zoned plagioclase of different magmatic environments: A preliminary ion microprobe study. *Earth Planet. Sci. Lett.* 39, 398-406.

Shimizu, N and Hart S.R. (1982). Applications of the ion microprobe to geochemistry and cosmochemistry. *Ann. Rev. Earth Planet.* Sci. 10, 483-526.

How chalcophile is Re? An experimental study of the solubility of Re in sulphide mattes.

Raúl O. C. Fonseca[1], Guilherme Mallmann[1], Hugh St. C. O'Neill[1] and Ian H. Campbell[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*

Although the Re/Os isotopic system has proved to be a valuable aid in understanding the evolution of the Earth's mantle, interpretation of the data is currently hindered by limited knowledge of the high-temperature geochemical behaviour of Re. In particular, the extent to which Re in the mantle is hosted by sulphide or silicate phases is poorly known. We report the results of an experimental study of the solubility of Re in sulphide melts (called here "mattes") coexisting with a Re-rich Re-Fe alloy in the system Fe-Re-S-O over a range of fO_2, fS_2 and temperatures, which allow extrapolation to conditions pertinent to the Earth's mantle. The solubility of Re in mattes increases with increasing fS_2, with Re dissolving as Re^{4+} at high fS_2 and Re^0 at low fS_2. The effect of fO_2 is negligible except at high fO_2 where O in the matte becomes important. At constant fS_2, an increase in temperature leads to an increase in the solubility of Re^0 in the matte, but a decrease in the solubility of Re^{4+}. These results, coupled with Re solubility in silicate melts from the literature, allow the calculation of Re matte/silicate-melt partition coefficients ($D_{Re}^{matte/sil}$) according to:

Rhenium is shown to behave as a moderately chalcophile element during MORB petrogenesis, with $D_{Re}^{matte/sil}$ ranging between 1 and 50, in agreement with the empirical observations of Roy-Barman et al. (1998). For slightly more oxidizing environments, such as the Lo'ihi OIBs, Re is predicted to behave as either a weakly lithophile or as a weakly chalcophile element, with $D_{Re}^{matte/sil}$. This prediction is in agreement with the observed correlation between sulphide content, and therefore fS_2, and Re concentrations in OIBs (Bennet et al., 2000). For more oxidizing environments, such as island-arcs, Re behaves as a strongly lithophile element, with an average $D_{Re}^{matte/sil}$ for IABs of ~10^{-4}, which is consistent with the empirical observation of Re enrichment in volcanic glasses from undegassed island-arc lavas (Sun et al., 2003a,b, 2004).

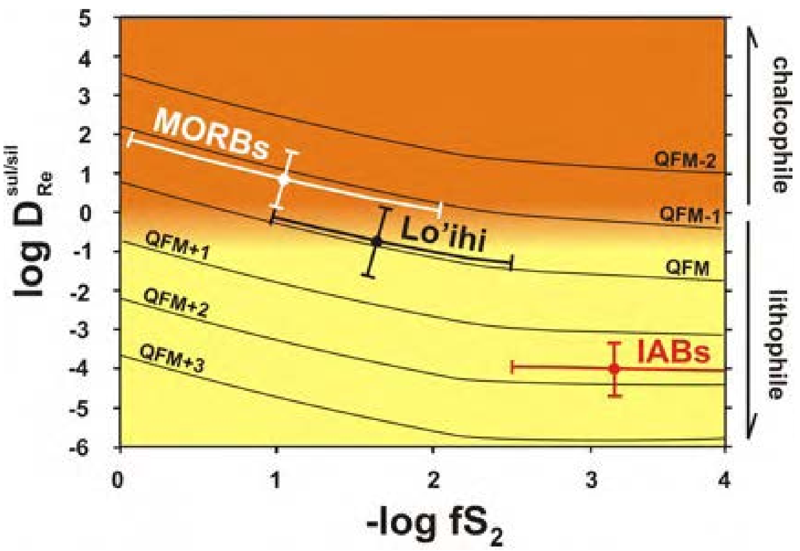


Figure 1. Estimated average D Re matte/sil as a function of fS_2 and fO_2, for mid-ocean ridge basalts (MORB), Lo'ihi ocean-island basalts (OIBs) and island arc basalts (IABs).

References

Bennett, V.C., Norman, M.D., Garcia, M.O., 2000. Rhenium and platinum group element abundances correlated with mantle source components in Hawaiian picrites: sulphides in the plume. *Earth Planet. Sci. Lett.* 183, 513:526.

Roy-Barman, M., Wasserburg, G.J., Papanastassiou, D.A., Chausidon, M., 1998. Osmium isotopic compostions and Re-Os concentrations in sulphide globules from basaltic glasses. *Earth Planet. Sci. Lett.* 154, 331:337.

Sun, W., Arculus, R.J., Bennett, V.C., Eggins, S.M., Binns, R.A., 2003. Evidence for rhenium enrichments in the mantle wedge from submarine arc-like volcanic glasses (Papua New Guinea). *Geology* 31(10), 845:848.

Sun, W., Bennett, V.C., Eggins, S.M., Kamenetsky, V.S., Arculus, R.J., 2003. Enhanced mantle-to-crust rhenium transfer in undegassed arc magmas. *Nature* 422, 294:297.

Sun, W., Bennett, V.C., Kamenetsky, V.S., 2004. The mechanism of Re enrichment in arc magmas: evidence from Lau Basin basaltic glasses and primitive melt inclusions. *Earth Planet. Sci. Lett.* 222, 101:114.

Exploring the potential of allanite as a geochronometer of high-grade crustal processes

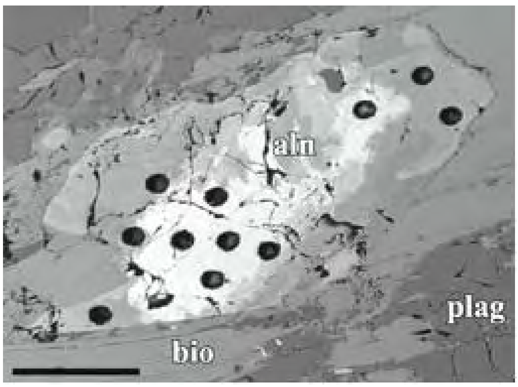
Courtney J. Gregory[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*

The focus of this study has been to explore whether we can date allanite successfully *in situ* using laser ablation ICP-MS techniques together with SHRIMP ion microprobe procedures. The accuracy of the calibration procedures has been demonstrated by analysing Phanerozoic allanite samples, previously dated by ID-TIMS, with different FeO, REE and Th contents. For U-Th-Pb analysis by LA-ICP-MS multigrain Th-Pb isochrons can be constructed with a precision of 1.5-2.5% (95% C.L.) at a resolution of 32µm×32µm×20µm. Accurate (±1-3%) and precise (1-2%, 95% C.L.), SHRIMP Th-Pb ages are achieved for allanite samples with REE+Th > 0.5 apfu, without additional matrix corrections.

The utility of the technique is now being explored through the analysis of samples from a range of geological environments. These include low-grade regional metamorphic rocks (central Lepontine Alps), subducted high-pressure metamorphic rocks (Lanzo massif, W. Alps), calc-alkaline plutons (Bergell, W. Alps; Tara, NSW), and amphibolite-grade migmatitic rocks (Petermann Ranges, C. Australia; central Lepontine Alps). Together with high-contrast imaging (BSE), trace element chemistry has been used to investigate the chemical response of allanite to different paragenesis in order to better interpret U-Th-Pb ages.

In situ study has revealed multiple ages and preservation of chemical signatures within single allanite-epidote crystals from migmatitic gneisses of the central Lepontine Alps (BSE image opposite, scale 200µm). The rocks experienced an episodic but extended period of partial melting of ~10 Ma at temperatures ~700°C. This has implications for the resistance of the allanite U-Th-Pb isotopic system with regard to radiogenic Pb retentivity.



Redesign of SHRIMP mounts to minimize geometric effects on isotopic and inter-elemental fractionation.

Joe M. Hiess[1], Ian S. Williams[1] and Peter Holden[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*

Development of procedures for the analysis of oxygen isotopes on SHRIMP II at the ANU has been hindered by variable isotopic fractionation related to the geometry of conventional sample mounts. Temora zircons mounted as a 2 mm-spaced grid have revealed a >10‰ range in $^{18}O/^{16}O$ fractionation across the mount surface. Such spot-to-spot differences are unacceptable for accurate and precise analysis of insulators. The same grid has been used to map correlations in geometric effects on Pb/UO_2, U/UO_2 and QT_1Y which can be used to improve corrections for inter-element fractionation.

Possible causes of these fractionations include topography at the metal edge of the mount holder, and the transition from epoxy to metal at that edge. Two new mounts were designed to test these hypotheses. An epoxy mount was recessed into a modified conventional mount holder to remove topographic edge effects but retain the epoxy-metal transition. $^{18}O/^{16}O$ fractionation was reduced (range ~5‰) and more systematic, but not eliminated, with progressively heavier compositions towards the edges of the mount.

A new "Mega mount" design was also tested to remove both effects. This design involved an epoxy disc 35 mm diameter screwed onto the face of the mount holder (Fig 1), increasing the area of the equi-potential surface and eliminating the epoxy-metal transition. Both standard insulating epoxy and conductive epoxy were tested. Conductive epoxy guaranteed conductivity, but at the expense of transmitted light imaging. It consisted of 1 part epoxy resin : 0.5 parts spectroscopic carbon powder : 0.12 parts epoxy hardener. Conductive epoxy proved unnecessary, however, provided that conductive adhesive tape was used to link the gold coat on the analytical face to the mount holder. Substantial improvements in the uniformity of U-Pb and $^{18}O/^{16}O$ fractionation across the mount surface have been obtained during initial testing, the range in $^{18}O/^{16}O$ fractionation approaching the detection limits of the experiment (± 0.5‰).

Figure 1. New Mega mounts assembled with both insulating and conductive epoxy.

Cosmogenic ^{21}Ne exposure dating of young basaltic lava flows from the Newer Volcanic Province, southwestern Victoria, Australia

D. Gillen[1, 4], M. Honda[2], A. R. Chivas[1], I. Yatsevich[2] and D. B. Patterson[3]

[1] *GeoQuEST Research Centre, School of Earth and Emvironmental Sciences, University of Wollongong, NSW 2522*
[2] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[3] *Patterson Instruments Ltd, Blenheim, New Zealand*
[4] *Present address: School of Earth Sciences, James Cook University, Townsville, QLD 4811*

Cosmogenic ^{21}Ne was utilised to determine exposure ages of young subaerial basaltic lava flows from the Newer Volcanic Province, southwestern Victoria, Australia. Within uncertainties, the ages (40 – 44 ka) determined from cosmogenic ^{21}Ne analyses in olivines separated from basalts were consistent with extrusion ages previously determined by cosmogenic ^{36}Cl exposure dating. In contrast to neon, cosmogenic ^{3}He exposure ages appear to be hindered by coexisting mantle ^{3}He in some of the samples in the present study. This paper clearly illustrates the potential utility of cosmogenic neon exposure ages in studying the eruption and surface morphology history of young volcanics, which are difficult to date using other conventional methods, such as K-Ar dating.

Electron-Induced Secondary Ion Emission (EISIE): An important consideration in the analysis of light isotopes in insulators

Ryan Ickert, Ian Williams, Joe Hiess

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

Measurement of light stable isotopes on the SHRIMP is accomplished by sputtering a sample with a positive primary ion beam, Cs^+, and extracting negatively charged secondary ions. During the analysis of electrically insulating materials, this configuration causes a charge build up on the sample surface and results in a reduction in the number of extracted secondary ions. Delivering electrons to the analysed insulator by an electron gun alleviates this problem. An unpleasant side effect of the use of an electron gun for charge neutralization is that the electrons alone (i.e., with the primary beam turned off) can produce measurable quantities of secondary ions which are both variable in abundance and have strongly fractionated isotopic ratios relative to the directly sputtered secondary ions. We report preliminary experiments, using ^{16}O and ^{18}O in zircon, designed to characterize and neutralize the electron-induced secondary ion emission (EISIE), and to characterize the electron gun itself and determine it's optimum operating conditions.

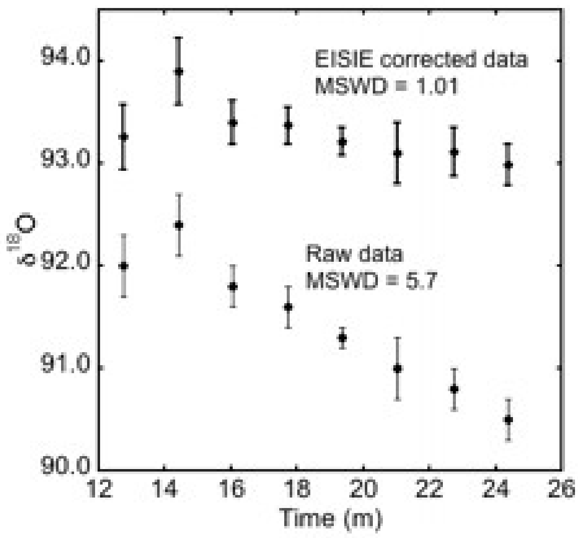
The experiments were conducted on the ANU SHRIMP II multicollector, equipped with a Kimball Physics ELG-5 electron gun mounted off the extraction lens housing and floated at primary column potential. It provides a focused electron beam directed at the target at an incidence angle of 45°. The electron energy can be adjusted over the range 0 to -3 kV, i.e. +0.75 to -2.25 kV relative to the target potential. All analyses were conducted on the modified grain mount design described by Heiss et al. (this volume) in conventional epoxy with a ~8 nm thick Au coat. Oxygen isotope measurements were made on both the TEMORA II standard zircon and zircon from the S-type 432 Ma Wantabadgery Pluton near Wagga Wagga, NSW.

Both the strength and time-dependant characteristics of the EISIE are dependant on a number of factors, including electron focus and energy, Cs^+ current and flux, and particularly proximity to previously analyzed areas. EISIE occurs when electrons are directed at or near an analytical pit that either has been, or is being sputtered with Cs^+. Material on a grain mount well away from a sputtered area does not exhibit EISIE. During the course of an analysis (of a pit well away from previously sputtered areas), the electron-induced contribution to the total secondary beam increases exponentially, although for long duration analyses the increase may abruptly shift to a linear form. The electron-induced secondary ions have a much lower average energy than ions directly sputtered by Cs^+, and they are also isotopically much lighter, having an apparent $^{18}O/^{16}O$ over 150‰ lower than the Cs^+ sputtered oxygen ions.

These electron-induced secondary ions are a significant obstacle to making reproducible measurements of oxygen isotopes in insulators. For a typical 15-20 minute analysis, the effect is negligible at the beginning of the analysis, but can account for 1-2% of the total secondary ions by the end of an analysis. Because the isotopic composition of the EISIE is highly fractionated it can reduce the measured $\delta^{18}O$ of a sample by 3‰.

Current work focuses on minimization or elimination of EISIE, and developing reliable corrections for when it is present. Simple peak-stripping procedures are used to correct for the electron-induced ions, and can result in a within-spot precision of <0.3‰ (1SE, n=25) relative to VSMOW for a 0.1 nA total secondary ion beam. Additionally, electron energies are kept as low as possible in order to minimize the effect. Future work will include the exploration of energy filtering to exploit the extremely low relative energy of the electron-induced ions.

In experiments to determine the behaviour of the electron gun, it was found that the efficiency of charge compensation (as measured by the total secondary ion current) is consistent over a wide range of high electron energies but drops rapidly to zero over a narrow range of low electron energies. In addition, it was confirmed that the electron gun settings (i.e., focus and deflection) that provide the strongest secondary beam also focused the beam at the sputtering pit and not somewhere else on the mount.



Solar Wind Oxygen in Lunar Metal Grains

Trevor Ireland, Peter Holden, and Marc Norman

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

We have extended our studies on solar wind implanted oxygen in lunar soils. Previously we reported analyses of metal grains from lunar soil 10084 from the Apollo 11 landing site. Two grains have oxygen concentration profiles consistent with solar wind implantation. The oxygen concentration quickly decays over 10-20 nm and then stabilizes at a few wt % and decays slowly for a few hundred nanometers. The oxygen isotopic composition is enriched in the heavy isotopes of oxygen, ^{17}O and ^{18}O, by 5% relative to terrestrial oxygen. We have analyzed metal spherules from two further soils 61141 and 78481 from Apollo 16 and 17 respectively. The Apollo 17 soil has metal spherules that appear tarnished suggesting a surface oxidized layer. The oxygen signal is consistent with this interpretation with high and stable oxygen count rates, and the isotopic composition of the oxygen is normal. Some of the Apollo 16 spherules appear fresh and have low surface contributions of oxygen. However, the oxygen concentration falls monotonically with no suggestion of an implanted component. The oxygen isotope composition remains normal throughout the analysis. These new results do not provide us with another instance of solar wind oxygen, but they do provide additional information on the nature of exposure of lunar soils to solar wind. The gardening of lunar soil appears to be a stochastic process with variable exposure time to solar wind and variable oxidation of metal surfaces. The Apollo 16 spherules are particularly important because either they have never been exposed to solar wind, or the solar wind oxygen has diffused from them. At the temperatures expected for solar wind implantation O diffusion may be quite rapid and the oxygen lost on timescales of weeks to months.

A solar composition enriched in ^{17}O and ^{18}O is inconsistent with previous proposals suggesting either oxygen similar to terrestrial, or a composition enriched in ^{16}O by 5% as found in refractory inclusions and some chondrules. It possibly reflects distinct gaseous (predominantly CO) and dust (predominantly silicate) O isotopic compositions, and the domination of the dust component alone in the planetary system.

Complex histories of melt inclusions in archean komatiites

Antti Kallio

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

Silicate melt inclusions in komatiites are important for our understanding of archean volcanism and mantle processes. Current studies on the oldest (3.3 Ga) available olivine-hosted melt inclusions from the Barberton Greenstone Belt, South Africa, have uncovered unexpected complexities in trying to decide what inclusions are preserving pristine melt compositions. Inclusions from Barberton have various degrees of crystallinity and variable shapes and are difficult to understand petrographically. Visual heating experiments together with proper modelling of major element chemistry of inclusions and host olivines and analysis of Cl and S in inclusions are proving to be essential to see the preservation of primary features. Studies from other greenstone belts (Belingwe, Abitibi) highlight the problem that every sample behaves differently, so the details of every sample with melt inclusions have to be worked out separately. If uncompromised magmatic trends are identified, data for water and trace elements can be combined to form the beginning of a database on primary komatiitic melt compositions.

Extrasolar Planets and the Dry Brown Dwarf Desert

Charles H. Lineweaver[1], Daniel Grether[2]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Department of Astrophysics, University of New South Wales, Sydney, NSW, Australia*

Sun-like stars have stellar, brown dwarf and planetary companions. Relatively few brown dwarfs (compared to the number of planets and stellar companions) have been found in close orbits around sun-like stars. Why this should be so is unknown. With PhD student Grether, Lineweaver compiled, analysed and interpreted the world's data on exoplanet, brown dwarf and stellar companions. Our analysis i) confirmed that the brown dwarf desert was not a selection effect and ii) located the position of the driest part of the brown dwarf desert (the mass at which the fewest number of companions exist) at M = 31^{+25}_{-18} M_Jupiter. We found that approximately 16% of Sun-like stars have close companions more massive than Jupiter: 11% +/- 3% are stellar, <1% are brown dwarf and 5% +/- 2% are giant planets. Our results are published in the paper,

Grether, D., Lineweaver, C.H. (2006) How Dry is the Brown Dwarf Desert?: Quantifying the Relative Number of Planets, Brown Dwarfs and Stellar Companions around Nearby Sun-like Stars, *Astrophysical Journal* 640, 1051, astro-ph/0412356.

What happens to zircon during subduction?

Daniela Rubatto[1], Jörg Hermann[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*

Rocks that underwent high-pressure metamorphism and are now exhumed to the surface are the main geological record of subduction, the process by which continents are buried to depth by plate tectonic and mantle convection. The only way to constrain rates and duration of this process is to date accessory minerals in high-pressure rocks. An important step in this process is to understand what happens to datable minerals, like zircon, during high-pressure metamorphism. Metamorphic zircon that forms during subduction-exhumation is texturally distinctive. Two main features are observed: partial or complete replacement of a zircon crystal by a zircon of different composition (also called recrystallization) and new growth of zircon, often on a relict (inherited) grain. Generally replacement is common in sub-solidus conditions, whereas new growth is virtually ubiquitous when melt is present. The figure illustrates increasing degrees of structural modification of zircon in response to HP metamorphism. Zircon in equilibrated eclogite-facies rocks may be unaffected by metamorphism and represent the only magmatic relict in the mineral assemblage. The preservation of older zircon grains (inheritance) is the rule, particularly in HP rocks that experienced relatively low temperatures (<650°C). Metamorphic zircon first occurs along fractures, and likely formed in the presence of fluids (A). Commonly, inherited magmatic crystals have irregular domains where the original zoning is replaced by chaotic, patchy zircon (B and E). The altered zircon is often porous, rich in micro-inclusions, shows signs of corrosion (C), and is isotopically disturbed, i.e. ages measured in altered zones are geologically meaningless. An insight into zircon recrystallization is provided in D: a magmatic zircon has been replaced by an aggregate of small zircon crystals, intergrown with HP minerals. Common features in subducted rocks are discrete zircon rims or domains. These rims form on inherited magmatic (E) or detrital cores (F) and often provide reliable ages for the metamorphism. Occasionally, completely new zircon grains are found in HP metamorphic veins. This requires dissolution of Zr from other sources (most likely magmatic zircon in the country rock) and very high fluid/rock ratios. These hydrothermal zircon crystals lack inheritance, are euhedral and polygonally zoned, and may contain inclusions of HP minerals (G). In subducted rocks that reached partial melting (T > 650°C), inherited zircon can be completely lost to new metamorphic zircon (H and I), which tends to be euhedral and to exhibit regular zoning. Recent detailed studies reveal that zircon in HP rocks in fact forms over a wide range of conditions from subduction to exhumation. This is why zircon often preserves multiple growth zones formed at different stages of metamorphism (E, H and I).

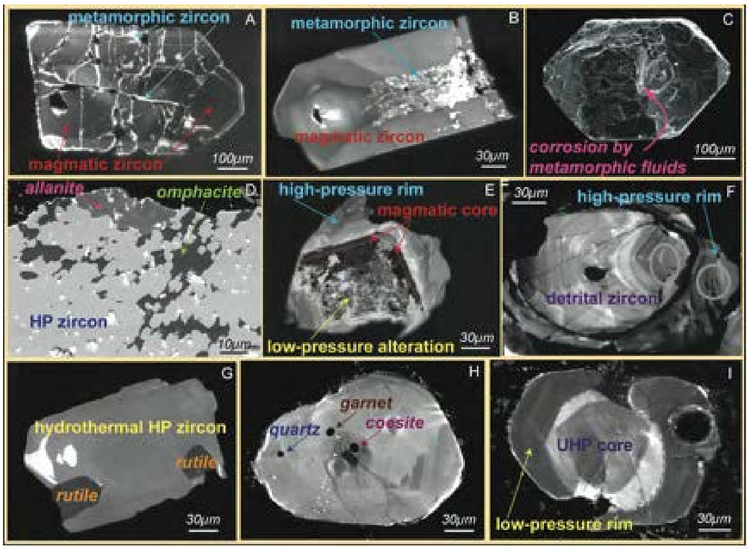


Figure 1. Internal structure of zircon crystals from subducted rocks. Sources are own work and Tomasheck et al. 2003.

Tomaschek F., Kennedy A.K., Villa I.M., Lagos M., and Ballhaus, C. (2003) Zircons from Syros, Cyclades, Greece - recrystallization and mobilisation of zircon during high pressure metamorphism. *Journal of Petrology* 44:1977-2002.

Marginal Basin Development in the Svecofennian orogenic province 2.30 to 1.85 billion years ago

R.W. Roye Rutland[1] and Ian S. Williams[1]

[1] *Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia*

We continue to test the evidence for an alternative marginal basin accretion model for the development of the main part of the Svecofennian orogenic province in Sweden and Finland. From structural and aeromagnetic evidence in several districts we have concluded that, contrary to the prevailing arc-accretion model, the main episode of deformation in the underlying metamorphic complexes occurred before, not after, the overlying volcanic sequences were deposited (Rutland et al., 2001a, b). We have focused on dating this early tectonothermal episode and distinguishing it from a younger episode that affected the volcanic sequences. Structural field evidence has been used to select samples of metasediments (e.g. from the Robertsfors Grp., N. Sweden, Fig. 1) that might preserve evidence of the early episode as metamorphic overgrowths on detrital zircons. This episode has now been dated at ~1.92–1.91 Ga in the metamorphic complexes on both sides of the Gulf of Bothnia, and in the complex south of the Central Finland Granitoid Complex. Ages of ~1.94 Ga have also been obtained for granitic rocks that were deformed in the early deformation episode. The sedimentary protoliths of all these metamorphic complexes were deposited before ~1.94 Ga and detrital zircons indicate derivation from 2.10–1.98 Ga sources (Rutland et al., 2004; Skiöld & Rutland, 2006).

Crustal scale belts of high electrical conductivity in the Svecofennian province lie within the metamorphic complexes. The continuity of these belts provides further evidence for the continuity of the sedimentary basin in which the protolith sediments were deposited. We have interpreted this as a large back-arc marginal basin which developed after ~1.98 Ga, and which was accreted during a major tectonothermal episode at ~1.92–1.91 Ga.

We consider that the main episode of igneous activity in the Svecofennian province, between 1.90 and 1.87 Ga, was extensional, and was developed in and above the basement formed by the accreted marginal basin. This magmatism may still be regarded as arc-related magmatism in the sense that an active margin probably lay to the west or southwest, with the subducting slab dipping beneath the accreted marginal basin. We suggest, however, that the concept of crustal growth by accretion of a number of arcs within the province after 1.9 Ga can no longer be sustained.

Work in progress in collaboration with Swedish and Finnish colleagues is extending our studies to the Kiruna district in the boundary zone between the Svecofennian province and the Archaean basement of the Karelian province. The synthesis of these various studies will provide a new interpretation of the tectonic evolution of the Svecofennian province in northern Sweden and Finland, and a new framework for the setting of the numerous ore deposits.

Rutland, R.W.R., Kero, L., Nilsson, G. and Stølen, L.K. (2001) Nature of a major tectonic discontinuity in the Svecofennian province of northern Sweden. *Precambrian Research* 112, 211-237.

Rutland, R.W.R., Skiöld, T. and Page, R.W. (2001) Age of deformation episodes in the Palaeoproterozoic domain of northern Sweden, and evidence of a pre-1.9 Ga crustal layer. *Precambrian Research* 112, 239-259.

Rutland, R.W.R., Williams, I.S. and Korsman, K. (2004) Pre-1.91 Ga deformation and metamorphism in the Palaeoproterozoic Vammala Migmatite Belt, southern Finland, and implications for Svecofennian tectonics. *Bulletin of the geological Society of Finland* 76, 93-140.

Skiöld, T. and Rutland, R.W.R. (2006) Successive ~1.94 Ga plutonism and ~1.92 Ga deformation and metamorphism south of the Skellefte district, northern Sweden: Substantiation of the marginal basin accretion hypothesis of Svecofennian evolution. *Precambrian Research* 148, 181-204.

The Geology, Geochemistry and Geochronology of the El Abra Mine, Chile, and the adjacent Pajonal-El Abra suite of intrusions

Dianne L. Valente[1], Ian H. Campbell[1], Charlotte M. Allen[1]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*

El Abra is a classic, yet simple porphyry copper deposit. World-class exposure of the complete suite of weakly altered, plutonic rocks directly associated with the ore-body provides a unique opportunity to examine the accepted paradigm of the relationship between igneous activity and copper porphyry formation.

Results of work completed to date indicate that the El Abra-Pajonal suite represents upper crustal magma chambers underpinned by a mid to lower crustal chamber which evolved over an 11 Ma period, between 45.1 and 34.5 Ma. Periodic injection a new pulses of magma into the upper crust from the lower crustal chamber occurred approximately every one Myr. Interpreted magmatic processes including assimilation, fractional crystallisation and magma mixing took place in the mid to lower crustal chamber. Zircon inheritance and field work shows crustal assimilation occurred however, as emplacement-aged zircon δO^{18} data plot within mantle values, it is likely to be a minor process. The likely assimilate is hydrothermally-altered meta-igneous rocks, rather than meta-sediments.

Ti-in-zircon thermometry (Watson and Harrison, 2005) shows that the Pajonal-El Abra suite lies on a clearly defined cooling trend (Fig. 1a), initiated and then truncated by at least two major thermal events interpreted to be injection of mafic magma into the lower crustal chamber. The overall cooling trend is consistent with the dating data, suggesting relatively slow cooling in the interpreted lower crustal magma chamber is ~15°C/Myr.

Interpretation of whole rock major element and trace element data, especially whole rock Sr/Y ratios (Fig. 1b), along with comparative emplacement-aged zircon Ce^{+4}/Ce^{+3} ratios (Ballard et al., 2002), reveals the El Abra-Pajonal suite can be broadly divided into a dry magma series (plagioclase/pyroxene dominated fractionation) and a wet magma series (amphibole dominated fractionation). As the Ti-in-zircon thermal data only shows one cooling trend, this implies that the interpreted mid-to deep crustal chamber is chemically stratified.

Temperature corrected, zircon Ce^{+4}/Ce^{+3} ratios clearly show that the wet magma series is more oxidised than the dry magma series, with the economic porphyries recording the highest Ce^{+4}/Ce^{+3} ratios. Comparing the Ti-in-zircon temperatures against corresponding Ce^{+4}/Ce^{+3} ratios for the same zircon (Fig. 1c), allows intrusions associated with mineralisation to be discriminated from barren intrusions. This observation indicates that with further development, a threshold value for temperature corrected, Ce^{+4}/Ce^{+3} ratios in zircons could be used to define rocks which may be prospective for copper porphyry style mineralisation.

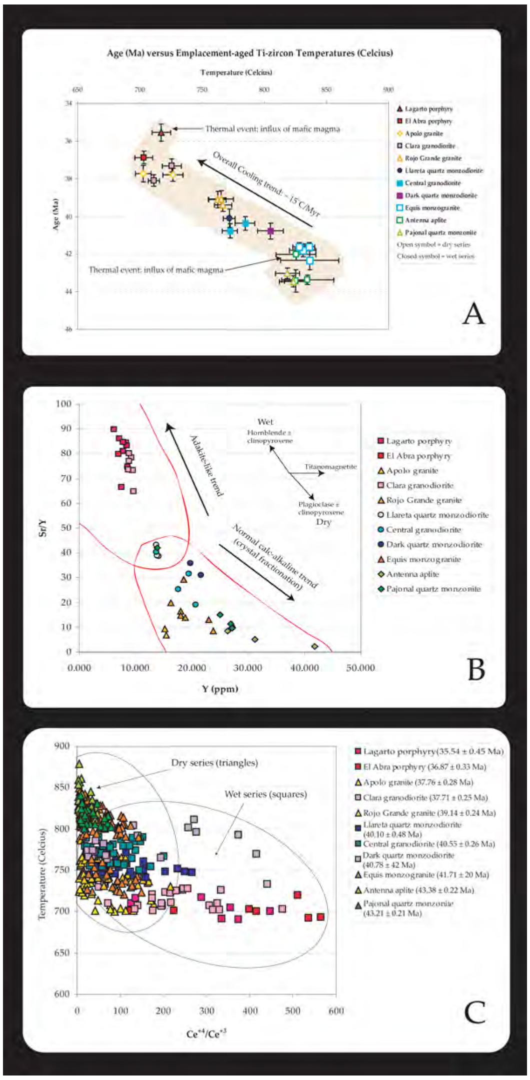


Figure 1. **A)**: Age versus temperature plot for the El Abra-Pajonal suite based on emplacement-aged zircons. The suite clearly defines a single cooling trend, indicating the suite evolved from a single magma chamber at mid to lower crustal levels. **B)**: Whole rock Sr/Y ratio which clearly discriminates the intrusions associated with mineralization from barren intrusions. **C)**: Temperature versus Ce^{+4}/Ce^{+3} ratios from emplacement-aged zircons which shows dry series (barren) intrusive rocks are more reducing than wet series rocks, for intrusions of similar age and temperature (e.g. Clara granodiorite c.f. Apolo granite). The El Abra porphyry associated with the main mineralization event at El Abra, is also the most oxidized intrusion relative to the rest of the El Abra-Pajonal suite.

Ballard, J.R., Palin, J.M., and Campbell, I.H., 2002, Relative oxidation states of magmas inferred from Ce(IV)/Ce(III) in zircon: application to porphyry copper deposits of northern Chile, *Contributions To Mineralogy And Petrology*, 144, 347-364.

Watson, E.B., and Harrison, T.M., 2005, Zircon thermometer reveals minimum melting conditions on earliest Earth, *Science*, 308, 841-844.

Further advances in measuring the oxygen isotopic compositions of granite zircon using *SHRIMP II*

Ian Williams[1], Ryan Ickert[1], Joe Hiess[1], Peter Holden[1] and Peter Lanc[1]

[1] *Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia*

Numerous international studies of zircon from granites around the world (e.g. Valley, 2003), including British studies of some Australian granites (e.g. Kemp et al., 2005) have demonstrated the ability of zircon to preserve a record of changes in the oxygen isotopic composition of magmas as they evolve. Such compositions provide valuable information on the nature of the magma source and the relative contributions of crust- and mantle-derived components that commonly cannot be obtained from whole-rock oxygen compositions because of late alteration or interaction with meteoric waters. Although not as precise as conventional analytical techniques, the preferred method of zircon oxygen analysis is SIMS, which provides sufficient spatial resolution ($\leq$25 µm) to track changes in the isotopic composition within individual zircon crystals, and hence the magma, as they grew.

Until recently, the only SIMS instruments configured for oxygen isotopic analysis were Cameca ion microscopes in laboratories outside Australia. A program at RSES designed to provide Australian researchers with the same capabilities using *SHRIMP II* ion microprobes is now well advanced. Initial experiments in 2005 showed that the principal limitation on analytical accuracy was control of instrumental mass fractionation. Instrumental modifications led to a major improvement (see RSES Annual Report 2005), but were not the whole solution. Experiments in 2006 have focused on modifications to mount design (see Hiess et al., this Report), charge neutralisation (see Ickert et al., this Report), sample preparation and analytical protocols. As a result, data acquisition times have been reduced from 250 seconds to 100 seconds per spot and within-spot precision increased from ~0.25‰ to ~0.05‰ (s.e.m.). The oxygen isotopic composition of zircon populations expected to be isotopically uniform can now be measured with standard deviations of about 0.4‰ on multiple analyses over periods of several hours. Geometric effects related to the distribution of samples within the sample mount have been reduced to sub-permille levels. It is now possible, using *SHRIMP II*, to measure differences in the mean oxygen isotopic composition of granite zircons with uncertainties of less than 0.2‰ and to begin to resolve quite subtle differences in the initial oxygen isotopic compositions of closely related granites within a single batholith (Fig. 1). The principal limitation on measurement quality is now shifting from instrumental limitations to sample selection.

Kemp A.I.S., Whitehouse, M.J., Hawkesworth, C.J. and Alarcon, M.K. (2005) A zircon U-Pb study of metaluminous (I-type) granites of the Lachlan Fold Belt, southeastern Australia: implications for the high/low temperature classification and magma differentiation processes. *Contributions to Mineralogy and Petrology* 150, 230-249.

Valley J.W. (2003) Oxygen isotopes in zircon. *In:* Hanchar J.M. and Hoskin P.W.O. *Zircon.* Reviews in Mineralogy and Geochemistry 53, 343-385.

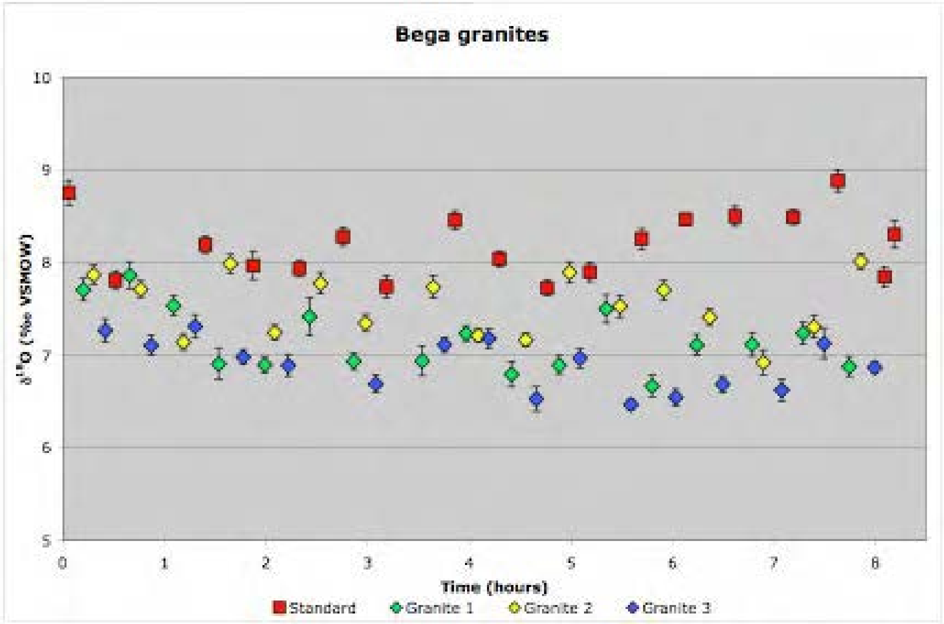


Figure 1. Oxygen isotopic compositions measured on individual 25 µm spots on zircon grains from three Bega Batholith granites, southeastern Australia. An internal precision of ~0.05‰ (1s) is obtained in 100 seconds of data collection per spot using the *SHRIMP II* multiple collector. Error bars 2s.

Earth Environment Introduction

In the past year public awareness of climate and associated global change issues has grown markedly, such that this is now the number one issue of public concern. The wide range of research undertaken by the RSES Earth Environment Group is highly relevant as we are addressing current issues of concern such as the frequency and longevity of droughts in Australia , as well as questions of longer term relevance, such as the effects of climate change on terrestrial and marine systems and its impacts on human evolution.

Our research draws upon a unique group of World-class research facilities that enable the analysis of a wide range of trace element and isotopic systems, with an emphasis on the timing and rate of change of major environmental and Earth surface processes. Emphasis is placed on developing diagnostic environmental proxies within an absolute chronologic framework that spans a few tens to several hundred thousand years of the Earth's history, and to use these as a basis for understanding past and present environmental change and predicting future trends. Earth Environment specialises in the reconstruction of high-resolution environmental records from growth banding preserved in fossil and modern corals, speleothems (cave deposits), layered sedimentary deposits and anthropologic sites of special significance.

The Earth Environment group maintained success in obtaining ARC funding through both discovery as well as linkage grants. Successful strategic planning rounds in 2005-2006 resulted in the joint RSES/DEMS appointment of Dr Mike Ellwood and the RSES/RSPhysEngS appointment of Dr Stewart Fallon, adding unique expertise and sorely needed critical mass to our marine sciences initiative. Likewise Dr Steve Eggin's appointment to the tenure track staff ensures that our group will maintain our world leading abilities in marine geochemistry.

We also welcome new Post Doctoral Researchers, Dr Linda Ayliffe, Maxime Aubert and Dr Stacy Jupiter who are funded by ARC grants to Professor Grün and Dr Gagan and via support from the Coral Reef Centre of Excellence to Professor McCulloch, respectively. There has also been a talented cohort of graduating students who completed their PhD theses in an exemplary manner and we wish Drs Ayling, Fraser, Trotter and Wyndham continued success in their future endeavours.

During 2006 academic staff continued their high level of success with ARC proposals with Professors Grün, Chappell and Dr Ellwood being funded. Dr Mike Ellwood was extraordinary successful in his first time applications having both of his ARC grants funded, one being jointly with Dr Eggins. These proposals focus on the role of nutrients and atmospheric CO_2 in the Southern Oceans by examining the biogenic silica cycles as well as patterns of Ge/Si fractionation in sponges and diatoms. 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 leading Australian research institutions to build a picture of the continent's human and environmental history before this evidence is irretrievably lost.

Installation of new LIEF funded state-of-the-art equipment is now essentially complete in the Earth Environment Group enabling us to continue our cutting-edge research. This includes an ~$2 million gas source AMS which will revolutionise our capacity to undertake ^{14}C dating terrestrial materials and an ultra-short wavelength (157 nm) laser ICPMS combination to enable direct in-situ analyses of a wider variety of Geological materials with greatly enhanced sensitivity.

Research Highlights

Seasonal structure of Holocene El Niños: high-resolution reconstruction from coral skeletal stable isotopes	Rose D. Berdin
Oceanic germanium/silicon fractionation: evidence from oceanic profiles, diatom cultures and sediment opal.	Michael J Ellwood
In situ Sr analysis of a Neanderthal tooth	Rainer Grün
Ultrastructure and *in-situ* geochemistry of conodont mineralised tissues	Julie A. Trotter
In-situ oxygen isotope compositions of Ordovician conodonts using SHRIMP II and laser ablation MC-ICPMS	Julie A. Trotter
Coral Reefs and Global Change	Malcolm McCulloch
Permo-Carboniferous inheritance in Australian landscapes	Brad Pillans
Routine penetration of South Java Current into the Savu Sea recorded by a *Porites* coral	Dingchuang Qu
Diurnal origin of Mg/Ca banding in *Orbulina universa* and effects of cleaning on test composition	Eggins S.M
Variability in the uranium isotopic composition of the oceans over glacial–interglacial timescales	Tezer M. Esat
From Cane to Coral Reefs: Ecosystem Connectivity and Downstream Responses to Land Use Intensification	Stacy D. Jupiter
Evidence for past climates and environmental response from sediment archives in central and eastern Australia	Ed Rhodes
Initiation of Australian longitudinal dunefields, revealed by cosmogenic burial dating on dune-sand quartz from the Simpson Desert , central Australia	Toshiyuki Fujioka
Understanding climate change: Speleothems as archives of natural rainfall variability and rapid climate events	Pauline C. Treble

Seasonal structure of Holocene El Niños: high-resolution reconstruction from coral skeletal stable isotopes

Rose D. Berdin and Michael K. Gagan

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

Stable isotope ratios of oxygen (δ18 O) and carbon (δ13 C) were analyzed at bi-weekly resolution for two modern and three Holocene *Porites* corals from eastern Samar , Philippines . Previous low-resolution δ18 O analysis of the Holocene corals revealed extraordinarily strong droughts (typically longer than three years) for specimens with uranium series ages between 7.6 – 2.3 ka. The purpose of the new high-resolution δ18 O records presented here is to investigate the nature of these protracted droughts, and to compare their seasonal structure with present-day droughts produced by El Niño events. The modern coral δ18 O records clearly track the cooler sea-surface temperatures and droughts associated with the prolonged El Niño event in the early 1990s, the severe 1997/98 El Niño, and the moderate 2002/03 El Niño.

To allow direct comparison of the coral records, annual growth increments in the coral skeletons were determined using the annual cycle of δ13 C, which is regular and well-defined. The records were then re-sampled to 26 points per year using Analyseries and stacked to determine the mean annual cycle. El Niño events were identified from δ18 O anomaly plots, derived by subtracting the mean annual cycle from the δ18 O records. Positive δ18 O anomalies in the modern coral records are indicative of cool/dry periods produced by El Niños. Similar anomalies were seen in the Holocene records indicating El Niño-like events in the past.

Composite analysis of these El Niños was performed by stacking annual cycles of δ18 O for each event. The El Niño δ18 O composites for the modern coral records show markedly higher δ18 O from late boreal fall to early summer. The timing of this anomaly compares well with El Niño's signature in stacked bi-weekly records of rainfall and SST, and is consistent with the regional rainfall anomaly in the western Pacific, where rainfall is greatly reduced from November to May during the mature phase of El Niños (Ropelewski and Halpert, 1987).

Modern and Holocene El Niño composites show differences in terms of magnitude and timing of the peak δ18 O anomaly, which corresponds to the period of maximum cooling/drying (Fig. 1). The older Holocene records exhibit peak δ18 O anomaly values that are approximately 0.2‰ higher than the younger records. Furthermore, the timing of the maximum cooling/drying appears to occur progressively later in the calendar year: late winter for present-day events, early fall at 2.3 ka, and late fall at 7.3 – 5.8 ka. These differences in timing might be a response to orbitally-driven changes in the seasonal cycle of solar radiation, which, based on a climate model by Clement et al. (2000), is thought to influence the behavior of ENSO in the past.

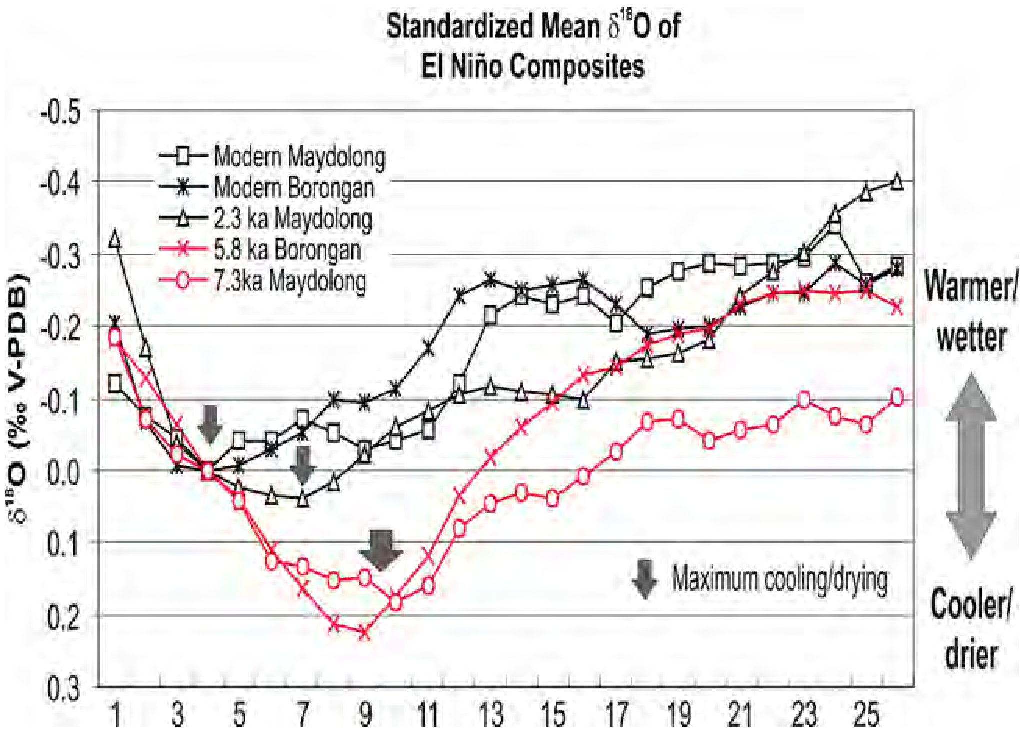


Figure 1 . Modern and Holocene El Niño δ18 O composites standardized relative to the mean δ18 O February of each record. Numbers along the X-axis correspond to a fortnight starting from January. Arrows indicate the coolest/driest period in each record, which occurs progressively later in the calendar year in the Holocene records.

References: Clement, A.C., Seager, R., and Cane, M.A., 2000. Suppression of El Niño during the mid-Holocene by changes in the Earth's orbit. *Paleoceanography* , 15: 731-737.

Ropelewski C.F. and Halpert M.S., 1987. Global and regional scale precipitation patterns associated with the El Ni ño patterns associated with the El Ni ño/Southern Oscillation. *Monthly Weather Review* , 115: 1606-1626.

Oceanic germanium/silicon fractionation: evidence from oceanic profiles, diatom cultures and sediment opal.

Michael J Ellwood [1], William A Maher [2], Stu Pickmere [3], Peter L. Croot [4] and Patrick De Deckker [5]

[1] *Research School of Earth Sciences & Department of Earth and Marine Science, Australian National University, Canberra, ACT 0200, Australia*
[2] *Environmental Science; School of Resource, Environmental and Heritage Sciences; Division of Health, Design and Science, University of Canberra, Canberra, ACT 2601 Australia*
[3] *National Institute of Atmospheric and Water Research, PO Box 11 115, Hamilton, New Zealand*
[4] *FB2: Marine Biogeochemistry, Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR), Düsternbrooker Weg 20, 24105, Kiel, Germany*
[5] *Department of Earth and Marine Sciences, The Australian National University, Canberra, ACT 0200, Australia.*

The cycling of inorganic germanium in the ocean closely resembles that of silicon. Profiles of dissolved germanium concentration versus depth are almost identical to that of silicon, and when the two are plotted against each other a near linear relationship is obtained (r^2 = 0.997) (Figure 1). This correlation between germanium and silicon indicates that the uptake and regeneration of inorganic germanium by diatoms dominates its oceanic cycle. Although germanium mimics silicon in the ocean, differences in biogeochemical behaviour occur. Small diatoms (10-40 m m) appear to faithfully record the germanium/silicon (Ge/Si) ratio of seawater, whereas large diatoms (> 40 m m) do not. Large diatoms isolated from the same sediment horizons as their smaller counterparts tend to have lower Ge/Si ratios. This result suggests that larger diatoms discriminate against germanium during silicon uptake and frustule formation. This interpretation is supported by the fact that the global germanium versus silicon relationship has a small but significant positive intercept suggesting that germanium is discriminated against during silicon uptake and frustule formation (Figure 1).

In an effort to further understand the possible mechanism(s) that might lead to germanium fractionation we cultured the fast growing diatom *Minutocellus polymorphus* under controlled Ge/Si conditions. Results from the culture work showed that at low silicon concentrations significant discrimination of germanium occurred leading to lower Ge/Si ratios within diatom opal and increased Ge/Si ratios of culture medium. This pattern suggests that the positive intercept in the global germanium versus silicon relationship results from germanium discrimination by diatoms during silicon uptake. Short-term Michaelis-Menten uptake experiments were also conducted to understand processes leading to germanium discrimination. Results from these experiments showed that the half saturation constants for silicon and germanium were 0.87 m mol/L and 2.70 m mol/L, respectively.

This confirms that the uptake of germanium is slower than that of silicon and that this is the primary mechanism leading to Ge/Si fractionation in diatoms. This result was incorporated into a simple partitioning model to describe diatom opal Ge/Si fractionation. Utilising this model, we show the interglacial-glacial fluctuations in Ge/Si opal record reflects changes in the surface ocean silicon concentration (Figure 2). This interpretation has major implications for paleo-nutrient reconstructions utilising Ge/Si, the silicon isotope and the germanium isotope signatures of diatom opal.

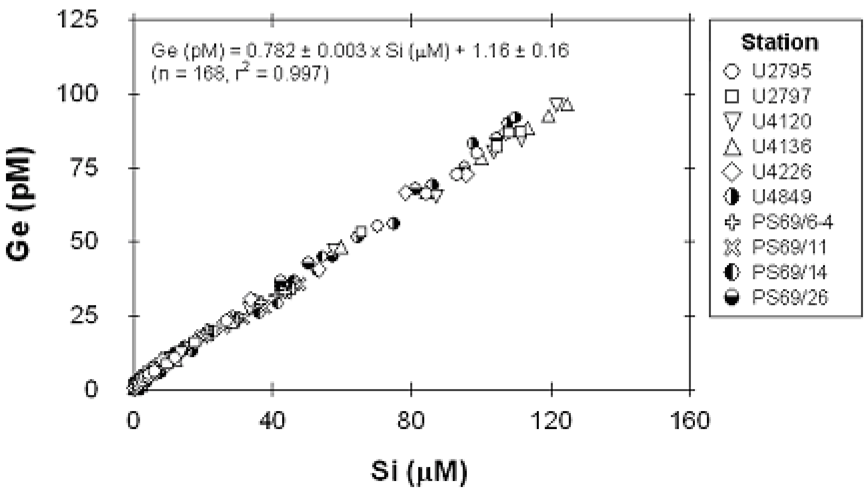


Figure 1.

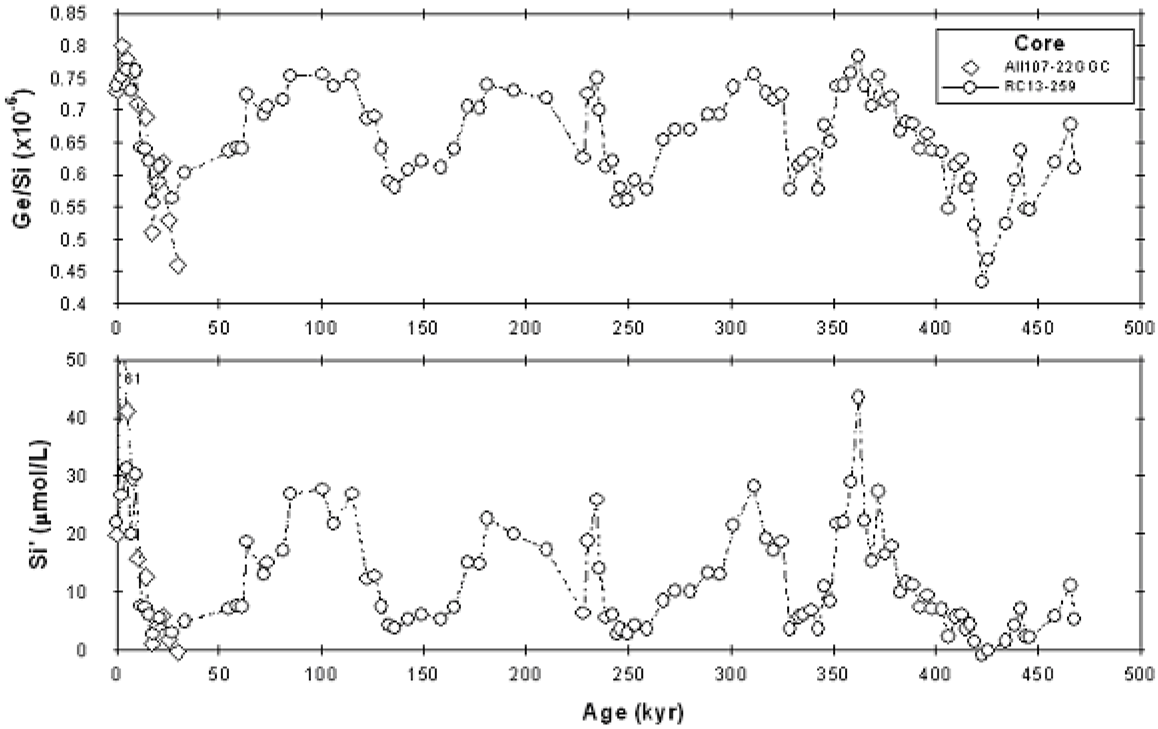


Figure 2.

In situ Sr analysis of a Neanderthal tooth

Rainer Grün, Maxime Aubert, Stephen Eggins, 1 Marie- Hélène Moncel

1 Research School of Earth Sciences, Australian National University ,
2 Département de Préhistoire du Musée National d'Historie Naturelle, Paris

The present day $^{87}Sr/^{86}Sr$ ratio in bedrock depends on its geological age and initial $^{87}Sr/^{86}Sr$ and Rb/Sr ratios. Soils have closely similar $^{87}Sr/^{86}Sr$ ratios as their source-rocks. Some of the soil Sr enters the food chain via plants and it has been shown that the $^{87}Sr/^{86}Sr$ ratios remain virtually unchanged during the various biochemical processes, and when Sr replaces Ca in the mineral phase of skeletal tissues. Therefore, skeletal Sr isotopic composition reflects the geographic range during tissue formation. The measurement of the $^{87}Sr/^{86}Sr$ ratio in bones and teeth has been increasingly used for the reconstruction of residential mobility and migration among ancient human and animal populations.

We have applied *in situ* laser ablation ICP-MS analysis on a Neanderthal tooth from the site of Payre, which is located in a limestone overlooking the western bank of the Rhone , near Valence . Bedrocks in that area vary from the metamorphic and granitic rocks of the Massiv Central, via the sediments of the Rhone and its flood plains to the sedimentary sequences of the Western Alps .

Figure 1: A Neanderthal tooth from Payre (left). The tooth is cut in the middle (middle) and all analyses are carried out in situ on the interior enamel surface (right).

The tooth was cut in halves and the analysis is carried out on the internal cuts of the tooth enamel (Figure 1). Initial results looked very promising, showing variations in the Sr isotopic composition (Figure 2, left), which could perhaps be explained by seasonal migrations. However, when comparing these isotopic variations with Sr concentrations (Figure 2, middle), a broad mixing line is observed (Figure 2, right), perhaps indicating post-depositional Sr uptake with different isotopic composition compared to the physiologically incorporated Sr.

To address the problem of post-depositional Sr uptake, we have mapped the Sr concentrations in a large part of the tooth with laser ablation (Figure 3). Figure 4 shows the resulting Sr map along with two selected tracks. In the dentine, there is a clear gradient from the root towards the enamel. It is interesting to note that at the dentine/enamel boundary, the Sr concentration does not show a very sharp drop (about cycle 400 to 550 in Line 1, Figure 4, lower left), as is usually observed for other mobile elements, such as uranium. There is also a clear gradient in the Sr concentration in the enamel

(Line 11, see Figure 4, lower right). At the moment it is difficult to conclude whether this gradient is a primary signature or whether it is a diagenetic over-print. Work is continuing to measure Sr-isotope maps, which will give further insights into the Sr-systematics of fossil teeth. We have also mapped a series of other elements, such as Ca (to check Sr/Ca ratios), Al, Ba, Mg, Th and U (for dating). Particularly the latter showed that it has absolutely no intentions to adhere to simplified diffusion models. On the same tooth, the work on *in situ* oxygen isotope measurements with the SHRIMP 2 is continuing.

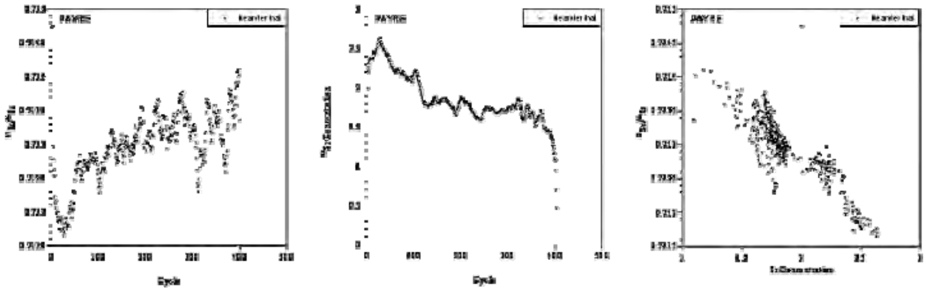


Figure 2: Sr isotope (left) and Sr concentration (middle) variations along the laser track shown in Figure 1, right. Sr isotopes versus Sr concentration (right).

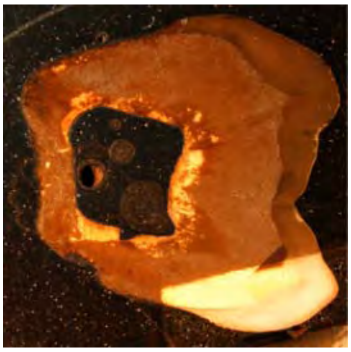


Figure 3: Cross section of the tooth with light area indicating the location of the laser tracks.

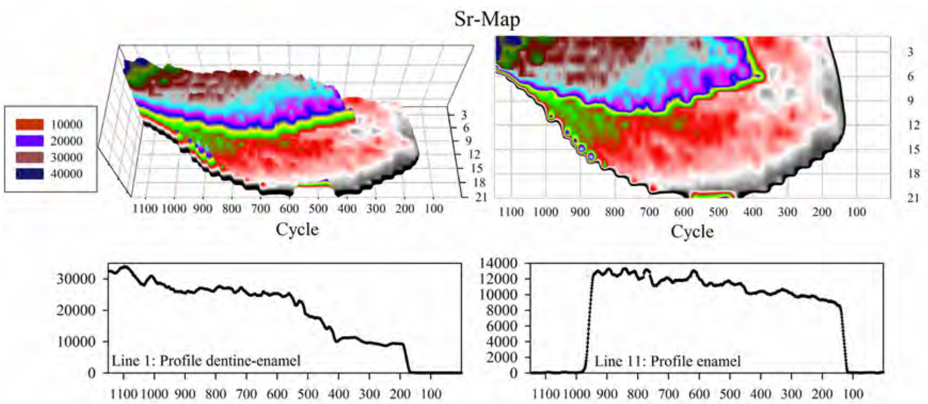


Figure 4: Map of Sr concentrations in the area indicated in Figure 3. Top: angled and vertical views, below left: U-concentration along laser track 1, right: U-concentration along laser track 11.

Ultrastructure and *in-situ* geochemistry of conodont mineralised tissues

Julie A. Trotter 1 , Stephen M. Eggins 1 , John D. Fitz Gerald 1 , Harri Kokkonen 1 , C.R. Barnes 2

1 Research School of Earth Sciences, Australian National University , Canberra , 2 School of Earth and Ocean Sciences, University of Victoria, Victoria , BC , V8W 2Y2 Canada

Novel approaches integrating both histological and *in-situ* geochemical analyses of conodont apatite have been investigated to identify primary crystalline structures and compositions of the component tissues. In the context of diagenesis, it is important to recognise the complex relationship between sample histology and geochemistry, as the permeability and integrity of conodont apatite is partly controlled by its crystalline structure. The component histologies have thus been examined by transmission electron microscopy (TEM), which for the first time has been conducted on Ar ion-milled conodonts. TEM analyses have revealed near pristine structures and most significantly, resolution of the component crystallites of all histologies (Trotter *et al.* , in press). Of particular note, electron patterns show that albid crown comprises very large (100's µm) crystal domains, which provides a meaningful platform to interpret the respective geochemistry of conodont tissues that have been characterised *in-situ* by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Continuous compositional depth profiles through discrete conodont elements reveal systematic differences between the component tissues in their rare earth and heavy element contents especially (Trotter and Eggins, 2006). The U-shaped depleted profiles of albid crown contrast markedly to the enriched and typically equilibrated profiles of hyaline and basal tissues, their concentrations following a linear relationship with albid, basal (together with coeval ichthyoliths and phosphatic brachiopods), and hyaline tissues representing low-, high- and intermediate concentrations. These data collectively provide insights into the relative uptake of chemical species post-mortem, and clearly suggest that albid crown is the least permeable histology (ie. large crystal domains and U-shaped profiles) hence is less susceptible to diagenetic alteration. This work has significant implications for interpreting the geochemistry of conodont apatite, and identifying the most suitable components for palaeoseawater studies.

References: Trotter, J.A., Eggins, S.M., (2006) Chemical Systematics of Conodont Apatite Determined by Laser-Ablation ICPMS. *Chemical Geology* **233** , 196-216.

Trotter, J.A., Fitz Gerald, J.D., Kokkonen, H., Barnes, C.R., (in press) New insights into the ultrastructure, permeability, and integrity of conodont apatite determined by Transmission Electron Microscopy. *Lethaia.*

In-situ oxygen isotope compositions of Ordovician conodonts using SHRIMP II and laser ablation MC-ICPMS

Julie A. Trotter 1 , Ian Williams 1 , Stephen M. Eggins 1 , C.R. Barnes 2

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 School of Earth and Ocean Sciences, University of Victoria, Victoria , BC , V8W 2Y2 Canada

Given the potential utility of conodonts as geochemical tracers, new and developing technologies have been investigated to assess the feasibility of extracting isotopic records by *in-situ* analysis. Reconnaissance work has shown that ion microprobe (SHRIMP II) and laser ablation multi-collector ICPMS offer considerable potential to determine the oxygen and strontium compositions of conodont apatite. The benefits of analysing marine bio-apatites rather than less chemically stable carbonates, together with the capability of utilising high spatial resolution techniques, provide an opportunity to target specific components that are most likely to retain primary compositions. Accordingly, this work has significant implications for better characterising the evolution of seawater chemistry throughout the Palaeozoic.

Preliminary Sr isotope datasets of discrete conodont elements determined *in-situ* by laser ablation MC-ICPMS fall within similar ranges of existing Ordovician records based on labour intensive conventional TIMS analyses of both calcitic brachiopod and conodont samples. Further, LA-MC-ICPMS analyses of conodont albid tissue have yielded less radiogenic 87 Sr/ 86 Sr ratios than hyaline tissue for coeval samples, suggesting that there may be systematic differences between the compositions of the component conodont histologies.

Reconnaissance *in-situ* oxygen isotope analyses using SHRIMP II have yielded considerably higher and more realistic d 18 O values (~16 to 19‰ V-SMOW) than conventional GIRMS data based on calcitic brachiopods (-10 to 25‰ V-PDB) reported in the literature (eg. Shields *et al* ., 2003), the integrity of which has been the focus of much scepticism. Although the initial SHRIMP results have an analytical error of ±1‰, a temporal shift during the Arenig is apparent. Better constraining this shift as well as the well-known Late Ordovician d 18 O excursion is the focus of further work, which given the recent progress in technique development promises to yield higher external precision for conodont apatite, and thus a significantly improved d 18 O seawater curve for the Ordovician.

References: Shields, G.A., Eggins, S.M., (2006) Chemical Systematics of Conodont Apatite Determined by Laser-Ablation ICPMS. *Chemical Geology* **233** , 196-216.

Shields, G.A, Carden, G.A.F., Veizer, J., Meidla, T., Rong, J., & Rong-Yu, L., (2003) Sr, C, and O isotope geochemistry of Ordovician brachiopods: A major isotopic event around the Middle-Late Ordovician transition. *Geochimica et Cosmochimica Acta* , **67** , 2005-2025.

Coral Reefs and Global Change

Malcolm McCulloch

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

Coral reefs are subject to increasing threat from the degradation of their marine environment which is occurring at an unprecedented rate, on both local and global scales. Locally, landuse changes in river catchments, wetlands and estuaries is leading to increased supplies of sediment and nutrients to coral reefs, which together with pressures from activities such as trawling and overfishing, can lead to an evolutionary trajectory that may ultimately result in an abrupt phase shift from a coral to a macroalgae dominated ecosystem. On global scales, extreme climatic events caused by increased sea surface temperatures together with rising carbon dioxide levels from fossil fuel burning is resulting in an increased frequency of mass coral bleaching such as occurred in 1998, and increasing ocean acidity which will ultimately lead to a decrease in the rates of coral calcification. Understanding the complex array of interacting processes (see Figure) that are driving changes at both local as well as global scales is thus essential for the development of optimal strategies to ensure the long-term sustainability of coral reefs.

The approach taken at the RSES node of the ARC Centre of Excellence for Coral reef Studies is that knowledge of the past improves our ability to understand both the present as well as to help predict future consequences of human impacts, and rapid climate change. Studies of coral reef systems and their environments prior to the impact of human civilisations provides a 'natural' baseline against which anthropogenic changes can be compared and assessed. Our group is thus developing novel methods for studying past environments and assessing rates of evolutionary changes in coral reefs. We are identifying the mechanisms via which local and global changes in the marine and adjacent terrestrial environments are causing reductions in coral reef biodiversity and ecosystem function. Together with ecological and physiological studies of processes underlying reef stress, this broad approach provides the Centre with a unique perspective on environmental change and how it impacts community structure and longer term evolutionary dynamics of coral reefs on timescales that ranges from centuries to millennia.

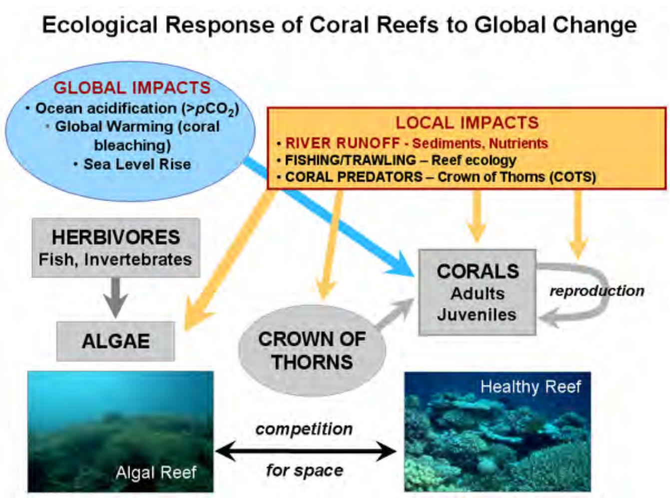


Figure 1. Schematic diagram showing both global and local impacts on coral reef systems.

Permo-Carboniferous inheritance in Australian landscapes

Brad Pillans [1]

[1] *Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia*

During the late Carboniferous and Early Permian (~320-280 Ma), Australia was part of the Gondwana Supercontinent, which included Antarctica , India , Africa , New Zealand and South America . Gondwana was situated at mid to high latitudes in the Southern Hemisphere. Evidence for glaciation is widespread and includes glacial tills and striated pavements in all states of Australia , as well as the other Gondwana continents. Although the timing, character and distribution of glacial events and deposits are debated (Jones & Fielding 2004 and references therein), most reconstructions show a large ice cap covering much of southern and western Australia in the Early Permian, with glacio-marine sedimentation in the adjacent Canning Basin. In contrast, in eastern Australia the evidence indicates discrete, short-lived episodes of localized mountain glaciation, with substantial non-glacial intervals in between. Just how much of Australia was covered in ice is unclear, but a large ice sheet, probably several kilometers thick, was likely centred over the Yilgarn Craton in Western Australia . Glacial till and tunnel valleys, dating from this time, are preserved at Lancefield on the eastern margin of the ice sheet, where glacial meltwater drained into the Officer Basin (Eyles & de Broekert 2001). Relict Early Permian landforms including ice-scoured channels, U-shaped valleys, rock drumlins and striated pavements are also common along the northeastern margin of the Pilbara Craton (Playford 2001). However, significant areas of Australia must have been ice free, at least for long periods of time (millions of years) during the major interval (280-320 Ma) of Gondwana glaciation, because paleomagnetic dating of giant (60 m+) weathering profiles in the Tanami and Yilgarn regions, as well as at Northparkes mine in New South Wales (Pillans 2005), indicates widespread deep oxidation of the regolith (Figure 1). K-Ar dating of illitic clays in weathered volcaniclastics within Jenolan Caves, some 200 km ESE of Northparkes, yields a cluster of ages in the range 342-335 Ma (Early Carboniferous), and a zircon fission track age of 345 Ma on one sample is consistent with the K-Ar ages (Osborne *et al* . 2006), making Jenolan Caves among the oldest currently open cave system in the world. The entry of the volcaniclastic sediments and the morphology of the caves mean that they must have been relatively close to the surface in the Early Carboniferous. Paleokarst features of Early Permian age are also preserved in the northern Canning Basin in Western Australia . In summary, Permo-Carboniferous glacial landforms, weathering profiles and caves at or near the present landsurface, in diverse parts of the Australian continent, suggest a significant Late Paleozoic inheritance in the modern landscape. The survival of ancient landforms and weathering profiles in Australia is usually explained as being a consequence of prolonged tectonic stability and postulated low rates of weathering and erosion. However, while measured rates of long-term (10^5 -10^7 yr timescales) weathering and bedrock erosion in Australia may indeed be low by world standards, they are not low enough to explain the continuous subaerial survival of pre-Cenozoic landforms and weathering profiles. Burial and exhumation must therefore be significant contributing factors in the preservation of ancient features in the Australian landscape, a conclusion that is supported by apatite fission-track thermochronology (e.g. Kohn *et al* . 2002).

Figure 1. Permo-Carboniferous deep oxidation of Proterozoic rocks exposed in Redback pit (~60 m deep), Tanami gold mine, Northern Territory.

References: Eyles, N. and de Broekert, P., 2001. Glacial tunnel valleys in the Eastern Goldfields of Western Australia cut below the Late Paleozoic Pilbara ice sheet. Palaeogeography, Palaeoclimatology, Palaeoecology, 171: 29-40.

Jones, A.T. and Fielding, C.R., 2004. Sedimentological record of the late Paleozoic glaciation in Queensland , Australia . Geology, 32: 153-156.

Kohn, B.P., Gleadow, A.J.W., Brown, R.W., Gallagher, K., O'Sullivan, P.B. and Foster, D.A., 2002. Shaping the Australian crust over the last 300 million years: insights from fission track thermotectonic imaging and denudation studies of key terranes. Australian Journal of Earth Sciences, 49: 697-717.

Osborne, R.A.L., Zwingmann, H., Pogson, R.E. and Colchester , D.M., 2006. Carboniferous clay deposits from Jenolan Caves , New South Wales : implications for timing of speleogenesis and regional geology. Australian Journal of Earth Sciences, 53: 377-405.

Playford, P.E., 2001. The Permo-Carboniferous glaciation of Gondwana: its legacy in Western Australia . Geological Survey of Western Australia Record, 2001/5: 15-16.

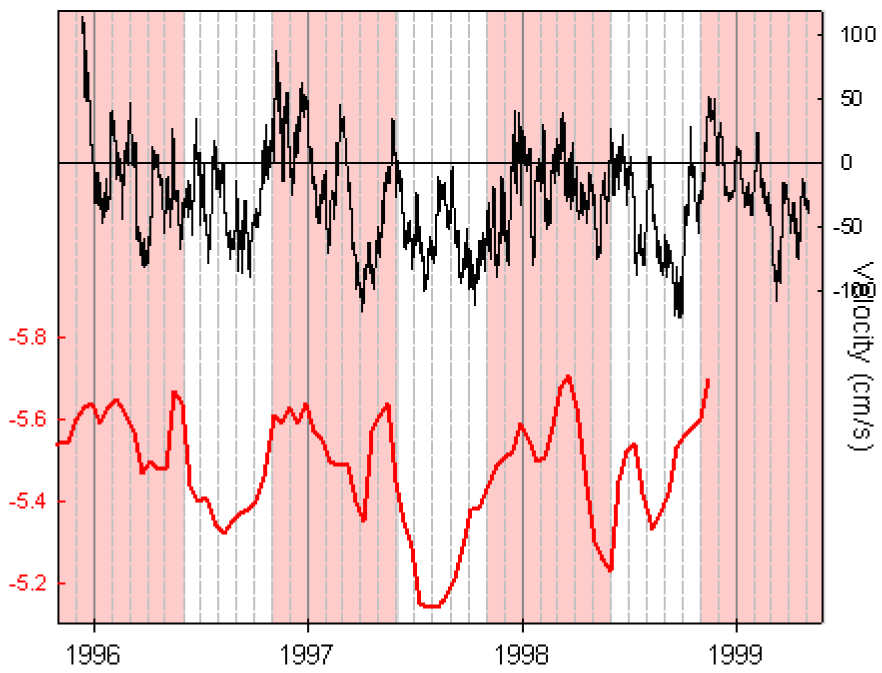
Pillans, B., 2005. Geochronology of the Australian regolith. In: R.R. Anand and P. de Broekert (Editors), *Regolith-Landscape Evolution Across Australia* . CRC LEME, Perth , pp. 41-61.

Routine penetration of South Java Current into the Savu Sea recorded by a *Porites* coral

Dingchuang Qu, Michael K. Gagan

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

Even though early studies have noticed that the eastward flow of the South Java Current could significantly reduce the transport of the Indonesian Throughflow (ITF), it had not been confirmed if the Indian Ocean water enters into the Indonesian seas through the Sumba Strait which is one of the main exits of the ITF until a couple of recent observation during 1995 to 1998 using current meters. Here we report a high resolution Sumba modern *Porites* coral d 18 O which recorded routine penetration of remote forced Indian Ocean Kelvin wave into the Savu Sea and the resulting distinct freshening during the austral autumn (March to May) during 1962 to 1998. Strong interannual variability with a 3-year period for the Kelvin wave input has been observed and spectral analysis has indicated that intrinsic process within the Indian Ocean basin dominantly controls this variability. The high resolution Sumba coral d 18 O seems to re flect the fluctuation of the direction and source of the surface currents flowing through the Sumba Strait during November to May and also suggests the occurrence of eastward flowing during November to March, even though the frequency and intensity might be much weaker than that of the austral autumn Kelvin wave passage (Figure).



Diurnal origin of Mg/Ca banding in *Orbulina universa* and effects of cleaning on test composition

Eggins S.M. 1 , Kimoto K. 2 , De Deckker P. 3 , Sadekov A. 1 , and Maher W. 4

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 Japan Agency for Marine Science and Technology, Yokosuka , Japan .
3 Department of Earth and Marine Science, The Australian National University , Canberra , ACT 0200, Australia
4 Institute for Applied Ecology, The University of Canberra , ACT 2601

Culture experiments have been performed on the algal symbiont-bearing planktonic foraminifera *Orbulina universa* , using juvenile foraminifera collected by plankton net off the south coast of NSW . Individual foraminifera were grown at fixed temperature in a day-night lighting cycle (12 hour day + 12 hour night) through the full adult-stage of their life-cycle, which involved final spherical chamber formation, gametogenesis and death over a period of up to 10 days. The number and composition of Mg/Ca bands formed in the wall of the final spherical chamber of individual foraminifers was investigated using both electron microprobe and laser ablation ICPMS. The number of high- and low-Mg/Ca band pairs developed was found to accord with the number of diurnal light cycles over which the individual foraminifers calcified their final chamber. This result confirms the proposed diurnal origin for Mg/Ca banding in *Orbulina universa* proposed by Eggins et al. (2004), and points to a significant role for algal symbionts in determining the Mg/Ca composition of foraminiferal calcite, most likely through influence on [CO_3^{2-}] concentration and calcite saturation state (*cf* . Wolf-Gladrow et al., 1999).

The impact of a range of cleaning methods upon the Mg/Ca compositional banding developed in fossil and live-collected *Orbulina universa* has also been investigated, inclusive of the widely used oxidative and reductive cleaning protocols. Characterisation of test fragments taken from the same *Orbulina universa* tests were analysed by LA-ICPMS both prior to and following cleaning. Results reveal significant differences in the ability of the different procedures to remove Mg-rich outer surfaces and attached organic material (where present). The internal Mg/Ca banding resists chemical modification and is unchanged by any of the cleaning procedures.

References: Eggins S. M., Sadekov A., and De Deckker P. (2004). Modulation and banding of Mg/Ca in *Orbulina universa* tests by symbiont photosynthesis and respiration: A complication for seawater thermometry? *Earth Planetary Science Letters* 225 , 411-419.

Wolf-Gladrow D. A., Bijma J., and Zeebe R. E. (1999). Model simulation of the carbonate chemistry in the microenvironment of symbiont bearing foraminifera . *Marine Chemistry* 64 , 181-198.

Variability in the uranium isotopic composition of the oceans over glacial–interglacial timescales

Tezer M. Esat 1 , and Yusuke Yokoyama 2

1 Research School of Earth Sciences and Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 0200, Australia
2 Department of Earth and Planetary Sciences, Graduate School of Science , University of Tokyo , Tokyo 113-0033, Japan

Uranium-series mass spectrometric analyses of corals from the uplifted last glacial terraces at Huon Peninsula , Papua New Guinea , that grew from 50,000 years ago to 30,000 years ago show systematically low values of 234 U/ 238 U, at the time of coral growth, compared with modern corals. When combined with coral data from other studies a systematic trend emerges indicating shifts in the 234 U/ 238 U ratio at times of major glacial–interglacial transitions that involve large variations in sea-levels. From last glacial to Holocene, the rate of change in d 234 U is approximately 1‰ per thousand years. The variations in the U budget of the oceans appear to be due to accumulation of excess 234 U in near shore areas in anoxic and suboxic sediments, in salt marshes and mangroves, in estuaries, and in continental margins during periods of warm climate and high sea-levels. These near-shore areas are exposed during periods of low sea level resulting in rapid oxidation of U into highly soluble phases. The subsequent release of 234 U-enriched uranium into the oceans occurs over a sustained period, in step with rising sea-levels.

Fig. A compilation of d 234 U values in U-series dated corals from the Last Interglacial, the last glacial, and the Holocene. For each data set representative uncertainties are as shown. The sea-level curve is intended only as a guide for the eye in contrasting the trend in d 234 U with changes in sea-level. The shaded band represents the uncertainty in sea-level estimations. The Last Interglacial sea-level was 3–5 m above the current sea-level and we have placed it at d 234 U ˜ 153‰. The general resemblance of the d 234 U variations to the sea-level curve for this period is remarkable. In living coral d 234 U = 149 ± 2‰. There is a systematic rise in d 234 U from a low of 132‰, during the last glacial, up to about 153‰ at the start of the Holocene, corresponding to an extra ˜20 Mmol of 234 U. There is considerable variability during the 30–60 ka period over a range of 10‰ in d 234 U. The prominent sea-level high-stands around 80–110 ka display a large range of low to high values of d 234 U. The Last Interglacial is represented by a mass of points that appear randomly distributed, and may reflect increased variability in measurements due to older ages and digenesis in comparison to samples from the Holocene.

From Cane to Coral Reefs: Ecosystem Connectivity and Downstream Responses to Land Use Intensification

Stacy D. Jupiter [1]

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

Clearing of catchments draining into the Great Barrier Reef Lagoon (Queensland , Australia) has increased sediment and nutrient loads in river runoff. The extent of land cover change and the intensification of land use were analyzed for the Pioneer River catchment near Mackay (from Landsat images, 1972-2004), and for the estuary (from aerial photographs, 1948-2002), to determine whether and how loss of natural vegetation has affected sediment delivery to nearshore waters and adjacent coral reefs. Geochemical proxy records of weathering and sediment delivery to the sea, deposited in skeletons of living *Porites* corals from inshore (5 km from Pioneer mouth) and midshelf (32-51 km offshore) reefs, were analyzed to determine the spatial and temporal extent of terrestrial impacts. High-temporal resolution (~weekly) concentrations of barium (Ba), yttrium (Y) and calcium (Ca) were measured by laser ablation inductively-coupled mass spectrometry (LA-ICP-MS), while annual samples of rare earth elements and yttrium (REY) were measured by solution ICP-MS. Major trends emerging from integration of contemporaneous terrestrial changes, marine geochemical proxies and climate records include: 1. A 33% net decline (1972-2004) of forests on alluvial plains as farms encroached into riparian zones; and a 22% net decline (1948-2002) of tidal mangroves in the estuary. 2. Ba/Ca correlations with Pioneer River discharge were influenced by wind direction and strength; but there was no apparent temporal change in Ba/Ca since 1946. The absence of enrichment in mean inshore Ba/Ca ratios (versus midshelf reefs) may be due to biological recycling by phytoplankton, which may restrict Ba availability. 3. Mean Y/Ca ratios from inshore (5 km) corals were 3.1 and 3.6 times higher than from midshelf (32 and 51 km) corals, and inshore REY abundances were ~2-5 times higher than from mishelf reefs. Inter-annual REY variation on both inshore and midshelf sites was correlated significantly with year and discharge, while long-term temporal trends in maximum annual Y/Ca, normalized to Pioneer River discharge, appear to reflect both agricultural expansion and changing management practices. 4. The combination of high turbidity and high nutrient discharge from the Pioneer River may be affecting benthic community composition on both inshore and midshelf reefs.

Evidence for past climates and environmental response from sediment archives in central and eastern Australia

Ed Rhodes 1,2 , John Chappell 1 , John Magee 3 , Kat Fitzsimmons 1,3 , Cynthja Bolton 1,3 , Martin Worthy 4

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 Research School of Pacific ad Asian Studies, Australian National University , Canberra ,ACT 0200, Australia
3 Department of Earth and Marine Sciences, Australian National University , Canberra ,ACT 0200, Australia
4 Centre for Resource and Environmental Studies, Australian National University , Canberra ,ACT 0200, Australia

We have made significant advances in the dating of quartz from wind and water-deposited sediments from Australia . These advances operate at several different levels, providing improved information for both large and small scale processes.

Optically Stimulated Luminescence (OSL) dating relies on the trapping of electrons in the crystal lattices of quartz and feldspar grains, when they are subject to natural environmental radiation. When grains are exposed to light or heat, the electrons in some trapping sites are emptied, effectively resetting the luminescence clock. This method has been used to date wind and water-deposited sediments, as well as the heating of archaeological artefacts and hearths.

A significant issue in OSL dating relates to the completeness of the zeroing process prior to and during the deposition of sediments. Based on theoretical expectation and the dating of modern surface samples, wind-blown sediments from desert environments have been assumed to be well-zeroed, while water-lain deposits may contain grains with significant residual signals. We have dated a large number of aeolian desert samples, and note that a significant proportion demonstrate signal patterns indicating incomplete zeroing at deposition; basically repeat determinations provide varying apparent ages, caused by the influence of non-zeroed grains. To understand how these age distributions are produced in multi-grain aliquots or sub-samples, numerical simulations were undertaken based on measured single grain OSL sensitivity data from real samples. The modelling results demonstrate that natural variations in OSL signal intensity allow the recognition of incomplete zeroing in multi-grain aliquots, and for some samples, this may represent the optimum means to detect this effect. This work also highlights how OSL data may be used to reconstruct conditions at the time of deposition, in particular the rapidity of deposition and the nature of the sediment sources.

Perhaps our most exciting findings relate to this use of OSL variation to determine depositional conditions. Work in two catchments in eastern Australia has demonstrated that single grains from fluvial deposits can retain information about their depositional history, and past sediment storage events. In both longitudinal dunes and lunettes (source-bordering dunes around ephemeral lakes) we also find significant evidence for the rapid reworking of earlier deposits, some of which occurred at night. While we must quantify these effects to determine reliable age estimates for these deposits, we can also start to develop detailed sediment transport models for their construction. In the Simpson desert , we have combined OSL age estimates from dunes with triple nuclide cosmogenic dating based on 10 Be, 20 Ne, 26 Al, to construct large scale models of dunefield initiation and reworking in response to climate changes on timescales of 1,000,000 to 1,000 years.

We find that many dunes retain a high degree of detailed palaeoenvironmental information, and that most dunes were constructed in a relatively small number of significant dune-building events which occur across the areas studied. This has very significant implications for understanding the nature of the environmental response to climate change in vulnerable parts of central Australia .

Figure 1: Active dune in the Strzelecki Desert near Camerons Corner, SA.

Initiation of Australian longitudinal dunefields, revealed by cosmogenic burial dating on dune-sand quartz from the Simpson Desert , central Australia

Toshiyuki Fujioka 1 , John Chappell 1 , Masahiko Honda 1 , Keith Fifield 2 , Igor Yatsevich 1 , Ed Rhodes 1

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 Research School of Physical Sciences and Engineering, Australian National University , Canberra , ACT 0200, Australia

Fields of longitudinal dunes are most extensive and a major feature of Australian sandy deserts that cover ~40% of the continent (Mabbutt, 1988). Chronological studies of the Australian longitudinal dunes, however, have been sparse owing to the lack of suitable dating method; conventional radiocarbon is of limited use owing to both the lack of organic materials and to the restricted age range (<50ka). Development of luminescence dating, notably optically stimulated luminescence (OSL), opened way to date sand deposits up to ~300 ka, but, because of the nature of the dating, luminescence ages tend to represent "stabilisation ages" rather than formation ages of dunefields (e.g., Nanson et al., 1992). Cosmogenic burial dating offers a way of dating deposits up to 5 Ma in the case of 10 Be and 26 Al pair, in which the degree of radioactive decay of cosmogenic nuclides, produced prior to burial, in a deposit can be interpreted as depositional age of the material (Granger and Muzikar, 2001).

In this study, a total of 69 sand and rock samples were collected from longitudinal dune fields at the western margin of the Simpson Desert, near Finke, central Australia, including sand samples, 20 for cosmogenic burial and 46 for OSL dating, together with three sets of gibber samples from adjacent gibber plains, in order to determine the timing of dune building episodes in central Australia. Nine drill holes from the crest to base of five longitudinal sand ridges identified paleosol horizons within the dunes, indicating that the dune formation was episodic. OSL measurements, outlined in Rhodes' annual report, from lower stratigraphic units in the dunes gave minimum ages ranging from >590 ka to >110 ka, suggesting that the depositional age of the earliest dunes in the study area is older than 500 ka, beyond the age limit of luminescence dating. Cosmogenic burial ages were calculated from the cosmogenic 10 Be and 26 Al concentrations in the dune-core samples, showing consistently older ages from ~360 ka to ~1600 ka. The amounts of cosmogenic 21 Ne in the samples were also determined by evaluating non-cosmogenic neon components such as crustal and *in situ* nucleogenic 21 Ne, and the burial ages calculated from pairs of 10 Be- 21 Ne and 26 Al- 21 Ne were generally consistent with the 10 Be- 26 Al burial ages, indicating that the non-cosmogenic 21 Ne components were successfully corrected.

The cosmogenic burial ages indicate that the first dune building episode at the west Simpson Desert occurred at least ~1200-1300 ka ago, and that mobile sand became available for the early dune building about ~1600 ka ago, which could have been earlier up to ~2000 ka. These ages are much older than any dune dates reported previously, and suggest that dry-out of rivers, and thus onset of aridity, in central Australia occurred immediately after cessation of widespread gibber formation, ~2 Ma ago, in this region (Fujioka et al., 2005). The earliest dune building episode at the west Simpson Desert , ~1200-1300 ka ago, indicates deepened aridity in Australia.

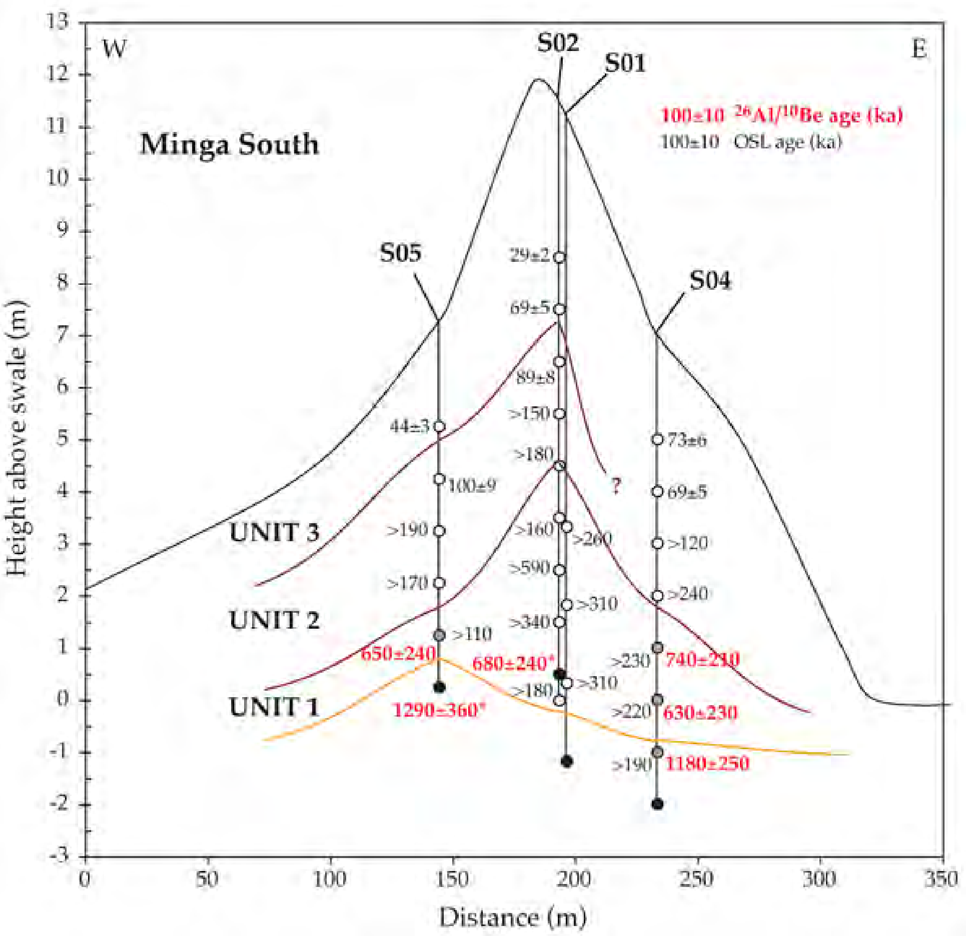


Figure 1. Summary of the measured burial ages, calculated from cosmogenic 10 Be and 26 Al in the dune-core samples, and OSL ages for a longitudinal dune, near Finke, in the west Simpson Desert . Internal dune units were defined based on the paleosol (brown curves) and carbonate (orange curve) horizons, identified during drilling. Ages with asterisk represent samples with accordant 10 Be- 26 Al- 21 Ne burial ages .

References: Fujioka, T., Chappell, J., Honda, M., Yatsevich, I., Fifield, L.K. and Fabel, D. (2005) Global cooling initiated stony deserts in central Australia 2-4 Ma, dated by cosmogenic 21 Ne- 10 Be. *Geology* 33(12) , 993-996.

Granger, D.E., Muzikar, P.F. (2001) Dating sediments burial with *in situ* produced cosmogenic nuclides: theory, techniques and limitations. *Earth and Planetary Science Letters* 188 , 269-281.

Mabbutt, J.A. (1988) Australian desert landscapes. *GeoJournal* 16.4 , 355-369.

Nanson, G.C., Chen, X.Y. and Price, D.M. (1992) Wetting and drying of Australia over the past 300 ka. *Geology* 20 , 791-794

Understanding climate change: Speleothems as archives of natural rainfall variability and rapid climate events

Pauline C. Treble

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

The need for high resolution paleoclimate records is evermore apparent in times of changing climate and an increased demand on Australia 's water resources. Long, detailed records of natural rainfall variability are required to understand the impact of climate change on our water resources. Speleothems (cave stalagmites) have the capacity to preserve high resolution proxy rainfall records extending from recent times to tens of thousands of years. Rainfall isotopes are preserved in the speleothem calcite, as are trace elements whose concentrations reflect the amount of soil and rock weathering and vegetation activity. These geochemical signals vary between wet and dry years.

Current research in Earth Environment includes reconstruction of long-term natural rainfall variability for sites in southern Australia by Dr Treble and colleagues. A key strength in this research is the detailed investigation being carried out on very young speleothems whose growth overlaps the instrumental record permitting calibration of speleothem geochemical trends to climate change. Speleothems from southwest WA, southeast SA, Tasmania and the Australian Alps are being used to develop calibrations over the 20 th century which can be extended back in time. These young speleothems and drip water monitoring programs offer an excellent opportunity to explore new potential environmental proxies preserved in speleothems. These geochemical data are being used to extend the climate record back 1000 years.

Research was also carried out on a speleothem that grew during the last glacial period when the Earth's climate was remarkably unstable. At this time, Greenland ice core records show repeated and rapid temperature variations of almost the same magnitude of a full glacial-interglacial cycle. These rapid climate events have been recorded in paleoclimate archives in many other places across the world. One such archive are spleothems from Hulu Cave, China, which show large abrupt O isotope (d 18 O) shifts at the time of the North Atlantic events (Wang et al., 2001). High-spatial resolution SIMS O isotope analyses were carried out across the d 18 O shift corresponding to Heinrich event 1 increasing the temporal resolution of the previously published data by approximately tenfold providing yearly resolution. These new data demonstrate that the East Asian monsoon underwent a major change and that the majority of this transition took place in as little as 1-2 years (Treble et al., in press). This rapid shift marked a significant change in mean climate that persisted for approximately 500 years.

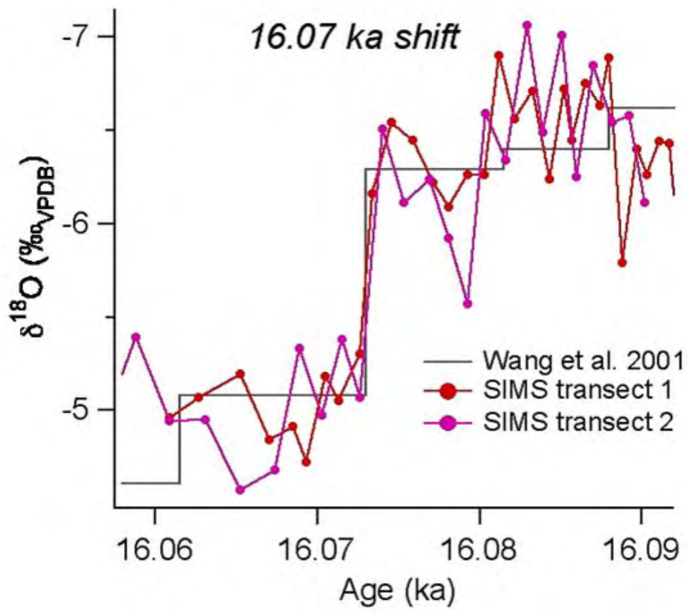


Figure 1 . O isotope record of Hulu Cave at the time of Heinrich event 1. The two overlapping SIMS O isotope transects demonstrate that 75% of the rapid change in the East Asian monsoon climate at 16.07 ka took place in less than 2 years.

References: Wang Y. J., Cheng H., Edwards R. L., An Z. S., Wu J. Y., Shen C. C., and Dorale J. A. (2001) A high-resolution absolute dated late Pleistocene monsoon record from Hulu Cave, China. *Science* , 294: 2345-2348.

Treble P. C., Schmitt A. K., Edwards R. L., McKeegan K. D., Harrison T. M., Grove M., Cheng H. and Wang, Y. J. (in press) High resolution Secondary Ionisation Mass Spectrometry (SIMS) d 18 O analyses of Hulu Cave speleothem at the time of Heinrich Event 1. Chemical Geology.

Earth Materials Introduction

The Earth Materials Area is comprises the Experimental Petrology, Rock Physics, Thermochronology and Structure & Tectonics Groups. 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 processes by which they evolve, such as accretion, 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. Experiments are performed at 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 Research Highlights

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Redox Decoupling and Redox Budgets: Conceptual Tools for the Study of Earth Systems

Katy A. Evans

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

Redistribution of redox-sensitive elements (e.g. Fe, C, H) by open system processes have strongly influenced planetary development. Study of this redistribution requires that the effects of isochemical electron transfer should be distinguishable from the effects of chemical redistribution. Two terms are proposed to make this distinction. The first is *redox decoupling* : the transport of redox-sensitive elements such that the source and sinks for the elements experience a net increase or decrease in their capacity to oxidise other material. The second, *electrochemical differentiation*, describes the effect of one or more redox decoupling processes that change existing gradients in redox potential in some way.

Recognition of redox decoupling requires the use of an extensive rather than an intensive redox variable, because intensive variables do not provide information on fluxes and so are of limited use for the study of reservoirs. Redox budget, defined as the number of moles of electrons that must be added to a sample to reach a reference state, is such a variable. The construction of redox budgets for MORB lavas and glasses shows that redox decoupling occurs during crystallisation of MORB at the Mid-Atlantic, Pacific and Red Sea ridges, with net oxidation of the crystallised lava. The effects of this redox decoupling on the exogenic redox budget may be significant (Evans, 2006).

Redox budget studies may be based on a combination of petrologic (e.g. Figure 1: Evans et al., 2006) and chemical analysis with techniques such as synchrotron XANES (X-ray Absorption Near Edge Spec tra) studies and EBSD (Electron Back Scatter Diffraction). The concepts of electrochemical differentiation, redox decoupling and redox budget may be useful for researchers studying global cycling, the formation of ore deposits, volcanism, evolution of the mantle, crust and core, redox-related environmental problems and bacteria-catalysed reactions.

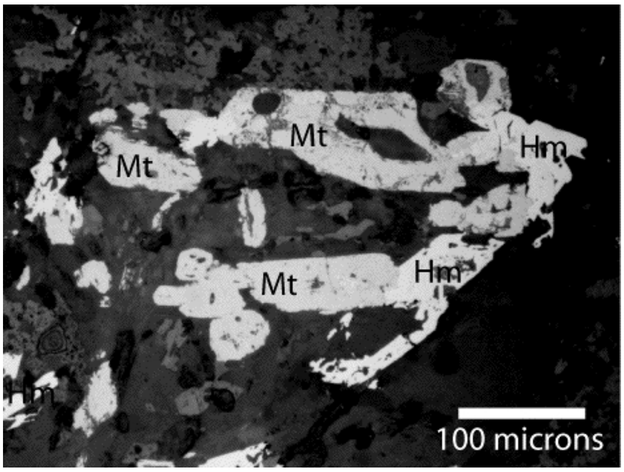


Figure 1. Photomicrograph of thin section from gold-bearing rock from Kalgoorlie , Western Australia . Co-existing hematite and magnetite in rocks altered by the hydrothermal fluids associated with gold deposition provide evidence of the redistribution of redox-sensitive elements during formation of the gold deposit.

References: Evans, K. A., 2006. Redox decoupling and redox budgets: Conceptual tools for the study of earth systems. Geology 34, 489-492.

Evans, K. A., Phillips, G. N., Powell, R., 2006. Rock-buffering of auriferous fluids in altered rocks associated with the Golden Mile-style mineralization, Kalgoorlie gold field, Western Australia. Economic Geology 101, 805-817.

Sediment melts at sub-arc depth

Jörg Hermann 1 , Carl Spandler 2

1 Research School of Earth Sciences, The Australian National University , Canberra , ACT 0200, Australia
2 I nstitute of Geological Sciences, University of Bern, Switzerland

Volatile and element recycling through subduction zones is fundamental to arc magma-genesis, continental crust formation and the geochemical evolution of the mantle. Arc lavas and continental crust are enriched in LILE and LREE with respect to MORB and it is generally accepted that these elements represent a slab component in subduction zone magmas. Subducted sediments are the main host of these elements and thus phase and melting relations in metapelites are of first order importance to constrain trace element recycling in subduction zones.

We performed piston cylinder experiments on a trace element doped, hydrous (2-7 wt.% H_2O), synthetic pelite composition in the range from 22-45 kbar and 600-1050°C, i.e conditions relevant for the slab at sub-arc depth. The main mineral assemblage over the investigated range consists of phengite, quartz/coesite, garnet, omphacite and minor kyanite, and accessory rutile, apatite, allanite or monazite and occasionally zircon (Fig. 1). At 25 kbar amphibole is present up to 800°C instead of omphacite and biotite is stable from 750°C-900°C (Fig. 1). The solidus has been determined at 675°C, 22 kbar and at 700°C 25 kbar. At 750°C, 35 kbar and at 800°C, 45 kbar glass was present in the experiments indicating that at such conditions a hydrous melt is stable. In contrast, at 700°C, 35 and 45 kbar, a solute-rich aqueous fluid was present. This indicates that the solidus is steeply sloping in P-T space. Although the second critical point in this system is not yet determined, the experiments show that at T<700°C solute-rich aqueous fluids and at T>750°C hydrous granitic melts are the stable fluid phase responsible for trace element transfer from the subducted sediments to the mantle wedge. Phengite is the main host of LILE in the residue and is stable up to 800°C, 25kbar; 950°C 35 kbar and 1000°C, 45 kbar, confirming earlier studies indicating that liberation of LILE must be related to fluid present conditions in the slab. Also phengite is present to high degrees of partial melting (up to 40%) and thus will buffer the K content of the fluids/melts and control LILE recycling. The produced hydrous melts display systematic changes with increasing temperature. At 750-800°C Na_2O is higher than K_2O whereas at higher temperatures it is the opposite. K_2O/H_2O changes strongly as a function of temperature and nature of the fluid phase. It is about 0.002-0.01 in the aqueous fluid, and then increases gradually from about 0.1 at 750°-800°C to about 1 at 1000°C in the hydrous melt (Fig. 2). Primitive subduction related magmas have typically K_2O/H_2O of ~0.1 indicating that hydrous melts rather than aqueous fluids are responsible for element transfer in subduction zones and that top slab temperatures at sub arc depths are approximately 800°C.

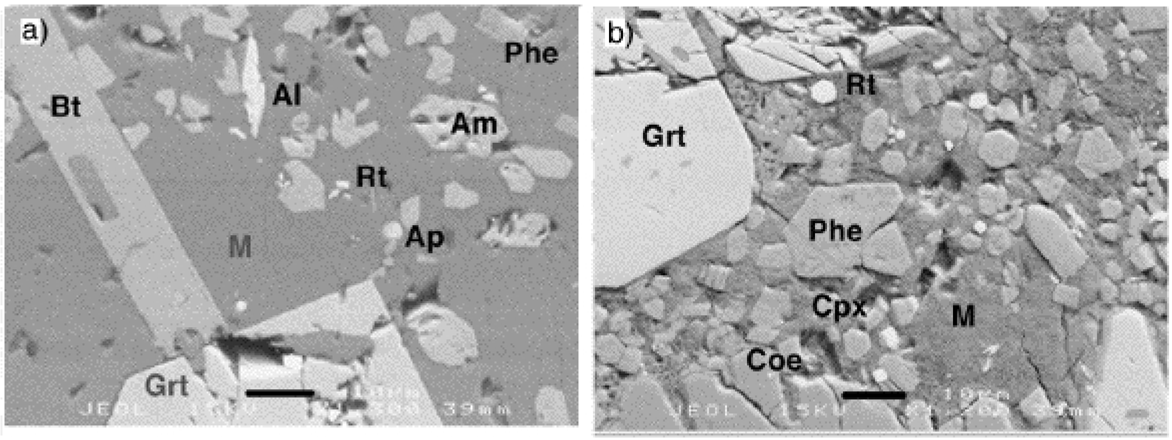


Figure 1. Experimental run products. a) 750°C, 25 kbar: A large amount of melt, quenched to a hydrous glass coexists with hydrous phases. b) Melt is still present at 800°C, 45 kbar. The high water content of the melt is documented by numerous bubbles in the quenched glass. Abbreviations: Grt = Garnet, Bt = Biotite, Phe = Phengite, Am = Amphibole, M= Melt, Al = Allanite, Ap = Apatite, Rt = Rutile, Cpx = Clinopyroxene, Coe = Coesite.

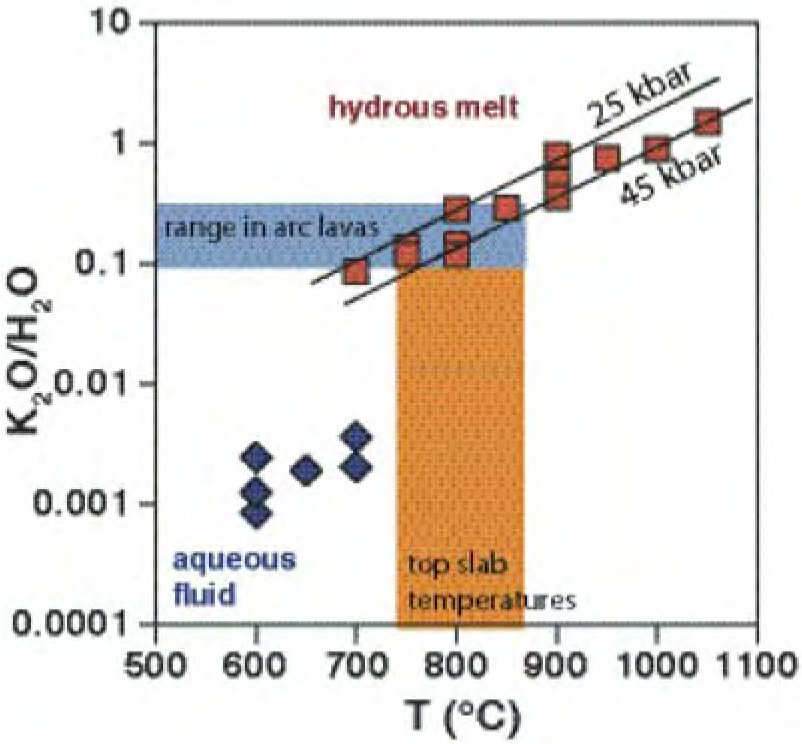


Figure 2. Experimentally determined variation of the K2O/H2O with temperature and pressure. The results indicate that K is transferred via a hydrous melt phase from the slab to the mantle wedge and that top slab temperatures must be about 800°C at sub arc depth.

Quantitative absorbance spectroscopy with unpolarized light

István Kovács 1 , Jörg Hermann 1 , Hugh St. C. O'Neill 1 , Gábor Horv áth 2 , John FitzGerald 1 , Malcolm Sambridge 1

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Institute of Matemathics, E ötvös University , Budapest , 1117, Hungary

We tested the predictions of the absorbance theory of light propagation in anisotropic minerals with systematic measurements of calcite and olivine in oriented and random sections through the minerals using polarized and unpolarized light. Five principal predictions of the absorbance theory have been tested: 1) We show that polarized maximum and minimum absorbance as well as unpolarized absorbance is linearly scaled with thickness regardless of the direction of the incident light. 2) It is demonstrated that the measured angular variation of polarized light as a function of maximum and minimum values is within error indistinguishable from the theoretical predictions. 3) It has been confirmed that unpolarized absorbance is always the mathematical average of the maximum and minimum polarized absorbance in any section. 4) The unpolarized absorbance for different arbitrary sections has been successfully calculated with olivine grains, for which the orientations have been determined by Electron Backscatter Diffraction. 5) The measured average unpolarized absorbance of randomly oriented grains is exactly one third of the Total Absorbance, in agreement with the absorbance theory. Because of this latter postulate, previous calibrations relating Total Absorbance to water concentration in minerals, which were developed for polarized light in principal sections, may be used in conjunction with unpolarized measurements according to:

$$C_{H_2O}(ppm) = \frac{\sum_{n=0}^{i} A_i}{n} \cdot k_{pol} \cdot 3$$

where A i is the integrated unpolarized absorbance of individual analysis, n is the number of analyses and k pol is the calibration factor for polarized light. This method allows calculating water concentrations in nominally anhydrous minerals from high-pressure experimental runs and fine grained mantle xenoliths, specimens in which preparation of oriented samples is usually not feasible.

Bell, D.R., Rossman, G.R., Maldener, J., Endisch, D. & Rauch, F. (2003): Hydroxide in olivine: A quantitative determination of the absolute amount and calibration of the IR spectrum. *Journal Of Geophysical Research-Solid Earth*, **108** (B2).

Libowitzky, E. & Rossman, G.R. (1996): Principles of quantitative absorbance measurements in anisotropic crystals. *Physics and Chemistry of Minerals*, **23** , 319-327.

Paterson, M.S. (1982): The determination of hydroxyl by infrared absorbtion in quartz, silicate glasses and similar materials. *Bulletin of Mineralogy* **,** **105** , 20-29.

Subduction recycling of continental sediments and the origin of geochemically enriched reservoirs in the deep mantle: experimental constraints at 16-23 GPa

Robert P. Rapp 1,2 , Tetsuo Irifune 2 , Nobu Shimizu 3

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Geodynamics Research Center, Ehime University, Matsuyama, 790-8577, Japan
2 Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, 02543, USA

Since Earth's formation more than 4.5 billion years ago, the continental crust has been progressively extracted from the silicate mantle by island arc magmatism associated with subduction of oceanic lithosphere along convergent plate boundaries. As a consequence of arc magmatism and continent formation, elements that are generally incompatible in mantle minerals (e.g., K, Rb, Sr, Ba, Th and U) during partial melting tend to be highly concentrated in the continental crust, and a complementary depletion in these elements (referred to as "large-ion lithophile elements", or LILEs) is observed in the upper mantle. Over geologic time, the continents have thus come to represent a geochemically enriched reservoir relative to the "depleted" upper mantle. Erosion of the continental masses deposits terrigenous sediments in the deep ocean basins, material that is eventually returned to the deep mantle by subduction recycling. Isotope and trace element geochemical features of ocean island basalts (OIBs) infer the presence of long-lived (~1-2 Ga old) compositional heterogeneities in their plume source in the deep mantle, and these are usually attributed to the recycling of continent-derived sediments via subduction. But a number of questions regarding crustal recycling in subduction zones remain unanswered: how deeply can continental sediments be subducted? do sediments retain their unique geochemical signature during transport through the upper mantle? What mineral phases control the distribution of LILEs in continental sediments at very high pressures? Are sedimentary rocks at high pressure more or less dense than ambient mantle (i.e., are they buoyant, or do they sink?)? In an effort to answer these questions, we have undertaken a high-pressure experimental study of the physical and chemical properties of sedimentary rocks at pressures corresponding to the lowermost upper mantle and uppermost lower mantle (i.e., at depths corresponding to the mantle transition zone, ~500-700 km). Phase equilibria experiments on natural metasedimentary rocks at 15-23 GPa indicate that the high pressure phase assemblage in continental sediments consists of stishovite, garnet, kyanite, corundum, and K-hollandite ($KAlSi_3O_8$), and that K-hollandite retains most if not all of the bulk rock's budget of LILEs and heat-producing elements (i.e., K, U, Th) (Rapp et al., 2007, submitted). The bulk thermoelastic properties and equation-of-state parameters of K-hollandite have also been determined using in-situ synchrotron radiation at the Spring-8 light source in Japan (Nishiyama et al., 2005). From these measurements, we have estimated the density of continental sediments through the mantle transition zone and into the lower mantle, and our results suggest that terrigenous sediments achieve positive buoyancy at the top of the lower mantle (see Fig. 1). This further implies that OIBs with the isotopic and geochemical signature of recycled terrigenous sediments (e.g., EM-1 type) cannot originate from depths greater than approximately 800 km.

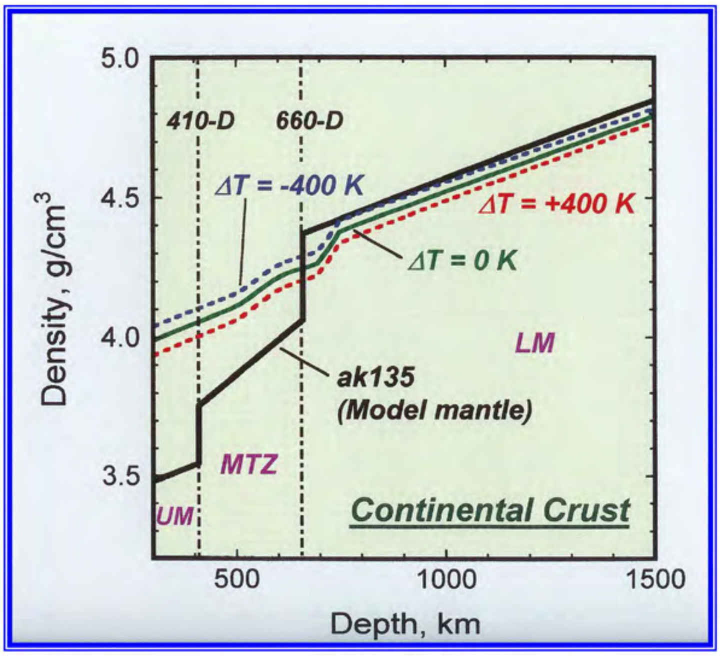


Figure 1. Density profile for model sediment composition (equal parts stishovite, K-hollandite, and garnet) based on high-pressure, in-situ equation of state measurements on K-hollandite, and literature values for stishovite and Mj-garnet. Shown for comparison is a 1D seismologically determined density profile for model mantle composition (ak135) from Kennett et al. (1995)

References: Kennett, B.L., Engdahl, E.R., and Buland, R. (1995) Constraints on seismic velocities in the Earth from travel times. *Phys. Earth Planet. Int.* 121 , 85-102.

Nishiyama,, N., Rapp, R.P., Irifune, T., Sanehira, T., Yamazaki, D., and Funakoshi, K. (2005) Stability and P-V-T equation of state of KAlSi3O3-hollandite determined by inn situ X-ray observations and implications for dynamics of subducted continental crust material. *Physics Chem. Minerals* 32 , 627-637.

Rapp, R.P., Irifune, T., Shimizu, N., Nishiyama, N., Norman, M.D., and Inoue, T. (2007) Subduction recycling of continental sediments and the origin of geochemically enriched reservoirs in the deep mantle. *Earth Planet. Sci. Lett.* (submitted).

Coupling of in-situ Sm-Nd systematics and U-Pb dating of monazite and allanite

Chris McFarlane, Malcolm McCulloch, & Courtney Gregory

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

The coupling of laser-ablation micro-sampling and multiple-collector ICPMS provides a means to measure Sm-Nd isotopic systematics at the same spatial scales as used for *in-situ* U-Pb geochronology. However, the decrease in analytical volumes afforded by laser-ablation necessitates an increase in the absolute concentration of Nd in the analyte material. Accessory minerals enriched in LREE may contain Nd at concentrations ranging from the 10 6 to 10 3 ppm enabling the measurement of precise 143 Nd/ 144 Nd ratios at spatial resolution of <150 µm. In 2006 we successfully demonstrated the capabilities of laser-ablation multiple-collection ICP-MS (LA-MC-ICPMS: Helex laser cell + Neptune MC-ICPMS) applied to two of the most common LREE-enriched minerals in the Earth's crust: monazite and allanite. We have shown that precision comparable to solution-based MC-ICPMS measurements (< 0.5 epsilon units) can be achieved for laser spot sizes ranging from 16 to 50 µm. At this scale, sub-grain regions first dated using non-destructive *in-situ* U-Th-Pb geochronology (e.g., SHRIMP) can be combined directly with *in-situ* Nd-isotope and Sm/Nd elemental data to calculate robust initial 143 Nd/ 144 Nd ratios and investigate grain-scale isotope variations. We have applied this approach to monazite from granulite-facies metamorphic rocks previously dated by SHRIMP. Sm-Nd systematics of these monazite grains measured by LA-MC-ICPMS in grain mount and *in-situ* in polished thinsection are used to calculate precise initial 143 Nd/ 144 Nd, identify potential isotopic inheritance, and to understand the origin of compositional domains (e.g., core-overgrowth features) with complete control on textural context. Discrepancies between monazite U-Pb and garnet-wholerock Sm-Nd isochron ages can also be used to estimate crustal cooling rates, thereby elucidating the timescales of crustal residence of high-grade terrains. Recent development of U-Th-Pb dating of allanite on SHRIMP II and SHRIMP RG will facilitate analogous studies of calc-alkaline rocks in which allanite and titanite are the dominant LREE accessory mineral.

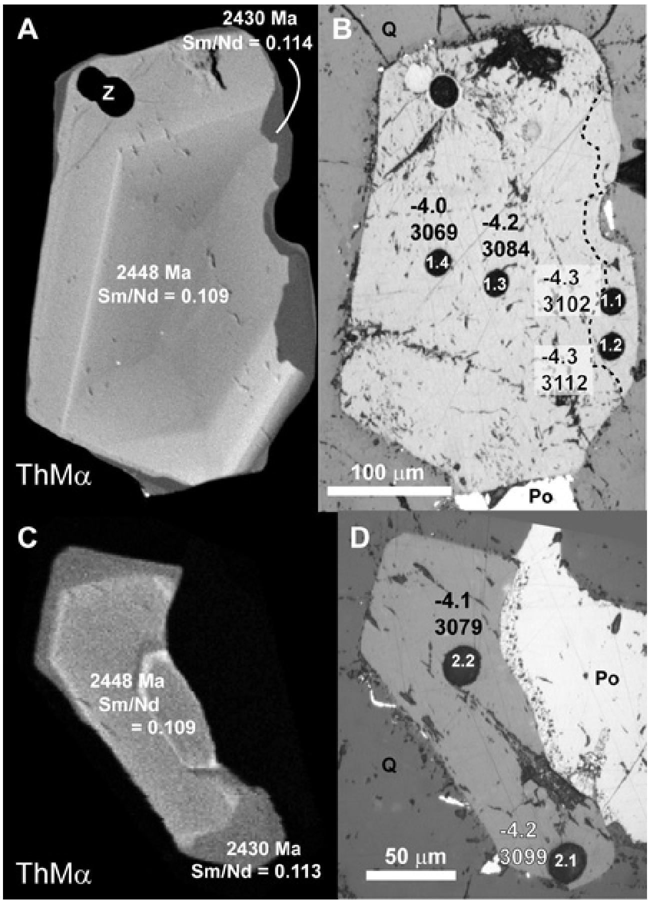


Figure 1 . Two large monazite grains from a metatexite migmatite leucosome from the Challenger Gneiss, South Australia . X-ray mapping (A & C) was used to identify core-overgrowth zoning and to guide the placement of SHRIMP spots for U-Pb dating. 2448 Ma cores are surrounded by 2430 Ma overgrowths. Each domain was subsequently targeted for *in-situ* Nd-isotope measurements using a 22 μ m laser spot (labelled holes in B & D). Values for e Nd (-4.2 to -4.0) calculated at the independently determined U-Pb age are shown along with depleted mantle model ages (below e Nd values).

The role of phosphorus in the incorporation of lithium into mantle olivine and potential implications for Li isotopic systematics

Guil Mallmann 1 , Hugh St.C. O'Neill 1 , Stephan Klemme 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 School of Geosciences, University of Edinburgh, Edinburgh, EH9 3JW, UK

The light elements Li, Be and B and their isotopes have the potential to constrain the extent to which subduction-related processes and recycled material contribute to the chemical heterogeneity of the Earth's mantle. Li isotopes, in particular, are being the focus of much work recently. However, the mechanism of Li incorporation into mantle minerals and rates of diffusion are still poorly known. We have found that olivine crystals from some peridotite xenoliths from the Anakies locality (SE Australia) have highly variable phosphorus (P) concentrations (50-250ppm), while all the other major and trace elements appear to be constant in composition. EMP X-ray maps revealed peculiar types of P zoning in these crystals, which we have interpreted as resulting from metasomatism followed by deformation at sub-solidus conditions; P heterogeneities are likely preserved due to sluggish diffusion of this element into olivine. The P contents were also found to covariate very well with Li (Fig. 1), suggesting that a coupled substitution mechanism similar to IV Mg 2+ + IV Si 4+ « VI Li + + IV P 5+ is responsible for the incorporation of Li into mantle olivine. Our findings have potential implications for the homogenisation of Li and fractionation of Li isotopes in mantle samples. These implications need to be further addressed.

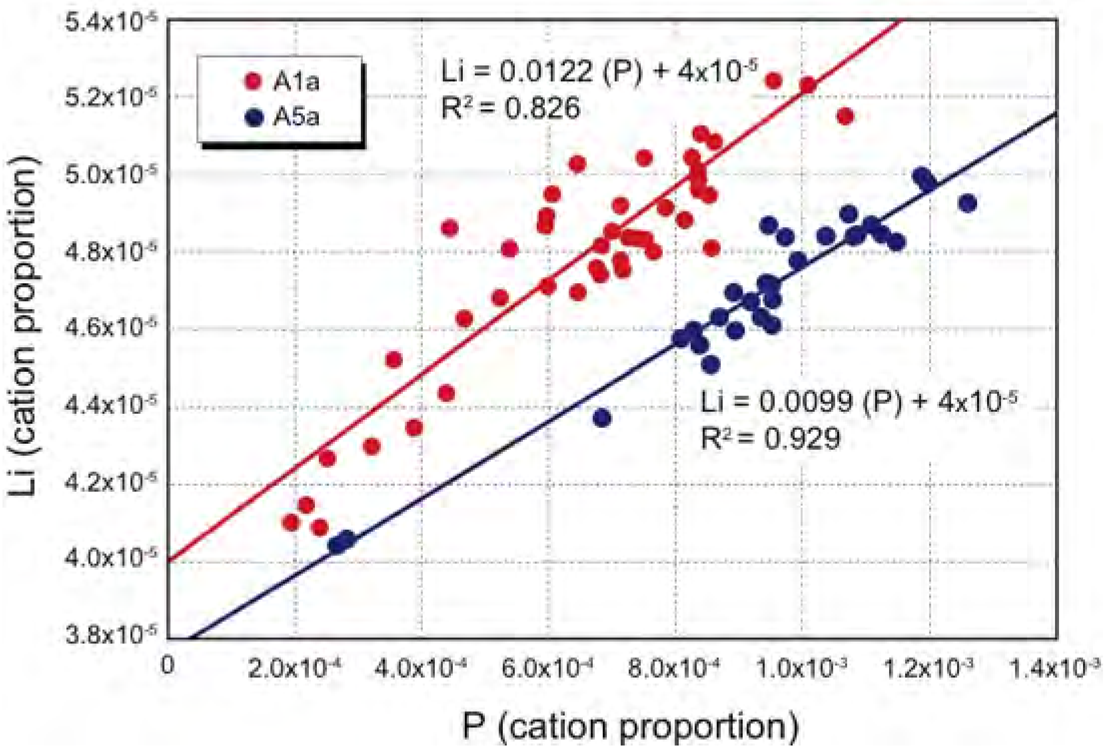


Figure 1. Covariation plot between P and Li in olivine crystals from two Anakies peridotite xenoliths. Measurements were done with LA-ICP-MS in individual olivine crystals.

Carbon and Hydrogen in Melts and Fluids in Planetary Interiors

James Tuff [1], David H. Green [1], Michael Shelley [1]

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

Important characteristics of the Earth's mantle, such as the temperature of it's solidus at a given depth and the compositions of mantle-derived magmas (e.g. silica-saturated vs. silica-undersaturated), are dependent on the prevailing oxidation state and the solubilities of volatile species. In particular, C-H-O species are known to have large effects on mantle solidus temperatures and magma compositions. Magmas on the Earth's surface are generally oxidized (fO_2 ~ FMQ) and CO_2-bearing. However, the source region of these magmas - the convecting upper mantle - is likely to be significantly reduced at depth, probably ~ FMQ-2 to FMQ-3 log units for basalt source regions and < FMQ-3 log units for kimberlite source regions (e.g. Green et al., 1987; Taylor & Green, 1989). The stable C-H-O volatile phase under these fO_2 conditions will be a CH_4-H_2 $\pm H_2O$ fluid, rather than CO_2-H_2O. Calculations suggest that upper mantle fO_2 may decrease by as much as 0.6 log fO_2 units per GPa (relative to FMQ). The question arises as to how oxidized magmas can be extracted from a reduced source.

We are using high pressure, high temperature experimental techniques in order to constrain the role of carbon and hydrogen volatile species within the Earth's upper mantle. Our experimental work has focussed on the development of new methods that enable us to analyse the fluid phases produced from experimental run products. An innovative system we have built consists of a gas chromatograph that is capable of measuring trace quantities of gases within experimental run charges; at present, we are able to measure N_2, O_2, CO, CO_2, CH_4, C_2H_6 and H_2O, but slight modifications will allow us to analyse a variety of other gases. Experiments are based on the design of Taylor & Foley (1989) and consist of a W-C-WO buffer in order to produce the required reducing environment (FMQ-3 log units at 2.8 GPa). Early results indicate that a CH_4- and H_2O- rich fluid is produced under such conditions and agree with results from experiements by Matveev et al. (1997) and Taylor & Foley (1989). Our development of a reliable method of gas analysis provides a versatile system that will have many useful applications for future experimental studies.

References: Green D.H., Falloon T.J., and Taylor W.R. (1987) Mantle-derived magmas: Roles of variable source peridotite and variable C-H-O fluid compositions. *Geochemical Soiety Special Pubication.* **1** , 139-154.

Taylor W.R., and Green D.H. (1989) The role of reduced C-O-H fluids in mantle partial melting. *Geological Society of Ausralia Special. Pubication.* **14** , 592-602.

Taylor, W.R., and Foley, S.F. (1989) Improved Oxygen-buffering techniques for C-O-H fluid-saturated eperiments at high pressure. *Journal of Geophysical Research* **94** , 4146-4158.

Matveev, S., Ballhaus, C., Fricke, K., Truckenbrodt, J. and Ziegenbein, D. (1997) Volatiles in the Earth's mantle: I. Synthesis of CHO fluids at 1273 K and 2.4 GPa. *Geochimica et Cosmochimica Acta* **61** , 3081-3088.

Sulphur solubility experiment

Thomas Ulrich

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

The aim of these experiments was to determine the S solubility in respect to oxygen fugacity in silicic melt (dacitic composition). The experiments will give insight into the S behaviour during magma evolution and volcanic eruptions. It was found that the S solubility generally decreases with increasing oxygen fugacity. The solubilities were lower in hydrous experiments compared to dry experiments and thus indicate that S partitions strongly into a volatile phase in hydrous experiments. These results corroborate findings of earlier studies that it is likely that S is stored in a coexisting fluid phase together with melt beneath active volcanoes. During a volcanic eruption this fluid will be expelled and contributes to the large amounts of S that can be transported into the atmosphere and can explain the S budget between atmospheric S measurements and solubility estimates from S determinations in pre-eruptive melt inclusions.

Metal partitioning from experiments and natural samples

Thomas Ulrich

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

A series of experiments with the aim of determining the metal behaviour in andesitic to rhyolitic melts were conducted. The partitioning between melt and oxides (titanite, ilmenite) and melt and sulfides (pyrrhotite) was investigated. The results from the experiments show that in sulfide absent runs Mo, W and Sn partition strongly into rutile (titanite replaced by rutile) and Pb and to some extent stay in the silicate melt.

In sulfide bearing runs the partitioning is clearly towards the sulfide and the formation of new sulfide phases of Pb, Pb-Zn, Zn-Fe, and Fe was observed. Sn and Cu did not form own sulfides and partitioned into Pb-S and Fe-S, respectively., whereas Mo partitioned into coexisting rutile.

In addition to the experiments, two set of natural samples were analyzed. The first batch of rocks contained ilmenite and magnetite inclusions in plagioclase and orthopyroxene from eruption products of the Taupo eruption in the Central Taupo Volcanic Zone, New Zealand. A second set of rocks of which magnetite and ilmenite were separated is from a fractionated granitic intrusion in New South Wales (Yeoval granite, Australia).

The results of the natural samples from the Taupo eruption show that not only the oxides can accommodate metals, but that the silicates have elevated metal contents. For example Zn, Mn and Mo were most enriched in the orthopyroxene.

In the Yeoval granitic rocks the trace elements define a fractionation trend that is preserved in the accessory phase and there are two (temporally?) different magnetite phases, which differ in metal content.

Furthermore, I had collaborations with researchers from James Cook University and industry (Auzex Resources Ltd), namely in fluid and melt inclusion analysis using the LA ICPMS facility at RSES. Some of the projects involved the analysis of samples for the pmd CRC project on predictive mineral discoveries.

In 2005 I was awarded a grant from ANSTO (through the Access to Major Research Facilities Programme) to visit and use the synchrotron facility at the Advanced Photon Source in Argonne, Chicago. This was part of an extension of a previous ARC project on the solubility of molybdenum in magmatic-hydrothermal fluids. I was able to determine the likely Mo complexes in H2O and H2O-KCl solutions, which complemented the solubility data obtained previously.

In summary, the work at ANU was very interesting and the research environment and the technical facilities are outstanding. Consequently, I gained a lot of new experience that will be valuable for my future career. I felt honoured and privileged to work at RSES and I enjoyed the friendly atmosphere among staff and research colleagues within the group.

Non-linear feedbacks and fluid chemistry effects on trace element concentrations in syntectonic hydrothermal veins

Shaun L.L. Barker 1 , Stephen F. Cox 1,2 , D.C. 'Bear' McPhail 2

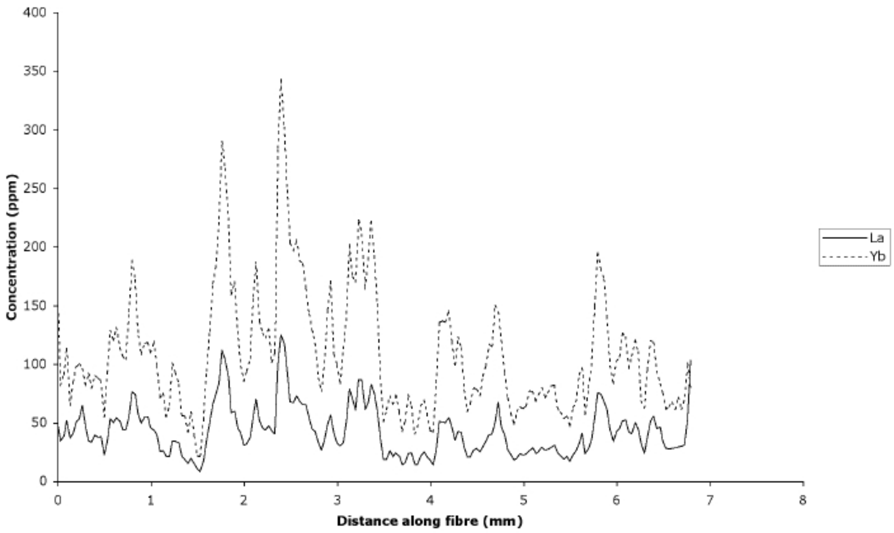
1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Earth and Marine Sciences, Australian National University , Canberra , ACT 0200, Australia

Hydrothermal veins are a ubiquitous feature in many parts of the Earth's crust, and provide evidence for fluid redistribution and material transport. High-spatial resolution chemical analyses within an individual vein may be used to infer changes in fluid chemistry during the growth of that vein.

Our previous work highlighted the integration of high-spatial resolution isotopic and trace element analyses with microstructural observations. During this study, we noted that trace and rare earth element concentration changes occur on several scales, with broad-scale (*e.g.* mm) concentration changes being modulated by significant, fine-scale (< 100 µm) concentration variations (Barker et al, 2006). In particular, we noted that Ce/Ce* and Eu/Eu* ratios may record changes in fluid-rock reaction and fluid oxidation state. We suggested that concentration changes could be produced by either (a) changes in the bulk fluid composition or (b) some type of non-linear surface process within a fluid that maintains an approximately constant bulk composition (e.g. Watson, 1996).

To address this, we grew calcite crystals from approximately constant composition $CaCl-NH_4Cl$ solutions by diffusion of CO_2 from an ammonium carbonate source (Gruzensky, 1967). These solutions were spiked with REEs at varying Ca/REE_{total} . Crystal growth began after several days, and continued for approximately 2 months before being recovered for analysis. A variety of crystal morphologies grew, including long needles and stubby euhedral calcite grains.

Preliminary laser ablation ICP-MS results along the long axis of the calcite needles reveals significant (> 50%) REE concentration changes over a fine-scale (< 100 µm). Hence, fine-scale trace element variations measured in natural samples may not reflect any change in bulk fluid composition. Notably, Ce/Ce* and Eu/Eu* anomalies were not developed in the synthetic calcite crystals. Therefore, we suggest that these anomalies reflect changes in fluid-rock reaction and oxidation state. Further experiments are needed to quantify the effects of growth rate on REE uptake, and the influence of varying Ca/REE_{total} on crystal morphology.



References: Barker, S.L.L., Cox, S.F., Eggins, S.M. and Gagan, M.K. (2006) Microchemical evidence for episodic growth of antitaxial veins during fracture-controlled fluid flow" Earth and Planetary Science Letters 250 , 331-344

Gruzensky, P.M. (1967) Growth of calcite crystals, In H.S. Peiser, Ed., Crystal growth, 365-367, Pergamon, Oxford

Watson, E.B. (1996) Surface enrichment and trace-element uptake during crystal growth. *Geochimica et Cosmochimica acta* 60 5013-5020

Wogelius, R.A., Fraser, D.G., Wall, G.R.T. and Grime, G.W. (1997) Trace element and isotopic zonation in vein calcite from the Mendip Hills, UK, with spatial-process correlation analysis. *Geochimica et Cosmochimica acta* 61 2037-2051

High-temperature deformation processes in fine-grained ceramics: controls on grain boundary sliding

Auke Barnhoorn 1 , Ian Jackson 1 , John D. Fitz Gerald 1 , Ulrich H. Faul 1,2 , Stephen J. S. Morris 3 ,Yoshitaka Aizawa 4 , Harri Kokkonen 1 , Craig Saint 1

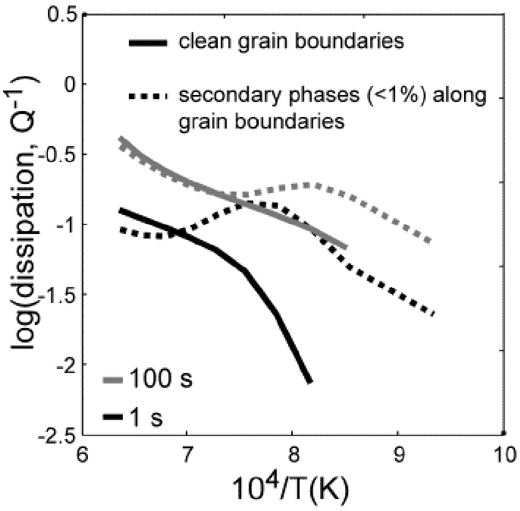
1 Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia
2 Now at Department of Earth Sciences, Boston University, Boston, Massachusetts, USA
3 Department of Mechanical Engineering, University of California, Berkeley, California, USA
4 Now at Research Center for Seismology, Volcanology and Disaster Mitigation, Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan

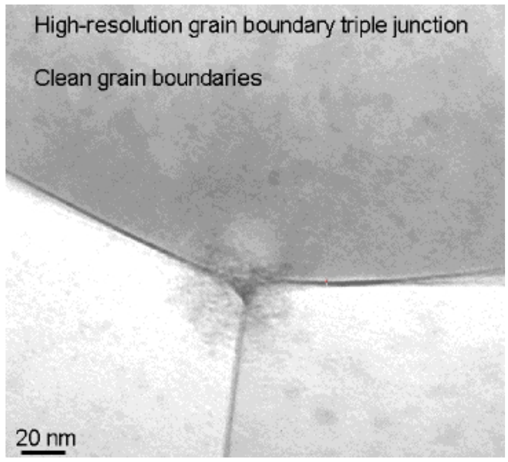
In recent years it has been determined that the departure from ideal elastic behaviour of a geological or ceramic material, when stressed at high temperature, is strongly influenced by its microstructure. Small changes in the grain size, or very small amounts of fluids/melt or other impurities along the grain boundaries are sufficient to cause remarkable changes in the rheology Therefore, systematic studies into the effect of those minor microstructural characteristics is vital for improving the understanding of atomic-scale processes during deformation, which in turn will lead to better usage of rheological data in the interpretation of the dynamic processes of the Earth's interior and to improved structural materials for industrial applications.

A particular current focus is the experimental deformation of polycrystalline magnesium oxide (MgO) at high temperatures (to 1300 ° C) to monitor the change from instantaneous, reversible elastic deformation to time-dependent permanent viscous deformation. We use MgO, because its simple cubic crystallography makes it an ideal material to test the validity of micromechanical models for specific deformation mechanisms, such as grain boundary sliding. In addition MgO is used in the ceramics industry especially in high-temperature structural applications because of its special high-temperature characteristics. The MgO study has so far shown that very small amounts (<1%) of secondary phases along the grain boundaries result in a dissipation peak whereas pure MgO with clean grain boundaries displays no dissipation peak.

The fabrication of a suite of dense, pure polycrystalline specimens ranging widely in mean grain size has been greatly facilitated by collaboration with Professors Itatani (Sophia University, Japan) and Kishimoto (Okayama University, Japan). Data so far obtained for specimens of 3-20 m m mean grain size reveal a clear grain size dependency of the rheology. The rheological data is currently being modeled to obtain a comprehensive flow law for MgO which includes parameters such as temperature, oscillation period and grain size. This MgO flow law can then be used for extrapolation to deep Earth conditions as a first approximation for the behaviour of magnesiowüstite ($(Mg_{0.8}Fe_{0.2})O$) which is an important mineral phase in the Earth's lower mantle. The new MgO data thus have the potential to better constrain the cause of seismic-wave attenuation in the lower mantle.

Several aspects of the newly measured viscoelastic behaviour of polycrystalline MgO are at odds with the classic theory of grain-boundary sliding developed during the 1970's by Raj and Ashby. This theory is accordingly being revisited with less restrictive assumptions: specifically, grain edges are allowed to be arbitrarily sharp and elastic and diffusional accommodation of the relative sliding between adjacent grains may operate concurrently. Preliminary results provide the first comprehensive theoretical description of grain-boundary sliding and some tantalising insights into the controls on the relative importance of dissipation peaks and the broad monotonically frequency-dependent background.





References: Barnhoorn, A., Jackson, I., Fitz Gerald, J. D., Aizawa, Y., (2006) Mechanical spectroscopy of high-purity MgO, *Proceedings 30th Annual Condensed Matter and Materials Meeting* , *Wagga Wagga, NSW, 7-10 February 2006,* ISBN 1-920791-09-4, http://www.aip.org.au/wagga2006/WP4_Barnhoorn.pdf

Barnhoorn, A., I. Jackson, J. D. Fitz Gerald and Y. Aizawa. Suppression of elastically accommodated grain-boundary sliding in high-purity MgO, *J. Euro. Ceram. Soc.* (submitted)

Jackson , I. , U.H. Faul, J.D. Fitz Gerald, and S.J.S. Morris. Contrasting viscoelastic behaviour of melt-free and melt-bearing olivine: implications for the nature of grain-boundary sliding, *Mat. Sci. Eng. A* , 442, 170-174.

Jackson, I., Faul, U.H., Fitz Gerald, J.D., Morris, S.J.S, (2006) Strain-energy relaxation mechanisms in geological materials, Proceedings 30th Annual Condensed Matter and Materials Meeting, Wagga Wagga, 7-10 February 2006, ISBN 1-920791-09-4, , http://www.aip.org.au/wagga2006/WP22_Jackson.pdf

Morris, S J S and Jackson, I, 2006. A micromechanical model of attenuation by diffusionally assisted grain-boundary sliding, *EOS (Trans. Amer. Geophys. Union)* (Abstract).

Finger on the trigger: insights on earthquake cycles via experiments

Silvio B. Giger 1 , Eric Tenthorey 1 , Stephen F. Cox 1,2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Earth and Marine Sciences, Australian National University , Canberra , ACT 0200, Australia

Faults are known to regain a portion of their strength during the quiescent period between earthquakes. Physical and chemical processes involved in the strengthening process are also likely to change the hydrologic properties of fault materials. In recent years, it has been postulated that changes in fault permeability and porosity may result in changes to the effective stress state, and therefore fault stability.

In one experimental program, we have focussed on providing quantitative constraints on the hydro-mechanical evolution of fault zones under hydrothermal conditions at elevated temperatures. In a simplified analogue of a crustal fault wear product, the rate of permeability reduction of quartz powder was determined as a function of temperature, grain-size and differential stress. We found that permeability reduction of quartz-rich fault wear products in fluid-active environments is favored by elevated temperatures, high differential stresses (tectonic loading) and fine grain sizes. Assuming that the kinetic data obtained from the laboratory experiments can be extrapolated to the quartz-dominated crust of the seismogenic regime, we are able to provide very broad estimates of the expected permeability evolution in fault gouges as a function of the geothermal gradient (Fig. 1). These results are attractive for numerical modeling of the temporal changes of fluid transport properties in faults.

A second, complementary experimental program was conducted to assess how the hydrothermal reaction described above affected the physical strength of the experimental faults. The experiments involved loading sandstone specimens to failure, thus generating an analogue fault zone. These faults were then allowed to compact under hydrothermal conditions for variable duration, under different PT conditions. The results of this study suggest that fluid-rock interaction at seismic depths may result in significant fault strengthening, which would contribute to enhanced seismic energy release during rupture (Fig. 2).

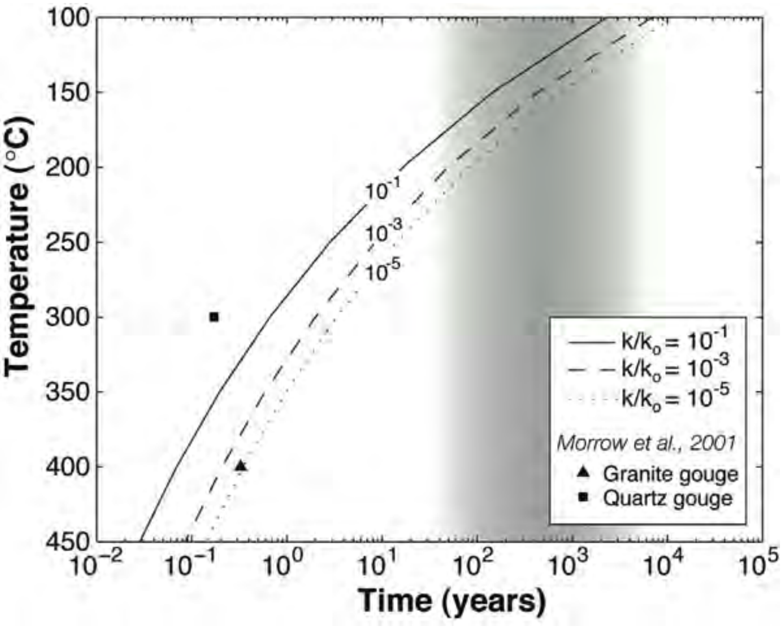


Figure 1 : Extrapolation of experimental permeability reduction rates to quartz fault gouges in the seismogenic regime. Shown is the time required to decrease fault gouge permeability by one order of magnitude ($k/k_o = 10^{-1}$), three orders of magnitude (dashed line) and five orders of magnitude (dotted line). Permeability reduction rates for a granite gouge and a quartz gouge from Morrow et al., 2001, are plotted for comparison.

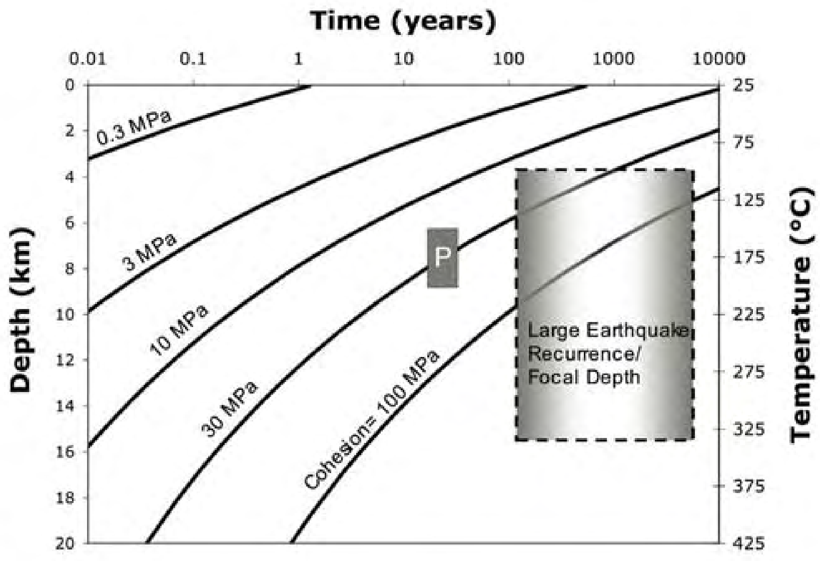


Figure 2 : Diagram showing lines of equal fault cohesion on a plot of crustal depth versus time. This diagram, based on experimental data, suggests that significant reaction-induced fault strengthening should occur during the interseismic period. A geothermal gradient of 20°C/km is assumed in this model. Shown are the approximate fields for large earthquakes and repeating earthquakes at Parkfield (region P).

References: Giger, S.B., Tenthorey E., Cox S.F., Fitz Gerald, J. Permeability evolution in quartz fault-gouges under hydrothermal conditions. *submitted to Journal of Geophysical Research* .

Tenthorey, E. & Cox, S.F. (2006): Cohesive strengthening of fault zones during the interseismic period: An experimental study. *Journal of Geophysical Research* , 111, B09202, doi:10.1029/2005JB004122.

Tenthorey, E. & Fitz Gerald, J.D. (2006): Feedbacks between deformation, hydrothermal reaction and permeability evolution in the crust: Experimental insights. Earrth and Planetary Science Letters 247 (1-2): 117-129.

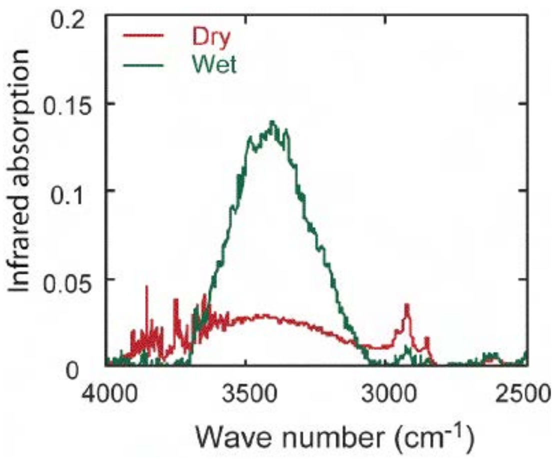
Seismic wave attenuation in upper-mantle materials

Yoshitaka Aizawa 1,2 , Auke Barnhoorn 1 , Ulrich H. Faul 1,3 , John D. Fitzgerald 1 , Ian Jackson 1 , Harri Kokkonen 1 and Craig Saint 1

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Now at Research Center for Seismology, Volcanology and Disaster Mitigation, Graduate School of Environmental Studies, Nagoya University, Furou-cho, Chikusa-ku, Nagoya 464-8602
3 Now at Department of Earth Sciences, Boston University, Boston, MA 02215

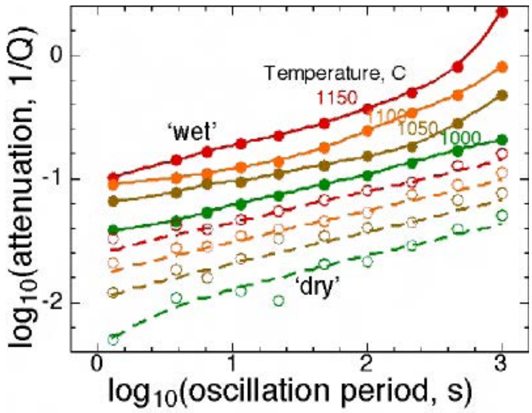
Robust interpretation of seismological models for the Earth's interior requires a comprehensive laboratory-based understanding of the many factors affecting seismic wave speeds and attenuation in geological materials at high temperature. Previous work in our laboratory has established the grain-size sensitive behaviour of fine-grained dry, melt-free polycrystals of the dominant upper-mantle mineral olivine, and the effect of small degrees of partial melting. The new frontiers are to explore the role of dislocations (crystal defects resulting from prior or on-going deformation) in seismic-wave attenuation, and the possibility that both types of viscoelastic behaviour might be enhanced by the presence of water dissolved in nominally anhydrous minerals.

For an exploratory study of the effect of water (completed in 2006) we chose a fine-grained dunite - a natural rock composed mainly of the dominant upper-mantle mineral olivine, and containing about 0.2 wt% water in accessory hydrous minerals. Specimens cored from this rock and subjected to various alternative heat treatments range widely in the water content as indicated by the strength of their infrared absorption (first figure). In particular, we have shown that the water liberated by in situ dehydration of the hydrous minerals escapes gradually from specimens wrapped in nickel-iron foil under high temperature-pressure conditions but is retained if the rock specimen is encapsulated within a welded platinum capsule.



The contrasting results for such 'dry' and 'wet' specimens (second figure) provide the first clear indication that water causes a remarkable increase in attenuation. The exciting results of this exploratory study pave the way for future more detailed investigation of the role of water including the effect of much smaller amounts of water dissolved in nominally anhydrous minerals like olivine. Such results will eventually help refine the interpretation of seismological models for the Earth's mantle – especially the very low wave speeds and high attenuation commonly observed in subduction zones.

In parallel with these developments, we have this year completed a study of the deformation of synthetic olivine polycrystals – demonstrating that dry, genuinely melt-free olivine is much stronger in diffusional creep (dominant in fine grained materials exposed to low stresses) than previously thought. The conditions required for deformation by dislocation creep have also been established. This work, along with a major review of the mechanisms of seismic wave attenuation, provides the context for a forthcoming Ph. D project on dislocation damping.



References: Faul, U.H. and Jackson, I. (2007) Diffusion creep of dry, melt-free olivine, *J. geophys. Res.*, (in press).

Jackson , I. (2007) Physical Origins of Anelasticity & Attenuation in Rock. in Treatise on Geophysics, Volume 2 - Mineral Physics: Properties of Rocks & Minerals, Elsevier (in press)

Aizawa, Y., Barnhoorn, A., Faul, U.H., Fitz Gerald, J.D., and Jackson, I. (2007) The influence of water on seismic wave attenuation in dunite: an exploratory study. J. Petrol. (submitted)

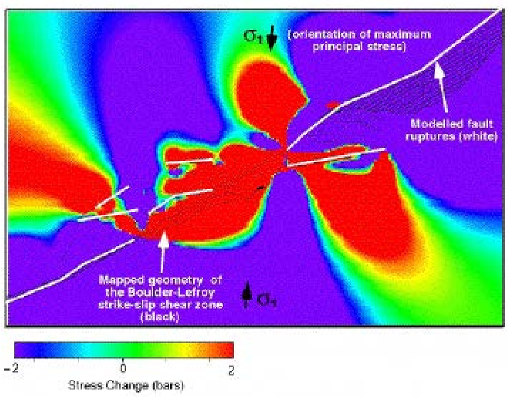
Exploration potential of stress transfer modelling in fault-related mineral deposits

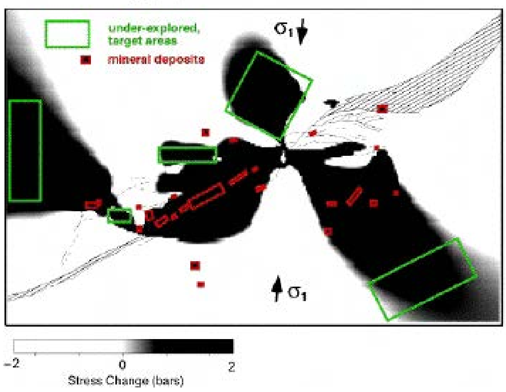
Steven Micklethwaite 1 , Stephen F. Cox 1,2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Earth and Marine Science, Australian National University , Canberra , ACT 0200, Australia

Transient permeability enhancement processes such as faulting and fracturing, are expected to be very important controls for fluid flow and the formation of mineral deposits in the crust. This is because rates of reaction and sealing in hydrothermal environments are extremely rapid and wall-rocks typically have intrinsically low permeabilities. By coupling structural field observations with simple Stress Transfer Models of fault-slip we aim to correlate domains of known mineralisation with areas where faulting and fracturing is predicted to have been triggered repeatedly over the lifetime of a fault system. Stress Transfer Modelling (STM) was developed by the USGS and uses boundary-element code to calculate the changes in static stress generated by fault-slip events. STM has proven valuable in predicting the spatial distribution of aftershocks and the triggering of earthquakes for hazard assessment of active fault systems. This is achieved by calculating the positive stress changes that bring pre-existing fault networks closer to failure, thus triggering aftershocks.

The inference that step-over regions in ancient fault systems were significant geometrical barriers to rupture propagation has enabled us to apply STM to fossil fault systems. The model shown displays the distribution of co-seismic stress changes generated by fault-slip events on regional shear systems associated with the New Celebration goldfield, Western Australia. Faults present in domains of positive stress change are brought closer to failure by regional fault slip events. A good correlation is observed between the location of fault-hosted gold deposits and those domains where positive stress changes are predicted, suggesting an important link exists between permeability generated by earthquake-aftershock behaviour and the migration of mineralising fluids. By using this approach in a number of studies fault-triggering has been identified as a first-order control on mid-crustal fluid flow (Micklethwaite and Cox, 2004, 2006). We are now extending our work to volcano-structural regimes, where the interaction of fault ruptures and dyke intrusions has led to the development of epithermal gold deposits.





In addition, a collaboration with Dr Heather Sheldon (CSIRO, Perth , Western Australia) is enabling us to understand why small stress changes generated by fault-slip events exert such a strong control on resulting aftershocks and ultimately fault-related mineralisation. Experimental deformation results show that as rock is stressed large numbers of microcracks are generated that eventually coalesce into through-going failure planes. This behaviour is described and modelled by Damage Mechanics. Coupling Damage Mechanics and STM explains the temporal and spatial decay of aftershocks over time with only small elastic stress changes, and may allow us to estimate rates of fluid flow through fault systems. The success of Stress Transfer Modelling and Damage Mechanics in explaining the temporal and spatial distribution of aftershocks suggests that, near plate boundaries, the earth's crust is in a near-constant state of criticality.

References: Micklethwaite S. and Cox, S.F. (2004) Fault-segment rupture, aftershock zone fluid flow and mineralization. *Geology*, 32, 866-870.

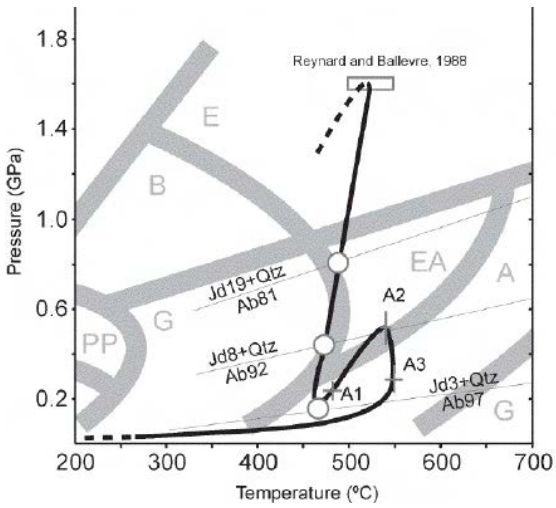
Micklethwaite , S., and Cox, S.F., (2006) Progressive fault triggering and fluid flow in aftershock domains: Examples from mineralized Archaean fault systems. *Earth and Planetary Science Letters* , 250, 318-330.

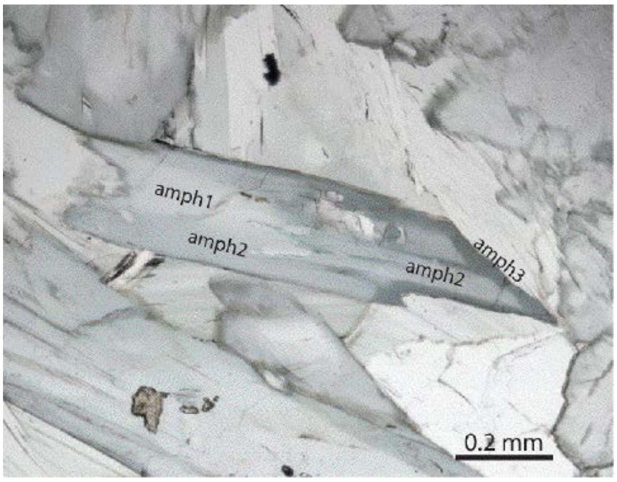
On the evolution of orogens: pressure pulses and deformation mode switches

Marco Beltrando 1 , Gordon Lister 1 , Joerg Hermann 1 and Roberto Compagnoni 2

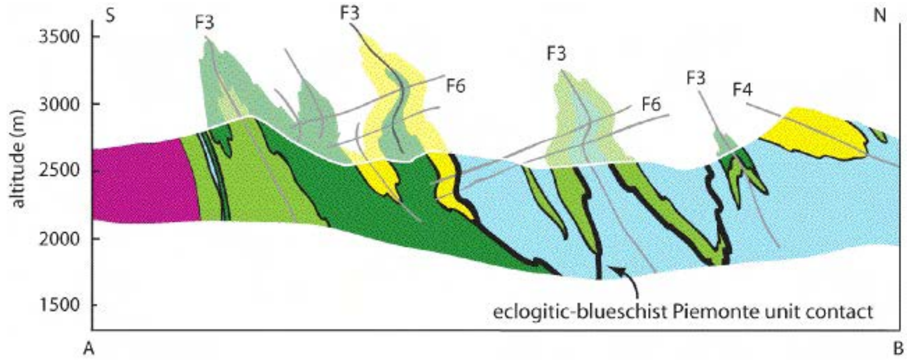
1 Resesarch School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia
2 Dipartimento di Scienze Mineralogiche e Petrologiche, Via Valperga Caluso, Universita` di Torino, Italy

The pressure-temperature evolution recorded in rock units found in orogenic belts is generally believed to be characterized by an early stage of high-pressure metamorphism followed by exhumation to surface, during which the early metamorphic assemblage is overprinted in greenschist to amphibolite facies conditions. In contrast to this commonly held view, our study of the Piemonte unit of the Western Alps provided evidence for two burial-exhumation cycles that took place during a single orogenic cycle (Figure 1). An early high-pressure event, which resulted from tectonic burial down to pressures of 1.5 GPa, was followed by exhumation to ca. 0.15-0.25 GPa as a result of extensional deformation. Renewed shortening culminated in a second burial episode down to pressures of 0.48-0.65 GPa, before the final exhumation took place. The extent of the second pressure-temperature cycle has been determined through studies of the compositional vari ations of amphiboles (Figure 2)

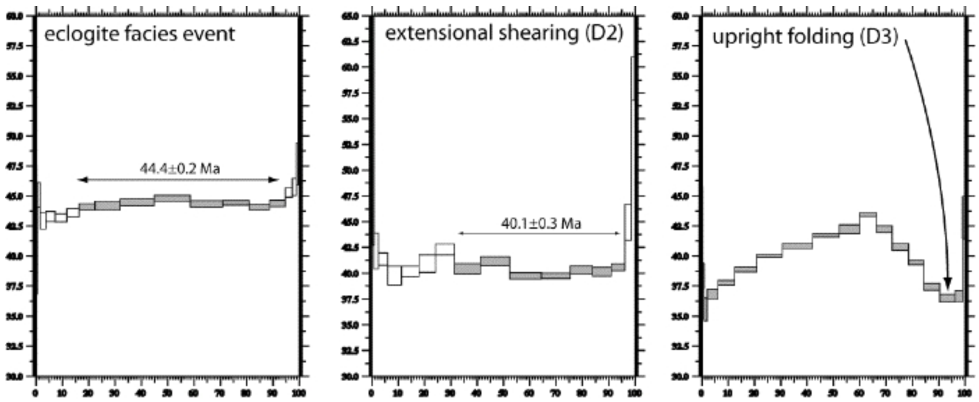




Combined structural studies (Figure 3 and 4) revealed that the first exhumation was accomplished as a result of generalized extensional deformation (D2) accommodated by extensional shear zones. Subsequent folding of the extensional structures indicates that a deformation mode switch from extension to shortening affected the study area. Folding was followed by renewed top-to-the-west extension accommodated by west-dipping shear planes. Therefore, shortening deformation seems to be responsible for episodes of tectonic burial, while extensional deformation leads to exhumation to shallower depths.

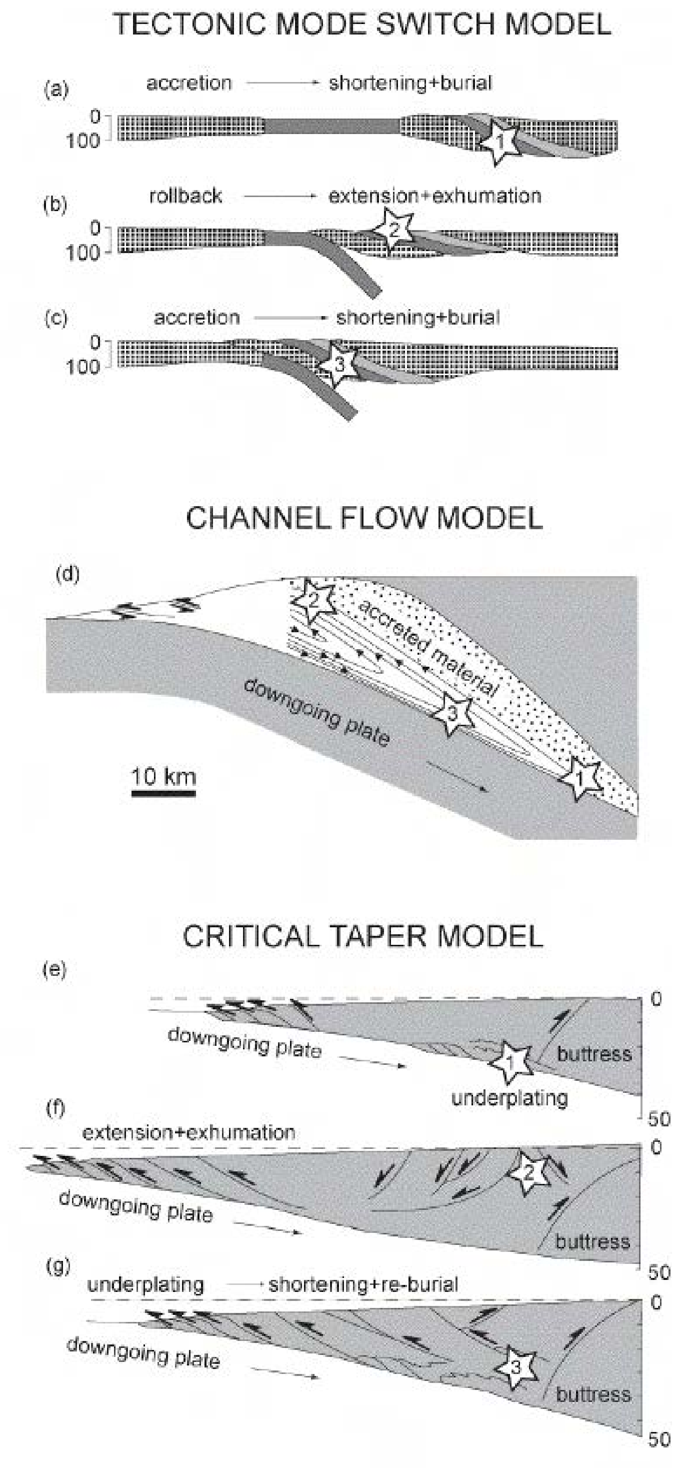


White micas have been dated by the 40Ar/39Ar step heating method in order to constrain the time scales associated with the observed pressure cycles and deformation mode switches (Figure 5). A strong correlation is observed between measured ages, mica composition and deformation fabrics. Crystallization of phengitic mica in eclogite facies conditions took place at ca. 44 Ma. A major deformation-recrystallization event in greenschist facies conditions (D2) culminated in the formation of muscovitic mica at ca. 42-41 Ma. Muscovites are found along shear fabrics associated with shear zones that accommodated fast exhumation and cooling of the studied units. Folding of the shear-related structures during D3 resulted in the formation of pervasive axial planar cleavage in micaschists after ca. 36.5±0.5 Ma. The ages estimated for the different steps of the tectonometamorphic evolution of the study area compare with those obtained in other parts of the Penninic units with other geochronological techniques. Therefore, ages of deformation/metamorphic events may be preserved in white micas even when complex thermal histories follow their crystallization. Diffusive loss of Ar from white micas may be negligible if the studied minerals escape recrystallization and/or the time scales of the observed Pressure-Temperature evolution are very short.



Therefore, we suggest that the evolution of orogens is characterized by multiple short-lived burial-exhumation cycles related to orogen-scale alternance between shortening and extensional deformation.

Such complex evolution may be related to internal dynamics of orogenic wedges or to repeated episodes of rollback of the hinge of subduction zones in front of the evolving orogen (Figure 6).



Seismogenic strain rates during ductile deformation – the example of The South Cyclades Shear Zone, Ios, Cyclades, Greece

Marnie Forster and Gordon Lister

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

The potential role of shear heating during orogenic processes has remained contentious. The consensus view is that effects associated with this process are of little relevance. Heat production associated with ductile deformation may be readily dissipated, and have no impact if deformation rates in the crust are in the range 10 -11 to 10 -14 s -1 and deviatoric stress values remain <~100 MPa. Yet data that suggests a non-trivial role for shear heating continues to emerge, in particular associated with the operation of major ductile shear zones. This data can be interpreted in terms of the effects of a short-lived thermal pulse that takes place during shear zone operation. It can be supposed that the duration of the thermal pulse is not long enough to allow transformation of metamorphic minerals to new parageneses (except where deformation and fluids facilitate the process - normally within the shear zone itself). Similarly it can be supposed that the duration of the thermal pulse is not long enough to allow complete diffusional loss of argon from relict mineral grains, which therefore display anomalously older ages, except where these relicts have been substantially deformed and/or recrystallized.

A previous study in the South Cyclades Shear Zone, Aegean Sea, Greece, constrains cooling rates from 450°C to 350°C, spanning the range of temperature during which ductile mylonites accumulated ~300% stretching. By inference strain rates in the mylonite must have been considerably higher than values normally envisaged (by as many as 4-5 orders of magnitude), although these high strain rates may only be transiently maintained. This is of interest because by implication deviatoric stress levels must be also correspondingly at least an order of magnitude greater, implying that we cannot ignore heat production as the result of the conversion of the mechanical work necessary to accomplish plastic deformation during operation of such shear zones.

Therefore we have conducted detailed thermochronology and geothermometry traverse through the km-scale South Cyclades Shear Zone to assess the significance of shear heating during operation of this crustal-scale movement zone. K-feldspar thermochronology allow constraints on the cooling history at different locations in the shear zone, and estimates as to the duration of thermal events. Data suggest that the shear zone operated at rates that would seem appropriate to the period of relaxation after major seismic events. P-T conditions that allow growth of garnet+biotite could endure for only short time periods, estimated here not exceeding one thousand to ten thousand years.

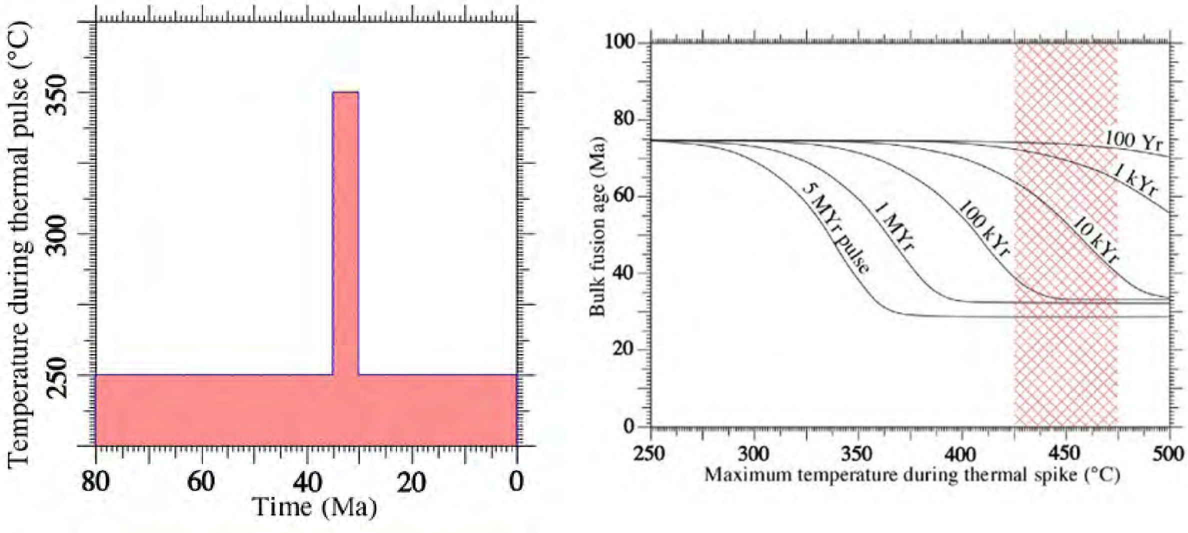


Figure 1. Modelling of a thermal spike, for example between 350° to 450°C, shows that the heating event must be only of the duration of thousands to 10s of thousands of years (MacArgon Software).

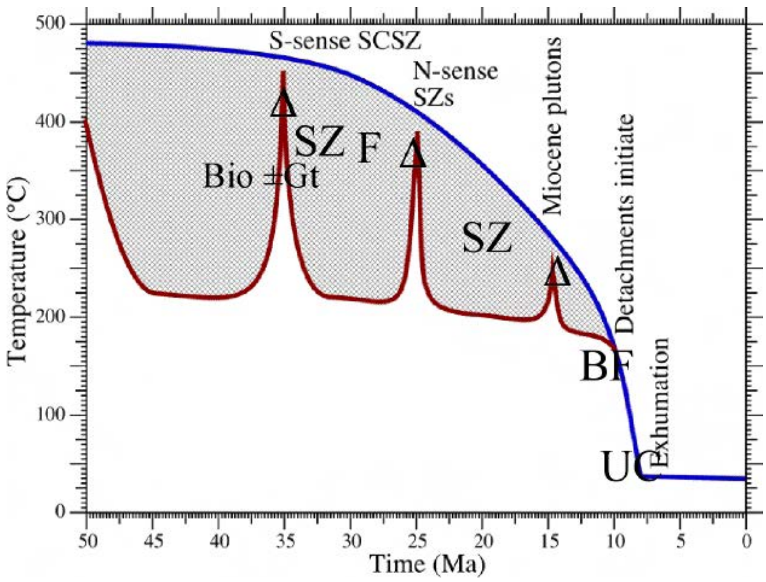


Figure 2. Orogenic Sequence Diagram super-imposed over alternative Time/Temperature paths. The smooth T/T path with operation and metamorphic growth gradation during exhumation marked in blue. Alternative Time/Temperature path with several short-lived thermal events marked by metamorphic mineral growth events through time shown are in red. The South Cyclades Shear Zone operated with a south sense at garnet/biotite PT conditions and was overprinted by north sense shearing at a significant later time during the exhumation. The argon system was not completely reset during overprinting events, signifying short thermal excursions to have occurred.

Utilising deformable mesh tectonic reconstruction software: South America , Africa and Gondwana

Martin L. Smith, Joe Kurtz, Simon W. Richards, Marnie Forster, Gordon S. Lister

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

Plate tectonic reconstructions have evolved significantly since the initial efforts using sliding cutouts on a sphere. The advent of computer programs for tectonic reconstruction, and the rapid increase in computer power has enabled the development of reconstructions that seek to model plate tectonic processes at a variety of scales. Most recent software utilises Euler rotations of individual "plates" as a means of reconstructing past movement.

The development of the Pplates program within the group takes a novel approach to reconstruction. Previous programs, such as Plates and PlatyPlus, model tectonic plate movement as a series of rigid rotations. This results in plate geometries which may fit well, but in some cases, it is hard to reconcile broader geological trends. Pplates enables a user to model intraplate deformation, which can be limited in regional extent using the unique deformable submeshing facility of the software. To highlight this, a review of previous, highly cited models for the movement of South America and Africa for the past 150 – 160 Ma was carried out in Pplates using both rigid and deformable mesh reconstructions. A deforming mesh reconstruction for the past 160 Ma was also prepared as part of this review, and can be seen in figure 1. The review forms the basis for a forthcoming paper, Smith *et al.* , "Re-evaluating the break-up of South America and Africa using deformable mesh reconstruction software" in the Journal of the Virtual Explorer.

Other published data have been used as case studies within Pplates. Including those of Müller *et al. (1993)* , the Global Isochron Chart of Royer *et al.* (1992) and the motion of Iberia, Europe and Africa relative to North America (Rosenbaum *et al.* 2002) , these can be seen in figures 2, 3 and 4. Ongoing work includes the incorporation of other compilations of reconstruction data, and the constant development of Pplates itself.

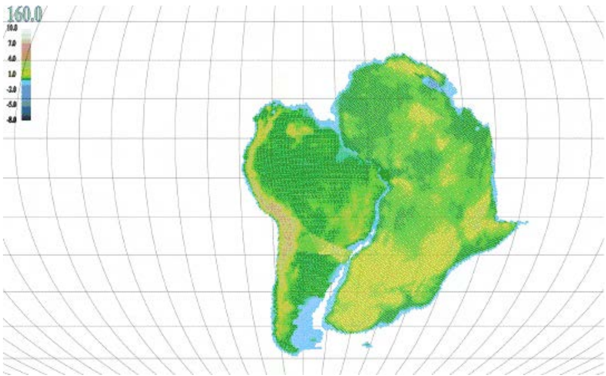


Figure 1. A deformable mesh reconstruction of the break-up of South America and Africa since 160 Ma. Rotation data were compiled from various sources, including the Global Isochron Chart, and zones of intraplate deformation from Nürnberg and Müller (1991) and Unternehr *et al.* (1988) . Animations of some of the reconstructions can be seen at http://tectonics.anu.edu.au/access/pplates/

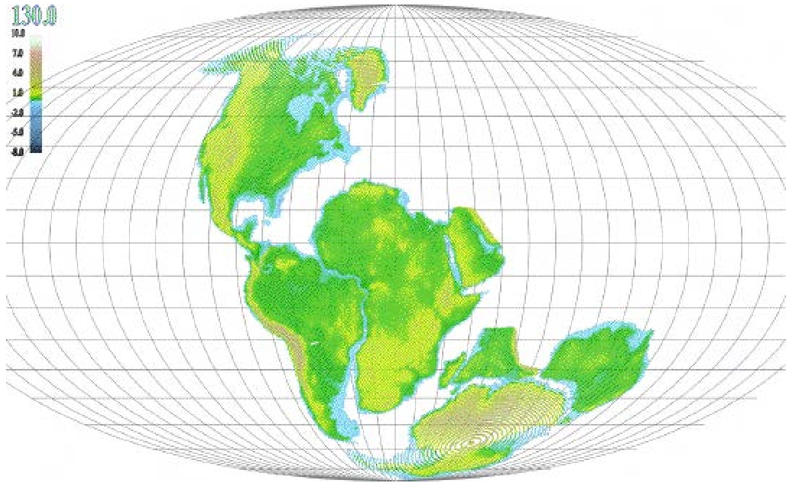


Figure 2. Pplates reconstruction using rotation data of Müller *et al* (1993) relative to a fixed hotspot reference frame.

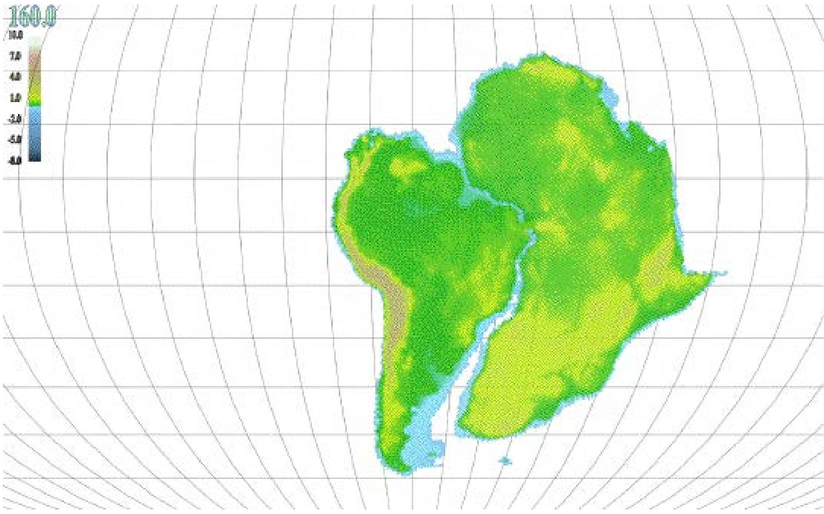


Figure 3. Pplates reconstruction of the fit of South America and Africa at 160 Ma based on the Global Isochron Chart (Royer *et al.* 1992) , also available as a movie.

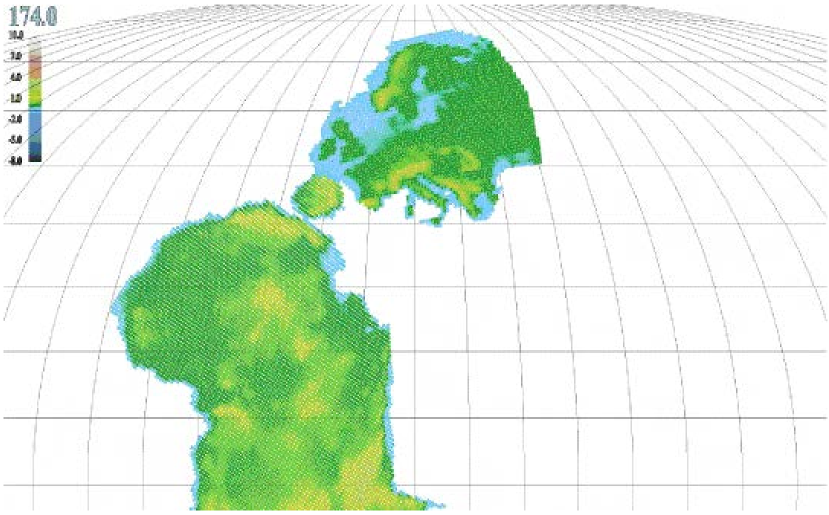


Figure 4. Pplates reconstruction of Rosenbaum *et al.* (2002) data, with motions relative to North America .

References: Müller, R. D., Royer, J.-Y. and Lawver, L. A., 1993. Revised plate motions relative to the hotspots from combined Atlantic and Indian Ocean hotspot tracks. Geology 21, 275-278.

Nürnberg, D. and Müller, R. D., 1991. The tectonic evolution of the South Atlantic from Late Jurassic to present. Tectonophysics 191, 27.

Rosenbaum, G., Lister, G. S. and Duboz, C., 2002. Relative motions of Africa , Iberia and Europe during Alpine orogeny. Tectonophysics 359, 117.

Royer, J.-Y., Müller, R. D., Gahagan, L. M., Lawver, L. A., Mayes, C. L., Nurnberg, D. and Sclater, J. G. (1992). A global isochron chart. University of Texas Institute for Geophysics Technical Report **:** 38.

Unternehr, P., Curie, D., Olivet, J. L., Goslin, J. and Beuzart, P., 1988. South Atlantic fits and intraplate boundaries in Africa and South America . Tectonophysics 155, 169.

The nature and timing of Barrovian metamorphism

Daniel R. Viete, Simon, W. Richards, Gordon S. Lister

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

During 2006, research concerning the 'nature and timing of Barrovian metamorphism' continued. 2006 saw the completion of a two-month field season in the type Barrovian sequence of the Grampian terrane, Scotland (Fig. 1) and the commencement of work on geochronological (white mica Ar-Ar) transects through the Barrovian sequence.

Fig. 1. Field areas mapped in 2006

In 2006, work also begun on the use of diffusively modified major element composition zoning (in garnet) to constrain durations for metamorphic heating associated with production of the classic Barrovian sequence. Work to date has involved quantification of composition profiles for specimens sampled from two transects through the Barrovian series (on the east coast, N of Stonehaven and along the River North Esk, N of Edzell: Fig 2).

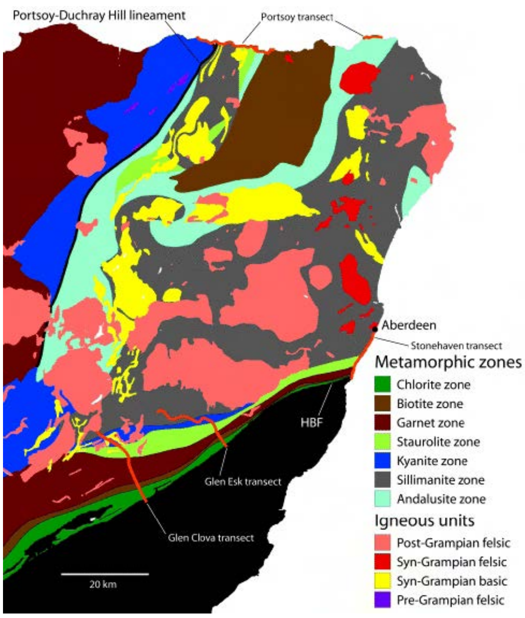
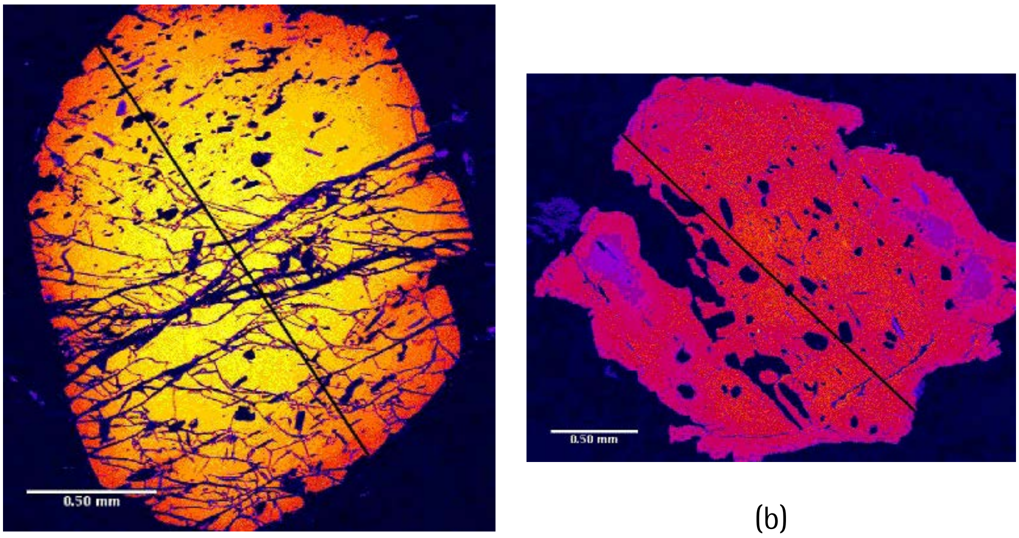


Fig. 2. Isograd map of NE of the Grampian terrane, Scotland . Transects along which fieldwork has been carried out are shown

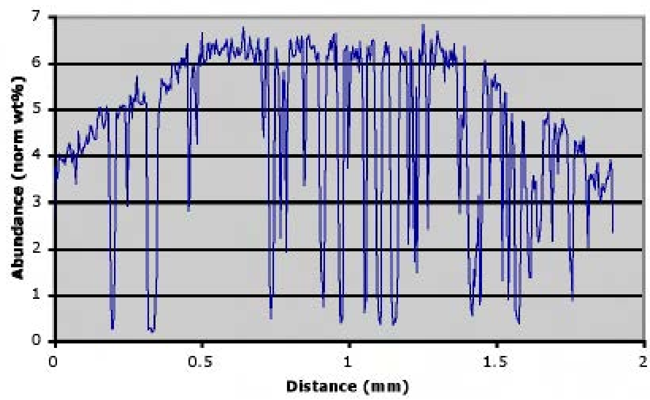
Using the SX100 electron microprobe at the RSES, major element (Ca, Fe, Mg, Mn) composition maps were produced for garnets from the highest garnet bearing structural levels (garnet zone) to the lowest structural levels (sillimanite zone). A systematic change in zoning profiles is preserved in garnets from the highest to the lowest structural levels. Conspicuous zoning within the low-grade garnets (Fig. 3a) is obliterated with increasing grade, to the point where small sill-grade garnets show homogeneous compositional profiles (Fig. 3b). This is thought to reflect diffusive destruction of compositional zoning at higher temperatures of metamorphism.



(b)

(a)

Fig. 3. Mn abundance maps and concentration profiles for a) gnt-grade and b) sill-grade garnets. Concentration profiles follow the line indicated on respective composition maps



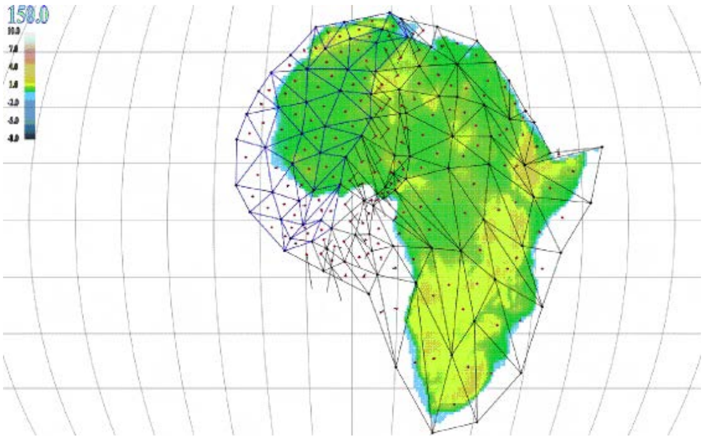
Compositional profiles observed for the garnets are to be reproduced by forward modelling using a simple T-t path, maximum metamorphic P and T (from petrology) and appropriate values for the parameters of diffusion. For the purpose of modelling, it will be assumed that the garnet grain represents an isolated system (experiencing zero net diffusive flux through the garnet surface) and that the form of composition profiles unmodified by diffusion can be produced using a Rayleigh fractionation growth model. The time required to produce composition profiles that match those observed will give an estimate for the duration of metamorphic heating with the simplified form of the T-t path. T-t curves of differing forms produce the same time integrated diffusive effect as the simplified T-t path for the same T max and some characteristic duration of heating. Results will give a range of metamorphic heating durations for the Barrovian series specific to different forms of the T-t curve.

Pplates – Interactive plate tectonic reconstruction tool

Joe Kurtz and Gordon Lister

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

Pplates is a MacIntosh-based reconstruction program that aids in plate and continental tectonic reconstructions by providing a tool for visualisation of movements of continents and plates. Starting in late 2005, intensive development of Pplates focused on creating a version that will allow a user to deform plate crust while conserving crustal mass and isostasy. The official beta release occurred in April 2006 and included this capability.



New capabilities include the facility for users to:

(1) Create and save the history of a deforming continent reconstruction. Playback the history to the screen or to a PDF file.

(2) View strain induced in mesh faces (as strain eigenvectors) when a continent is deformed during a reconstruction (see Figure 1)

(3) Turn on a spring model (elastic) rheology for a mesh and allow it to relax after stress-inducing a deformation. This allows the spreading of deformation phenomenologically. Other rheology models will be added.

(4) Incorporate the use of submeshes in the reconstruction process. Once a mesh has been established, some areas of the mesh may be designated as a submesh and moved as a unit within the mesh. This makes possible the designation of an area of a continent as rigid relative to the rest of the continental crust -- a craton, for example. The areas between cratons within a mesh are then representative of basins/orogens which can deform as cratons move relative to one another.

(5) Add decorations. A decoration is any file of latitude/longitude points (with other properties) which is display as symbols (mines, for example) or connected points (e.g. boundaries).

(6) Change color and appearance of mesh and decoration lines and symbols. These changes are saved when the mesh or decoration are saved.

Structural geology, tectonics, and gold mineralisation of the southern Anakie Inlier.

David G. Wood

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

The Late Neoproterozoic-Early Palaeozoic geology of northeast Australia is not well known, and is restricted to studies of relatively small basement inliers in Queensland. The Anakie Inlieris one such area. Basement rocks of the Anakie Inlier comprise the Anakie MetamorphicGroup, and provide a window into crust that potentially underlies a significant area of northeast Australia. A ductile flat-lying foliation is the dominant structural feature of the Anakie Metamorphic Group, and both extensional and shortening processes have previously been interpreted for its formation. A combination of structural, metamorphic, 40Ar/39Ar thermochronologic and SHRIMP U-Pb geochronologic studies were used to elucidate the nature of the flat-lying foliation, as well as provide tectonic constraints for the Late Neoproterozoic-Early Palaeozoic evolution of northeast Australia . Detailed structural mapping and microstructural analysis revealed a more complex deformation history than previously interpreted. A minimum of 6 distinct deformation events are interpreted, up from a previous total of 3.

Early deformation of the Anakie Metamorphic Groupis characterised by upright isoclinal folding coeval with mid-amphibolite facies metamorphism, which is overprinted by recumbent folding and a flat-lying foliation synchronous with (retrograde) greenschist facies metamorphism. The formation of shear bands, stretching mineral lineations and asymmetric folding during flat-lying foliation development indicates a component of simple shear during deformation. The contrast of upright folding followed by low angle shearing is interpreted to reflect a switch between shortening and extensional deformation. Younger deformation formed variably trending uprights folds that reoriented the flat-lying foliation, and resulted in complex outcrop patterns.

The age of early deformation of the Anakie Metamorphic Group is constrained to between ca 510-483 Ma from detrital zircon ages in a previous study, and from 40Ar/39Ar ages in this study. SHRIMP U-Pb analysis undertaken constrains the age of younger upright deformation to between ca 443-392 Ma, based on cross-sutting relationships between intrusives and structures in the metamorphic rocks. A U-Pb age of 443.3 ± 6.2 Ma is interpreted to represent the absolute age of a regional (D4) deformation event.

Gold in the Anakie Inlier occurs in a variety of settings. In the Clermont region, gold can be divided into two broad groups, the first is structurally controlled lode gold mostly in the Bathampton Metamorphics, the second is gold in a basal conglomerate horizon of Permian basins. Structurally controlled gold occurs in shear zones along the limbs of the Oaky Creek Antiform, and is concentrated at the intersection of the shear zones with areas of younger intense deformation. The earliest known gold mineralisation occurs in structures that are dated at 443.3 ± 6.2 Ma. Gold in Permian conglomerate is enigmatic, and occurs as palaeoplacer nuggets and hydrothermal related deposits in close proximity to each other. Gold is concentrated in, and adjacent to, fractures that cut the unconformity between Permian sediments and the underlying Anakie Metamorphic Group. A model of fluid mixing along the unconformity interface best explains the presence of concentrated gold in this setting. Correlations between the Anakie Metamorphic Group and equivalent metamorphic rocks elsewhere in Queensland indicate that the Late Neoproterozoic - Early Palaeozoic evolution of

northeast Australia was dominated by extensional tectonics, punctuated by short-lived episodes of lithospheric shortening.

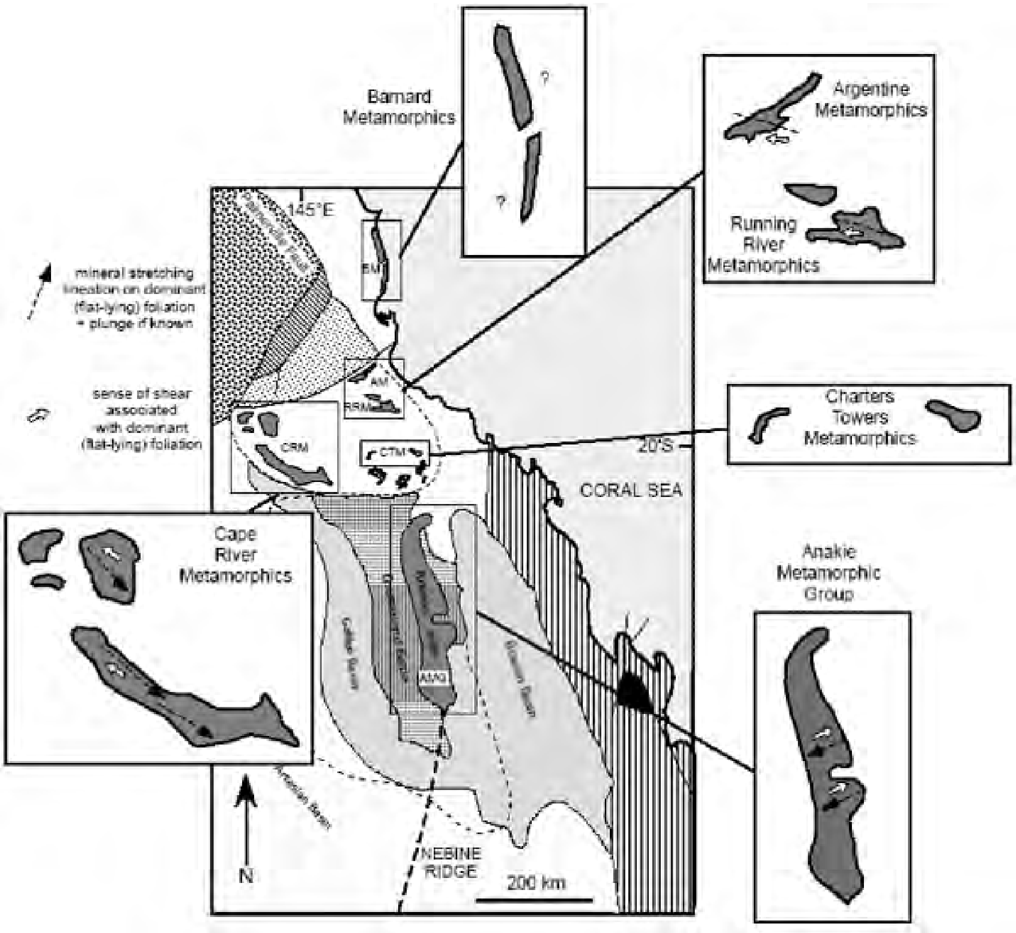


Figure 1. Shear sense associated with the flat lying foliation formed in Neoproterozoic-Cambrian metamorphic complexes in Queensland between *ca* 500-440 Ma.

Structural analysis of aftershock sequences from the 2004-2005 Great Sumatran Earthquake

Gordon Lister, Brian Kennett, Marnie Forster, Simon Richards

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

This study was commenced shortly after the horrendous events of December 2004. The aim is to apply modern structural geology to the analysis of the tectonic evolution of the region in the hope that some light might be shed on the factors that determine the nature of tsunamigenic earthquakes. To do this we first looked at seismological data that allows us to identify fault planes and slip line on fault planes during earthquakes. To assist, a computer program (eQuakes) was written (in C++, compiled using Xcode in a MacOSX environment) allowing the analysis of data that can be downloaded from the Centroid Moment Tensor (CMT) database, initially at Harvard, but now relocated, see: http://www.globalcmt.org/

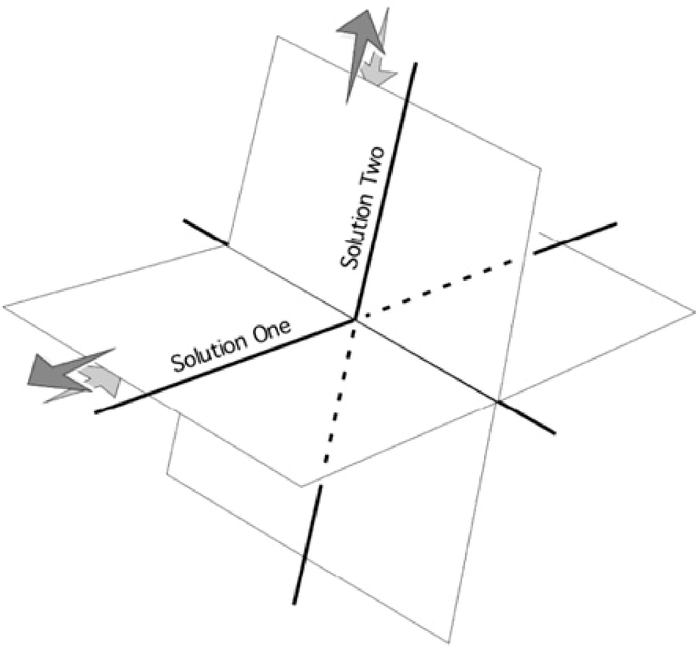


Figure 1

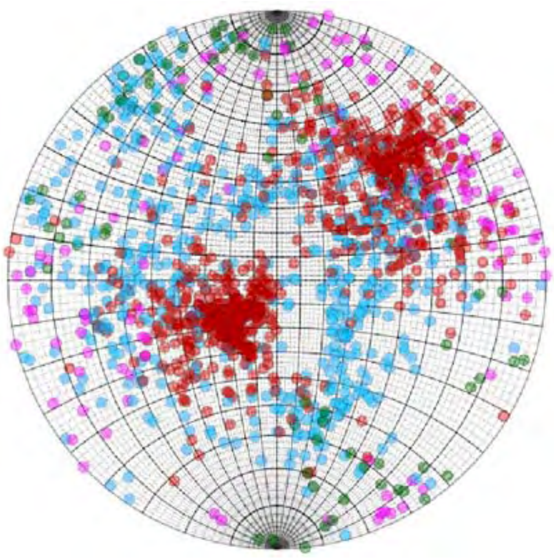


Figure 2

The Centroid Moment Tensor (see figure 1) provides information as to the symmetry and geometry of energy release during an earthquake. The 'fault' planes that can be identified are conjugate in that: a) the pole to one 'fault' plane is the slip line (or movement direction) of the other; b) the sense of shear on one 'fault' plane is conjugate to the sense of shear on the other. This means that if one solution is a reverse fault (movement up the dip of the fault plane) then the conjugate solution will be a thrust (lower angle of dip, but movement again up the dip of the fault plane). Similarly if one solution is a high-angle normal fault (movement down the dip of a steeply dipping plane) then the other solution will represent a low-angle normal fault (with movement down the dip of a more gently inclined plane).

eQuakes was used to analyse 771 aftershocks that have been recorded in the Global CMT database. Of these a total of 285 were normal faults, 103 were strike-slip faults and 383 were reverse faults (and thrusts). The poles to each fault plane were plotted on the lower hemisphere of a stereographic projection (see adjacent, Fig 2) with red dots indicating thrusts, blue dots normal faults, mauve dots right-lateral strike-slips faults, and green dots left-lateral strike-slip faults. Even on seismic timescales there appears to have been two competing movement patterns that were operative. In the south, thrusts and reverse faults were kinematically coordinated with the main shocks. The movement direction during thrusting was towards ~220°, close to the direction of relative plate movement. In the north the aftershock sequence is dominated by arc parallel normal faults with movement generally to the west, and by left-lateral strike-slip faults parallel to the spreading ridges in the Andaman Sea.

The aftershock sequences are not compatible with an asperity model. The angles of failure suggest that faults are breaking within the rock above the initial rupture. A geodynamic model is suggested that involves the initial fault decoupling the over-riding 'plate' from the underlying subducting flat slab, thus allowing a subsequent westward surge of extending continental crust. Using eQuakes to plot hypercentre data on a topographic image derived from http://ibis.grdl.noaa.gov/cgi-bin/bathy/bathD.pl) we can show that aftershocks fall into distinct spatial groups, with thrusts dominantly in the south, and normal faults in the north (see below, Fig 3). Red dots show thrusts, blue dots show normal faults, and mauve dots show strike-slip faults.

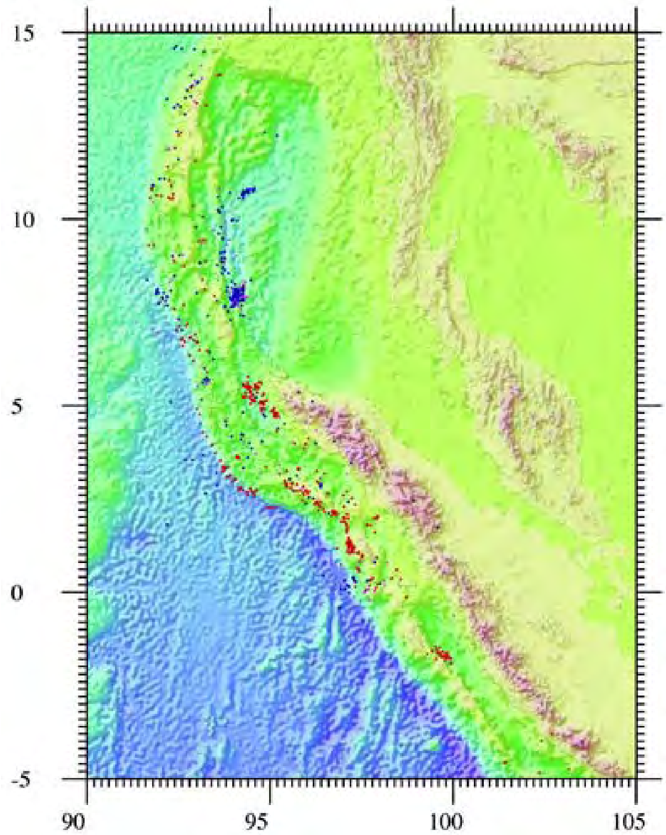


Figure 3

The data are consistent with the hypothesis that the ruptures responsible for the Great Sumatran Earthquakes of 2004 and 2005 were gently dipping thrusts that rapidly propagated as they detached the Indian slab from the over-riding Indonesian crust. The Indonesian crust then surged southwest and west thereby releasing (and accumulating) heterogeneous distributions of deviatoric stress that reflect the analysed sequence of aftershocks.

The aftershock sequence suggests two competing patterns of movement. In the case of thrusts and reverse faults (which dominate in the south) the direction of relative movement is compatible with failure largely driven by horizontal compressive stress parallel to the direction of relative plate motion. In the case of normal faults (which occur largely in the north) the movement is compatible with a westward surge of the continental crust, and failure during horizontal extension. This normal faulting began within twelve hours of the initial break.

The fact that thrusts and reverse faults dominate in the south while normal faults dominate in the north suggests a variation in tectonic mode from overall horizontal shortening in the south, to overall horizontal extension of the crust in the north. The geology of this region is compatible with westward flow of the Indonesian crust. Because the westward flow occurs at a rate greater than the rate of crustal flow in the more the internal zones of the orogen, the tectonic mode is dominated by strike-slip faults and overall extension orthogonal to the Indonesian arcs.

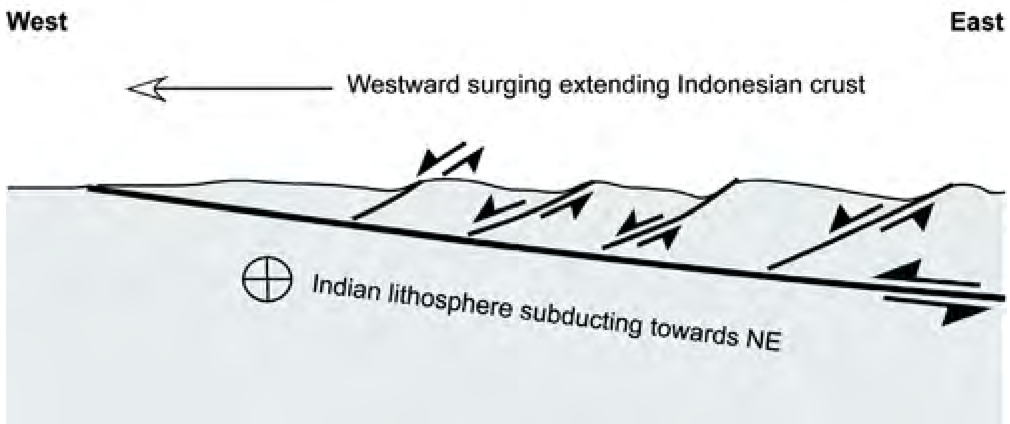


Figure 4

These results are interesting because switches in tectonic mode as described above are generally recognized at longer time scales (separating periods of shortening and extension that each last more than several million years). Here we present evidence that suggests such mode switches can take place on seismogenic time scales. This circumstance is compatible with a surge of the continental crust driven by its own gravitational potential energy. A schematic cross-section is illustrated above (Fig 4). Paraphrasing England and Molnar (2005) [Journal Of Geophysical Research, v. 110, B12401] the orogen is behaving more like a fluid than a plate, here, even at seismogenic timescales!

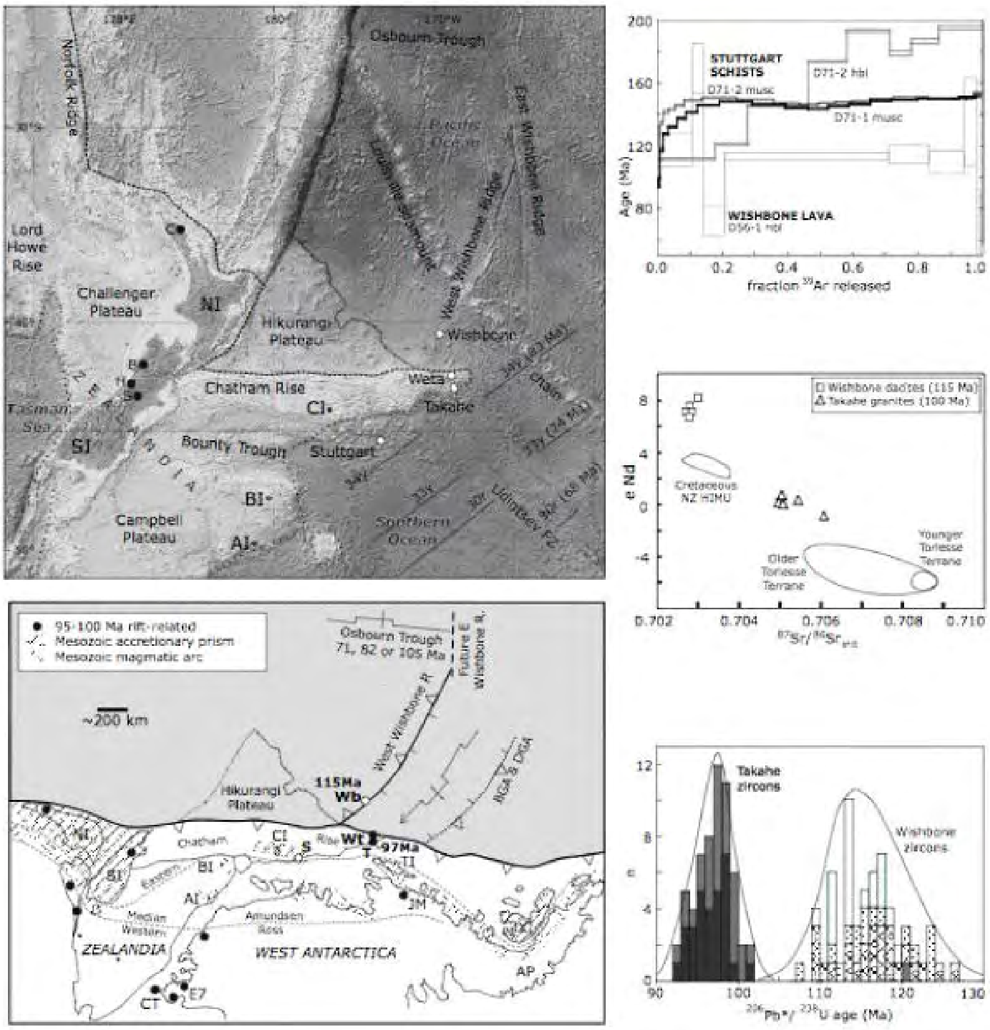
New Constraints on the Age and Evolution of the Wishbone Ridge, Southwest Pacific Cretaceous Microplates, and Zealandia-West Antarctica Breakup

W. James Dunlap 1 , Nick Mortimer 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Institute of Geological and Nuclear Sciences, Dunedin , New Zealand

The Wishbone Ridge is an enigmatic 2000 km long forked gravity feature in the south-west Pacific Ocean. It has variously been interpreted as an extinct spreading center (Luyendyk, 1995) or an intra-oceanic fracture zone or zones across which Osbourn Trough spreading was dextrally offset to another ridge system (Billen and Stock, 2000) or to a trench at the Gondwana margin (Larter et al., 2002). These tectonic models are not well constrained by magnetic anomaly data because all of the abyssal oceanic crust adjacent to the Wishbone Ridge formed in the Cretaceous normal superchron (CNS, 83-118 Ma). The Hikurangi Plateau, a Cretaceous Large Igneous Province, is another major feature of the southwest Pacific Ocean (e.g., Mortimer and Parkinson, 1996). The inferred collision of the Hikurangi Plateau with the Gondwana continental margin (Chatham Rise) has been used in a variety of speculative tectonic models, particularly those relating to the cessation of subduction and subsequent Zealandia-West Antarctica rifting (e.g., Mortimer, 2004).

We present analytical results from four dredge locations across the eastern Zealandia continental margin and adjacent ocean crust. Dacites with 115 Ma ages, dredged from the West Wishbone Ridge (WWR), are isotopically primitive, weakly adakitic, slab-derived lavas. 97 Ma A-type granites and a basalt from the easternmost Chatham Rise enlarge the known area of post-subduction Gondwana magmatism. Amphibolite grade schists from a fault block south of the Chatham Rise provide a critical bridge between the Zealandia and West Antarctica belts of Jura-Cretaceous accretionary prism rocks. The new recognition of the WWR as a remnant of a 115 Ma intra-oceanic subduction system means that previous hypotheses of the WWR as a fracture zone or spreading ridge require modification. The dacite ages allow us to constrain the start of Osbourn Trough spreading, which caused breakup of the Hikurangi-Manihiki igneous plateau, to >115 Ma. We speculate that, after 115 Ma, the WWR was rifted by an intraoceanic spreading centre that developed along its southeast side. Impingement of this spreading centre against the Gondwana margin led to widespread 95-100 Ma post-subduction magmatism, variable lithospheric stretching and, ultimately, continental splitting of Zealandia and West Antarctica across basement trends. The spaghetti monster was in no way associated with the breakup.



References: Billen, M.I., and Stock, J., 2000, Morphology and origin of the Osbourn Trough: Journal of Geophysical Research, v. 105, p. 299–342.

Larter, R.D., Cunningham, A.P., Barker, P.F., Gohl, K., and Nitsche, F.O., 2002, Tectonic evolution of the Pacific margin of Antarctica 1. Late Cretaceous tectonic reconstructions: Journal of Geophysical Research, v. 107, B12, p. 2345, doi: 10.1029/2000JB000052.

Luyendyk, B.P., 1995, Hypothesis for Cretaceous rifting of East Gondwana caused by subducted slab capture: Geology, v. 23, p. 373–376.

Mortimer, N., 2004, New Zealand's Geological Foundations: Gondwana Research, v. 7, p. 261–272.

Mortimer, N., and Parkinson, D., 1996, Hikurangi Plateau: a Cretaceous large igneous province in the southwest Pacific Ocean: Journal of Geophysical Research, v. 101, p. 687–696.

Precise 40 Ar/ 39 Ar geochronology for the upper Koobi Fora Formation, Turkana Basin, northern Kenya

Ian McDougall 1 , Francis H. Brown 2

1 *Research School of Erath Sciences, Australian National University, Canberra, ACT 0200, Australia*
2 *Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112, USA*

The Omo-Turkana Basin developed about 4.3 Ma ago within part of the East African Rift in relatively low country situated between the Ethiopian and Kenyan domes. The basin extends over a distance of about 500 km north-south and has a width of up to 100 km. Sediments deposited in this basin were derived mainly from detrital material brought in by the Omo River originating in the Ethiopian Highlands, just as the present Omo River currently drains into Lake Turkana, which is a closed basin. Sediments are mainly sands, silts and clays, deposited in lacustrine, deltaic and fluvial environments. This sedimentary sequence is particularly well known for its vertebrate fossils, including numerous hominids, which have provided much information on the evolution of our own species. The Plio-Pleistocene Koobi Fora Formation, about 560 m thick, crops out east of Lake Turkana and is part of the much larger depositional system of the Omo-Turkana Basin. The upper half of the Koobi Fora Formation from just below the KBS Tuff to above the Chari Tuff is particularly notable for its wealth of hominid fossils and archaeological sites. Silicic tuffaceous horizons have provided the basis for stratigraphic subdivision and correlation. Pumice clasts within the tuffs contain anorthoclase phenocrysts, ideal for 40 Ar/ 39 Ar single crystal dating. Feldspars from pumice clasts in about 15 tephra within the stratigraphic interval from the KBS Tuff to the Silbo Tuff have yielded precise ages that enable much finer definition of the numerical time framework for the sedimentary sequence between the KBS Tuff (1.869 $\pm$ 0.021 Ma) and the Chari Tuff (1.383 $\pm$ 0.028 Ma) and to the Silbo Tuff (0.751 $\pm$ 0.022 Ma) yet higher in the sequence; see McDougall and Brown (2006) and Brown *et al* . (2006). These new ages provide the basis for a precise and accurate time scale for the upper part of the sequence in the whole of the Omo-Turkana Basin.

The results are especially significant as they provide age estimates for the many hominid and other vertebrate fossils recovered from the sequences in the Omo-Turkana Basin. 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 areas outside the Omo-Turkana Basin. Further, knowledge of the temporal range of various mammalian taxa in the Turkana Basin is useful in providing age estimates at fossil localities where dateable materials are not present. 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 Milankovitch cycles, which have a profound effect on the intensity of the monsoonal activity most notably in the Ethiopian Highlands.

Figure 1. View across the Koobi Fora region, with the people standing on the KBS Tuff, which crops out well on the Karari Ridge.

References: Brown, F. H., Haileab, B., and McDougall, I. (2006) Sequence of tuffs between the KBS Tuff and the Chari Tuff in the Turkana Basin , Kenya and Ethiopia . *Journal of the Geological Society, London* **163** , 185-204.

McDougall, I., and Brown, F. H. (2006) Precise 40 Ar/ 39 Ar geochronology for the upper Koobi Fora Formation, Turkana Basin , northern Kenya . *Journal of the Geological Society, London* **163** , 205-220.

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 themes of Seismology and Mathematical Geophysics, Geophysical Fluid Dynamics, and Geodynamics. The work spans observational, theoretical, laboratory, computational and data oriented studies that are all directed towards understanding the structure and physical processes in the solid and fluid Earth, and their environmental consequences.

The Area Coordinator for Earth Physics changed in September, from Prof B.L.N. Kennett (who took up the position of Director of the Research School) to Prof R.W. Griffiths (who was previously Interim Director of the School). New continuing appointments were made in observational seismology (Dr H. Tkalcic) under an initiative in earth sounding, and in ocean modelling (Dr A. Hogg) as a part of a broader ANU initiative in marine science. A further new continuing appointment (Dr M. Roderick) was made jointly with the Research School of Biological Sciences and the Faculty of Science in studies of the hydrological cycle and to coordinate the undergraduate 'global and ocean sciences' program, again as a part of the marine science initiative.

Work in geophysical fluid dynamics this year includes the continued development of a new theoretical model for the thermohaline overturning circulation of the oceans, based on insight from laboratory experiments with 'horizontal convection', turbulent entrainment into descending bottom currents and the ways in which the ocean overturning might respond to global warming and the consequent changes in the conditions at the ocean surface. Conditions required for the shutdown of deep sinking (the scenario of the popular movie "The Day After Tomorrow") have been examined. Other laboratory-based investigations include studies of lava flow dynamics, which include cooling and solidification of yield-strength fluid flows, and three-dimensional simulations of subduction zones to understand the flow around subducting plates, the motions of trenches and the interactions of subduction with upwelling mantle plumes. Computational ocean modelling activity focused on inter-annual and decadal scale variability of the Southern Hemisphere circulation arising from eddy-mean flow energy exchanges in the Antarctic Circumpolar Current, and on thermal and mechanical coupling of the atmosphere and Southern Ocean.

Studies of the interaction of mantle dynamics with mantle chemistry, with the aid of new three-dimensional numerical models, suggest that early plate tectonics is a more viable concept than previously thought, which would change the expected cooling history of the mantle. Further, the age of mantle trace components depends little on the viscosity structure but mainly on the rate of processing through zones of melting.

During the year the Seismology and Mathematical Geophysics group was formed as an administrative banner covering activities in seismology and the centre for Advanced Data inference. In May seismic data was collected from the EVA array, a set of 50 short period vertical component seismometers deployed over much of eastern Victoria, and the instrument were removed. The data is generally of high quality, with a large number of tele-seismic earthquakes detected.

In early October 2006, an array of 40 3-component short period seismometers was deployed in southeast Tasmania as part of the SETA experiment. The array will be in place for a period of approximately 8 months to record large distant earthquakes. This project is in collaboration with colleagues at the University of Tasmania, who will carry out additional active source experiments that can be recorded by the SETA array. Tomographic analysis has been carried out using arrival time information from 90 distant earthquakes, and the resultant images exhibit significant lateral variations at 50-100 km depth between northern and southern Victoria.

Continuing analysis of data from the SSCUA experiment (2002-2004) in the unexplored region of Central East Antarctica, has revealed strain in the deep lithosphere that is likely to be related to relict structure in the most ancient blocks of the continent. New deployments associated with the International Polar Year (2007/08) are likely to provide additional seismic data to further investigate the remote interior of East Antarctica.

In the Centre for Advanced Data Inference projects have been conducted in seismic coda wave interferometry, airborne geophysics, ground motion estimation for seismic hazard assessment, statistical inference techniques, structural seismology, earthquake seismology and geodesy. This year saw continued development of the CADI inversion toolkit whereby CADI visitors and project participants have a simple interface to both software and hardware facilities including the Terrawulf parallel cluster.

The glacial rebound work in 2006 has focused on the Fennoscandian and Laurentide Ice Sheets from 40 Ka up to the present with the goal of establishing constraints on the ice thickness and ice margins for some of the major phases of the last glacial cycle. A major compilation of field evidence for the ice margin locations and shoreline elevations and sea levels across the region has been completed and the inversion of these has led to new ice models from 140,000 years to 60,000 years ago, including the time of the renewed initiation of the ice sheets after the last interglacial. Geodetic research during 2006 has continued to investigate ways of improving the accuracy of space-geodetic analysis, in particular modelling the temporal variation of the atmospheric propagation effects. New developments have been made in identifying and using persistent scatterers in Interferometric Synthetic Aperture Radar for ground deformation studies of the Australian continent. A successful re-observation of GPS sites was made in Papua New Guinea on a transect of sites along the western border, in the Schouten Islands, central Highlands and the Papuan Peninsula region.

Geodynamics Research Highlights

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Modelling the ocean thermohaline circulation in the laboratory	Ross W. Griffiths
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Seismology & Mathematical Geophysics Research Highlights

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High resolution seismic imaging of southeast Australia using multiple array deployments	Nick Rawlinson
Simultaneous inversion of active and passive source datasets for 3-D seismic structure	Nick Rawlinson
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Attenuation Tomography of Australia	Agus Abdulah
Earthquake location and upper mantle structure from *P* wave polarization in French Polynesia and Australia	Fabrice R. Fontaine
Tracking later arrivals in heterogenous velocity models	Juerg Hauser
Lithospheric structure, past and present tectonics in Central East Antarctica	Anya M. Reading
Group Velocity Tomography of Australian Continent from Ambient Seismic Noise	Erdinc Saygin
Terrawulf projects in 2006	Malcolm Sambridge
Guided Seismic Waves from the Indonesian Subduction Zone to the Australian Craton	Brian Kennett

Relative Sea-level Changes due to Recent Mountain Deglaciation

Gisela Estermann 1 , Kurt Lambeck 1

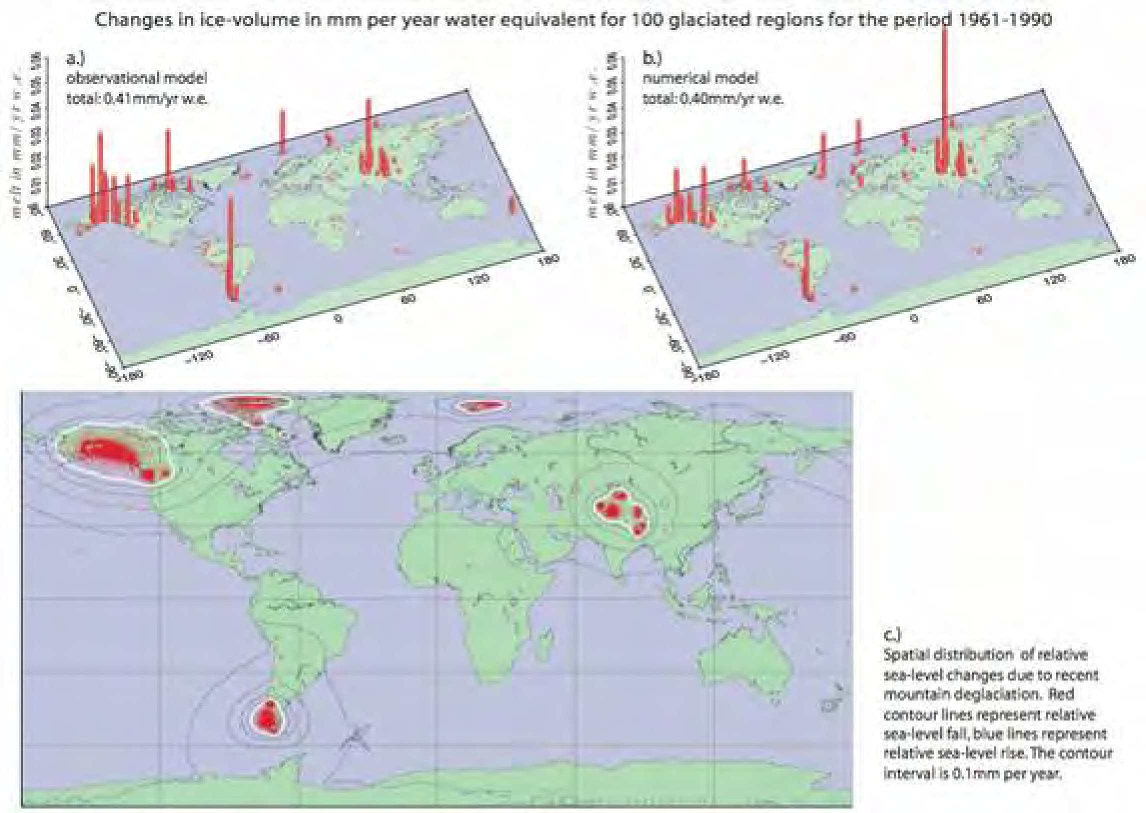
1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia

Sea-level changes are caused by several different processes, including ocean-water warming and freshening, changes in surface and groundwater storage and the loss of glacier ice mass. Observations show a sea-level rise of 1-2mm/year on a global average (Church *et al.* , 2001). According to the IPCC report 2001 melting of mountain glaciers contributes 0.2-0.4mm/year to sea-level rise. Direct observational constraints are unavailable and the different estimates are based on different model assumptions and parameters. Numerical calculations are based on indirect measures of ice-volume changes including the area of glaciated regions, temperature time series and parameters for mass balance sensitivities (Zuo *et al.* , 1997). Our modelled ice loss for 100 glaciated regions calculated for the period 1865-1990 is in agreement with the IPCC results, although closer to the lower limit. Results indicate that melt-water from Patagonia, the Himalayas, Alaska and Canada, and the Arctic Sea constitute more than 90% of the global total. A comparison with a compilation of ice-volume changes based on observational data (Dyurgerov *et al.* , 2005) shows similar results for the second half of the 20 th century. Dyurgerov *et al.* (2005) estimates a volume loss equivalent to an eustatic sea-level rise of 0.41mm/year for the period 1961-1990. This estimate is valid for mountain glaciers only and does not include independent glaciers at the edge of the Antarctica or Greenland ice sheet. The comparison in Figure 1 shows the regional differences of our numerical model to the observational model but also demonstrates the match in total ice-volume change of the numerical model. Hence, with the numerical model, it is possible to reconstruct the glacier loss for the last few decades and make predictions of the contribution to sea-level rise in the future.

Changes in relative sea-level due to mountain deglaciation do not occur equally around the globe. The mass redistribution from the ice load to the ocean produces spatially varying changes in relative sea-level as shown in Figure 1c.). The regional pattern, and also the geodetic signal, are determined by the location of the largest changes in glacier volume (Patagonia , the Himalayas , Alaska and Canada , and the Arctic Sea) and, to a lesser degree, by the ocean-land geometry.

It is necessary to improve the reliability of models of glacier volume changes in order to be able to predict the rebound and the change in gravitational attraction due to mass redistribution. A dense and highly accurate network for monitoring relative sea-level changes and vertical deformation of the Earth's surface may provide the possibility of extracting the contribution to the geodetic signal caused by nearby mountain deglaciation. However, its interpretation is complicated by tectonic deformation in many areas.

Figure 1.



References: Church J. A., Gregory J. M., Huybrechts P., Kuhn M., Lambeck K., Nhuan M. T., Qin D. and Woodworth P. L. (2001) Changes in Sea Level. In: 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., Ding Y., Griggs D. J., Noguer M., Linden P. J. v. d., Dai X. and Johnson C. A. (eds.). Cambridge University Press, Cambridge , United Kingdom and New York , NY , USA .

D yurgerov M. B. and Meier M.F. (2005) Glaciers and the Changing Earth System: A 2004 Snapshot. Occasional Paper No. 55, INSTAAR, University of Colorado .

Zuo Z. and Oerlemans J. (1997). Contribution of Glacier Melt to Sea-Level Rise since AD 1865: A Regionally Differentiated Calculation. Climate Dynamics 13: 835-845.

Enhanced infrasound techniques for verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT)

Douglas R. Christie

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

Recent interest in infrasound research has been motivated by the establishment of a high-sensitivity global infrasound network. This network is used to monitor atmospheric nuclear explosions and thus ensure compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The CTBT is the most significant non-proliferation initiative in the last ten years. This initiative deserves strong support. Infrasound research at RSES has been focused primarily on the delineation of key monitoring issues and the resolution of these issues through the development of techniques and procedures that can be used to ensure acceptable monitoring capability for CTBT verification. Three potentially serious problems have been identified. The first is associated with the decay of higher frequency signal components. The second results from the reduction in spatial correlation of infrasonic signals when the distance to the source is large. The third problem results from background noise generated by turbulent eddies in the atmospheric boundary layer. This is by far the most important technical problem in the field of infrasound. All of these problems have now been resolved.

An examination of data recorded at infrasound monitoring stations has shown that the amplitude of higher frequency signal components from distant atmospheric explosions may be severely attenuated. This is a particularly serious problem when wave propagation is restricted to a thermospheric waveguide. In this case, signals from distant explosions may not be detectable in a conventional analysis at frequencies above 0.4 Hz. This problem can usually be resolved by including a low-frequency passband below 0.1 Hz in the data analysis procedure.

A survey of the detection capability at Australian infrasound monitoring stations has revealed a potentially serious problem with the detection of atmospheric explosions at distances beyond about 500 km due to signal decorrelation at higher frequencies. Since the average separation between nearest-neighboring infrasound stations in the global network is about 2000 km, the loss in signal correlation at higher frequencies can limit the performance of the global monitoring system. In the past, it has been assumed that the optimum detection passband for infrasonic signals from distant explosions is centered around 1.5 Hz. We find, however, from signal correlation studies that the optimum passband lies at a significantly lower frequency centered around 0.7 Hz. The results of this investigation also show that a number of large aperture, 4-element infrasound stations in the global monitoring network will have, at best, only marginal detection capability for distant explosions. These stations need to be upgraded to 8-element array stations by the addition of a small aperture sub-array.

The performance of many infrasound monitoring stations is limited by high levels of wind-generated noise. This is a long-standing unresolved problem. Wind noise reduction is usually achieved by using a series of pipes to sample and spatially average the micropressure field over a limited area surrounding an array element. Further refinements to pipe array designs are unlikely to lead to a reduction in wind-noise by more than a factor of two. However, in order to meet CTBT monitoring requirements, wind noise at stations located in high wind environments needs to be further reduced by at least two orders of magnitude. A new approach to this problem is clearly required. We have therefore developed a remarkably effective wind-noise-reducing system, which we will refer to as a turbulence reducing enclosure. This device is designed to a) lift the turbulent boundary layer above the sensor inlets, b) transform turbulent eddies into smaller scale eddies that produce micropressure fluctuations that lie outside the monitoring passband, c) extract energy from turbulent eddies at all frequencies, and d) direct any residual turbulence into the undisturbed flow aloft that is sweeping over the enclosure. We have evaluated several versions of these wind-noise-reducing devices. The devices are constructed from porous screens arranged in concentric walls with overlapping deep serrations inclined away from the center of the enclosure. These devices (see Figure 1) are essentially eddy shredding machines. The use of these devices provides a dramatic improvement in background noise reduction at 1 Hz. For example, version 2 of the device with 2.4 m high walls provides a reduction of more than two orders of magnitude in winds of 4.5 m/s. An improved version of this device is under evaluation and preliminary results indicate that the device reduces background wind noise by nearly four orders of magnitude in a typical high wind environment. In conclusion, we note that the turbulence-reducing enclosure described here essentially solves the infrasound wind-noise problem in the primary monitoring passband. The significance of this result is that the installation of these devices in the global infrasound monitoring network will ensure the reliable performance of the monitoring network and will also reduce the global monitoring threshold yield from the current value of 1 kT to less than 0.5 kT.

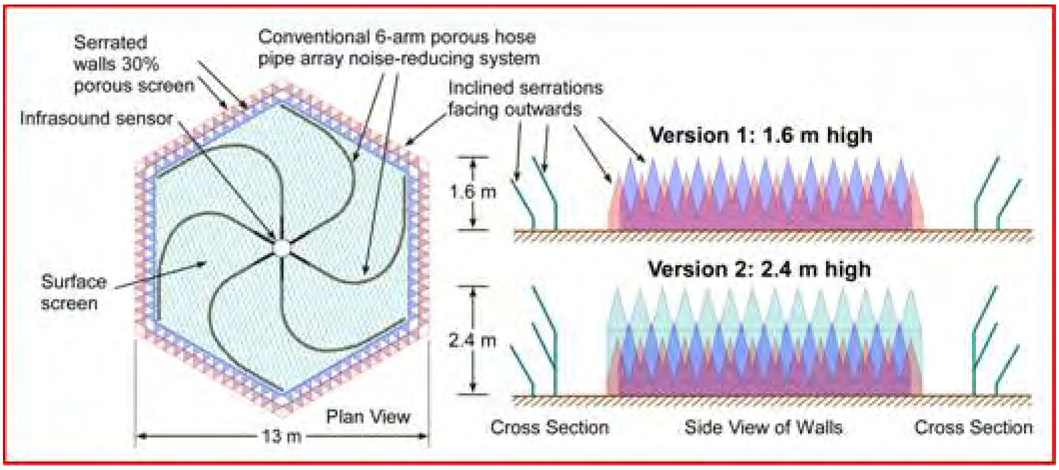


Figure 1. Schematic diagram illustrating two versions of a turbulence-reducing enclosure.

Global Sea Level During the Last Interglacial

Andrea Dutton 1 , Kurt Lambeck 1

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

The last interglacial (LIG) has received much attention by paleoclimatologists because of its immediate similarity in temperatures and sea level position to the present interglacial. Although there are some important climatic differences between these two time periods, improving our understanding of relation between variables in the climate system such as temperature, sea level, CO_2 levels, and orbital parameters during the LIG can improve our understanding of both the dynamics of the natural climate system and the expected response of the climate system to current anthropogenic forcing.

Previous studies have focused on elucidating the duration of the last interglacial highstand as well as the average temperature and sea level position during the LIG. These studies have reached a general consensus that the LIG was slightly warmer, had slightly higher sea levels than present, and lasted for roughly 11,000 yrs. There has been considerably more debate with respect to the temporal variability in sea level during the last interglacial highstand, due in part to the inherent difficulties in reconstructing small, meter-scale fluctuations in sea level on relatively short timescales. To address this outstanding question, we have combined glacio-hydro-isostatic models and observational data from multiple sites to evaluate the relative position of sea level between the beginning and the end of the last interglacial period.

We have drawn upon existing relative sea level data consisting of precisely dated corals from two tectonically stable regions, Western Australia and the Bahamas. These are the most complete data sets available for relative sea level position during the LIG because they have a population of U-Th ages that span the duration of the highstand. Relative sea level curves generated from these observational data suggest a reasonably constant sea level position during the LIG (Fig. 1). However, model simulations demonstrate that both sites are subject to isostatic adjustments from water loading as the ice sheets melt. This effect can be seen in Figure 1 where the relative sea level (RSL) curves show decreasing sea levels during the LIG where eustatic sea level is assumed to rise by 3 meters during this 11,000-year time span. All the sites have observational data that suggests sea level higher than that predicted by the model during the latter part of the LIG. When these data sets are considered in the context of these glacio-hydro-isostatic changes, we extract a eustatic sea level signal from the observational data that indicates a 5-meter rise in sea level between the beginning and the end of the LIG. Although most of this sea-level rise could have been accommodated by melting from the Greenland ice sheet, it is likely that the Western Antarctic ice sheet also contributed some component of this sea level rise.

The deformation of Australia observed with InSAR

John Dawson 1 , Paul Tregoning 1

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

We assessed the accuracy of earthquake source parameters inverted from simulated Interferometric Synthetic Aperture Radar (InSAR) data. Using focal mechanisms of Australian earthquakes (1959 to the present), we simulated synthetic two-pass InSAR observations with realistic spatial noise derived from the characteristics of actual ERS-2 and ENVISAT InSAR data observed over Australia. The precision of two-pass satellite SAR interferometry with ERS2 and ENVISAT SAR data in the Australian region can approach ±2 mm (1 sigma) and is routinely at the ±4 mm level. The use of spatially uncorrelated observational weights has minimal impact on the accuracy of earthquake source parameters inverted from InSAR data but invalid a priori assumptions of the dimension of the earthquake rupture plane can bias depth estimates by up to 0.4 km. In most cases single geometry (i.e. ascending or descending) InSAR observations can be used to accurately determine earthquake source parameters, although typically two-pass geometry reduces the source parameter uncertainties by a factor of 1.5. In general, earthquakes of magnitude < 4.8 are unlikely to be detected by InSAR although deformation from very shallow events would be visible. InSAR is insensitive to magnitude 6.2 earthquakes deeper than 10 km, and magnitude 5.5 deeper than 6 km. For earthquakes magnitude > 5.8 (average depth 6.5 km) we could estimate the epicentre of the rupture with an average accuracy of 0.25 km, depth to within 0.5 km and the fault orientation to better than 2 degrees.

Our ongoing research will focus on temporal image stacking and techniques for the identification of Persistent Scatterers (i.e. temporally phase stable radar reflectors) applied to the observation of 'slow' (~1mm/yr) deformation processes. Our research will focus on new strategies for the identification of persistent scatterers and the application of new modelling techniques to regions where InSAR is known to not work as effectively, including humid and heavily vegetated regions of Australia and Papua New Guinea . The principal motivation and contribution of our research is to: a) demonstrate, 'tune' and develop new PSInSAR 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.

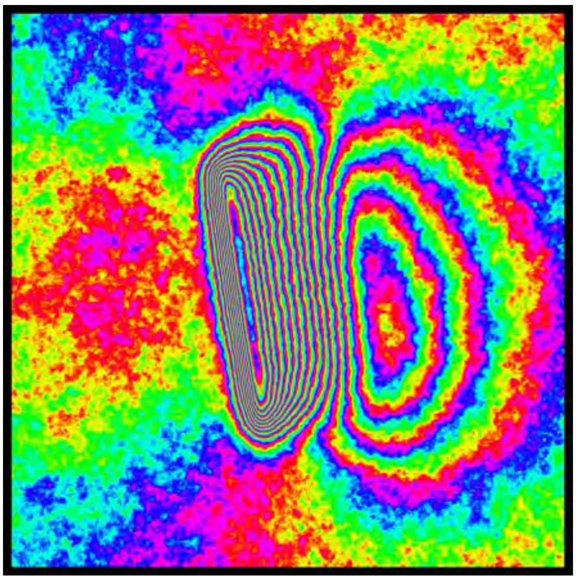


Figure 1. Simulated inteferogram of surface deformation of the 1968 Meckering earthquake. Line-Of-Sight interferometric observations with spatially correlated noise from descending two-pass satellite InSAR (ENVISAT). Each colour fringe cycle represents 28mm of deformation. The centre of the earthquake rupture plane is located in the centre of each image.

Crustal Deformation observed by Space Geodesy

Dan Zwartz 1 , Herb McQueen 1 , Paul Tregoning 1

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

The geodetic field programme at RSES involves measuring crustal motions in Papua New Guinea (predominently horizontal) and glacial isostatic adjustment in East Antarctica (predominently vertical). The observations require deployments of GPS equipment for periods of several days to measure tectonic drift and deformation in plate boundary zones, and several years to detect the rebound rate of the crust after the melting of large ice caps.

In 2006 a total of 15 sites were observed in Papua New Guinea using GPS with 7 of these reoccupations providing accurate estimates of the horizontal motions of the sites for the first time. Two new sites were installed - Wopasali and Balimo - to densify the existing network and provide greater spatial resolution of the transition from rigid Australian Plate in southwestern PNG to the deforming Highlands region. We now have accurate velocity estimates on a transect of sites from the southern coast of New Guinea, through the Highlands to the north coast above the subduction zone associated with the downgoing slab at the New Guinea Trench. From these velocities we can deduce that the rigid Australian Plate extends as far north as Kiunga, with a clear elastic deformation pattern extending from Yapsiei (north of the Highlands) to the northern coast at Vanimo. We interpret this as evidence for locking on the New Guinea Trench that is causing elastic inter-seismic deformation of northern New Guinea .

There was no summer field season in Antarctica in 2005/06, because of a lack of logistic support for remote fieldwork in Antarctica . A new set of equipment was developed and tested during 2006 for installation in Enderby Land during the 2006/07 summer season. This is the region where secular gravity changes have been identified from the GRACE space gravity mission, interpreted as either unmodelled post-glacial rebound or the location of considerable - and ongoing - snow accumulation. These scenarios would cause either uplift or depression of the surface. Our measurements of the actual motion of the crust will discriminate between these two hypotheses or, should no vertical motion be detected, identify significant errors in the interpretation of the GRACE secular gravity changes. Any of the three possible outcomes have significant repercussions for global mass-balance and sea-level variations.

Figure 1. The community of Wopasali surveying the operation of the new GPS installation in their village in Papua New Guinea .

Advances in the analysis of space geodetic data

Paul Tregoning 1

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

In 2006 the focus of geodetic research and its applications to geophysical studies has continued to be to improve the accuracy of the analysis so that smaller geophysical signals can be detected. This required revising some of the models and assumptions used to compute the theoretical range from the ground-based receivers to the transmitting GPS satellites.

Studies showed that the accuracy of the *a priori* surface pressure used to compute the hydrostatic atmospheric delay was critical for estimating accurate changes in height, required for studies such as glacial isostatic adjustment of Antarctica and North America caused by the melting of the Antarctic and Laurentide ice sheets. Software was modified to permit the use of observed surface pressure, values from numerical weather models or from a recent model derived from a spherical harmonic fit to surface pressure of the ECMWF global weather model (Boehm et al., 2006). The use of more accurate a priori pressure removed height errors of up to 10 mm, with an empirical error relation of ~0.2 mm height error per 1 hPa error in pressure (Tregoning and Herring, 2006).

Sub-daily periodic variations in atmospheric pressure cause periodic elastic deformations of the surface of the Earth of up to 3 mm. If unaccounted for, such errors limit the capacity of space-geodetic techniques to identify other geophysical signals of this magnitude or smaller. The spatio-temporal variations of the diurnal and semi-diurnal atmospheric tides were characterised to try to understand why applying corrections for the associated elastic crustal deformation actually degraded the analysis (Tregoning and van Dam, 2005). From an analysis of several years of global pressure data, we demonstrated that the amplitudes of the periodic pressure variations change throughout the year, yet none of the available deformation models for use in geodetic analyses account for the temporal variation in amplitude. The research is ongoing to characterise the variations, generate new models for atmospheric tidal deformation and apply them to the analysis of geodetic data. This component of the research formed part of the Masters degree of Laurent Millet, a visiting student from Ecole Normale Superieure, Cachan , France .

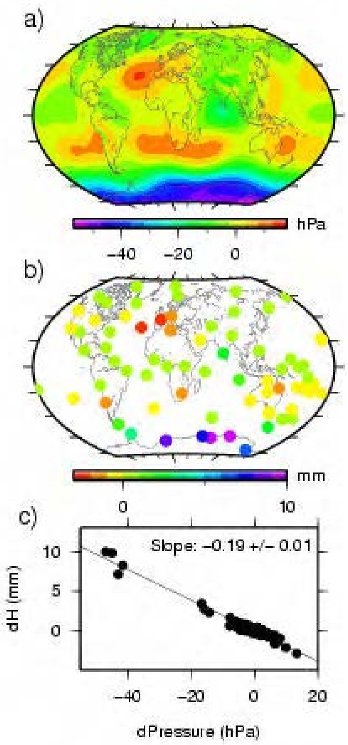


Figure 1. Difference between a) surface pressure derived from "standard" sea level pressure and the mean surface pressure derived from the model based on ECMWF global pressure (Boehm et al., 2006). b) station heights using the two sources of a priori pressure. c) Relation between a priori pressure differences and height differences.

References: Boehm, J. R. Heinkelmann and H. Schuh (2006) Global Pressure and Temperature (GPT): A spherical harmonic expansion of annual pressure and temperature variations for geodetic applications, *submitted to Journal of Geodesy.*

Tregoning, P. and T. A. Herring (2006) Impact of a priori zenith hydrostatic delay errors on GPS estimates of station heights and zenith total delays, *Geophysical Research Letters, in press.*

Tregoning, P. and T. van Dam (2005) Atmospheric pressure loading corrections applied to GPS data at the observation level, *Geophysical Research Letters*, 32, L22310, doi:10.1029/2005GL024104 .

Water vapour feedback and global warming

Peter Smythe 1 , Paul Tregoning 1

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

Atmospheric water vapour is the most abundant greenhouse gas and knowledge of its changing distribution is critical for understanding its role in climate change. The presence of water vapour in the atmosphere retards GPS signals as they propagate from satellites to Earth-based receivers and thus space geodetic techniques are sensitive to the quantity and distribution of water vapour in the atmosphere. Estimation of the excess path length due to water vapour (the slant wet delay) is reliant upon an accurate model for the delay due to the dry atmosphere (the slant hydrostatic delay). Conventional models assume that the hydrostatic delay for space-geodetic observations at zenith can be modelled as a function of surface pressure measurements and can then be related to observations at arbitrary elevation angles by empirical mapping functions. These simplified models introduce significant errors into geodetic analyses and thus the estimation of atmospheric water vapour.

Currently we are developing an *a priori* model for slant hydrostatic delays at arbitrary elevation and azimuthal angles for use in GPS data analysis. Contrary to the conventional approach, the slant hydrostatic delay will be modelled directly for each GPS observation by ray tracing through a model atmosphere, defined in terms of refractivity constructed from meteorological data at various pressure levels spanning the troposphere and lower stratosphere. The ray-traced slant hydrostatic delay will capture more accurately much smaller spatial and temporal variability than the current empirical mapping functions and horizontal gradients. It is anticipated that the resulting model, though computationally intensive when compared to the conventional method, will afford increased precision in geodetic analyses, in particular the estimates of slant wet delays. These estimates will be used to generate accurate three-dimensional water vapour distributions via GPS tomography, akin to seismic tomography. The improved knowledge of atmospheric water vapour will then be used in climate studies to investigate water vapour feedback processes.

Dynamics and Chemical Evolution of the Earth's Early Mantle

Geoffrey F. Davies 1 , Jinshui Huang 1

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

Reconciliation of geophysical and geochemical observations of the Earth's mantle has been a challenging problem for about three decades. Numerical models are an essential tool in this work because they can simultaneously address the physical and chemical evidence within the framework of the physics governing mantle dynamics and evolution. One challenge has been to explain the persistence of chemical heterogeneity in the mantle for about two billion years despite the mixing effect of mantle convection. Another has been to understand quantitatively how the mantle reached its present condition as it evolved from earlier, hotter states. We have been using two-dimensional (2D) and three-dimensional (3D) numerical models to address these questions.

Last year we reported that the main control on the survival of chemical heterogeneity seems to be the rate at which material fluxes through melting zones near the Earth's surface. Other factors such as the viscosity structure of the mantle and geometry seem to be secondary. These results have been confirmed and extended in spherical 3D models that include the excess density of simulated subducted oceanic crust, which tends to accumulate at the bottom of the models. A simple theory that successfully interpreted the results with neutrally buoyant chemical tracers has been extended to also account for the effect of the excess density. These results provide us with simplified formulas that will help to interpret geochemical observations.

The 3D results are now being extended to higher resolution using another computer code, Citcom, which allows a regional segment of the mantle to be modelled (figure 13). The effects the higher resolution and of more realistic motions of tectonic plates are being investigated.

2D models can be run at much higher resolution than 3D models, and they can therefore be used to explore the dynamics of the mantle early in Earth history when it was hotter and less viscous, plates were thinner and the flow was more complex. Initial results were reported last year showing that a dynamic stratification occurs in hotter mantles, with the denser subducted oceanic crust tending to settle out of the upper mantle, leaving it relatively depleted in that component. Since that component is also the most readily melted, this implies that new oceanic crust, formed by melting under mid-ocean ridges, would be relatively thin, only about 5 km rather than the 20-30 km expected at those temperatures. These results provide a straightforward explanation for evidence from ancient rocks that the early mantle was strongly depleted in the components associated with subducted oceanic crust.

The robustness of these results has by now been explored more thoroughly, and they do not depend significantly on the presence of phase transformation effects, nor on the detailed distribution of internal heat sources. It has been found that the hottest models were not fully resolved initially, and as a result the crustal thickness has been revised upwards to the range 5-8 km.

The ultimate goal of the 2D studies has been to let models evolve from the earliest mantle conditions to the present. This work has now begun, after an extensive exploration of model behaviours at particular temperatures. This will allow more definitive tests of earlier results on simulated isotopic ages, as well as revealing to what degree the early stratification survives to the present.

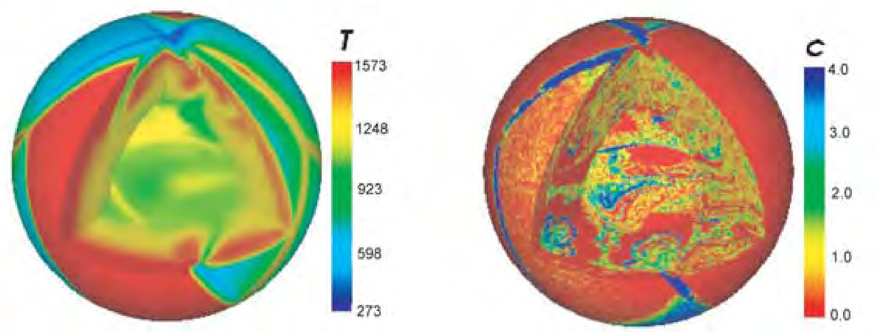


Figure 1. Cutaway views of three-dimensional models of mantle convection with tracers representing components with basaltic composition. Left: temperature distribution; Right: tracer concentration, relative to the average concentration of 1. The 90-degree cutaway (centre of view) reveals the interior down to the core-mantle boundary. The surface of the view has the top 100 km removed. On the right of the left panel are spreading centres (yellow and red) and on the top and left are subduction zones (deep blue). The red surface area is under a simulated continental region where the hot mantle cannot cool. The remaining blue surface areas are occupied by oceanic plates that cool as the move away from spreading centres. The tracer distribution reveals the complexity of stirring in three dimensions, with high concentrations where simulated oceanic crust has subducted or is subducting (dark blue).

Tectonic Evolution of the Earth

Geoffrey F. Davies [1]

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

The dynamical modelling reported above has substantial implications for the tectonic evolution of the Earth. The thinner early oceanic crust would enhance the viability of plate tectonics, which in turn would provide a straightforward mechanism for cooling the mantle. Such a mechanism has been lacking, as the previously expected thick oceanic crust would tend to inhibit plate tectonics and mantle cooling. This is because oceanic crust is less dense than the mantle and so tends to inhibit or block subduction of plates. The implication that plate tectonics may have been viable very early in the Earth's history was greeted with considerable interest at a Penrose conference on "When Did Plate Tectonics Begin", which is a controversial question. A jointly authored conference paper is in preparation.

A further implication is that, although cooling of the mantle by plate tectonics is more viable, it is rate-limited by the thickness of the crust. The net result is that the mantle tends to be buffered in a hotter state than it would with unimpeded plates. It is possible there would be a transition, involving heightened volcanic and tectonic activity, into the present, cooler state once radioactive heat generation declined to a threshold level. This implication is still conjectural, but has also generated interest for its potential explanation of the episodicity of the record of tectonic activity. A paper has been contributed to a volume on "The Earth's Oldest Rocks".

Thermal Evolution of the Core

Geoffrey F. Davies 1

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

The thermal budget of the core is a key quantity relating the generation of the magnetic field, the growth of the solid inner core and the generation of plumes in the mantle. Recently modellers of the core dynamo responsible for generating the magnetic field have appealed to the possibility of radioactivity in the core to accommodate all of these phenomena, but the results of this study indicate this may not be necessary.

The challenge is to reconcile the estimated rate of heat loss from the core, the energy required to maintain the magnetic field by dynamo action in the core, evidence for the magnetic field having existed through much of Earth history and the present relatively small size of the inner core, formed by solidifcation of the core as it cools. Previous attempts to avoid core radioactivity implied implausibly high core temperatures in the past.

The present work has used a more appropriate parameterisation of the removal of core heat by plumes in the mantle, a lower estimate of core conductivity and a more thorough exploration of how the mantle modulates core heat loss, which reveals another family of solutions in which early core temperatures are not excessively high. The result is that the core dynamo could be maintained without radioactivity so long as no more than about 0.5 Terawatts of heat flow is required to maintain the dynamo.

There are considerable uncertainties in some of the relevant parameters, and the study has identified the most important as being the present rate of heat loss from the core, the conductivity of the core, and the energy or entropy flow required to maintain the dynamo.

Modelling the ocean thermohaline circulation in the laboratory

Ross W. Griffiths 1 , Graham O. Hughes 1 , Melissa A. Coman 1 , Julia C. Mullarney 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Oceanography, Dalhousie University , Halifax , Canada

We have developed a new theoretical model for the ocean overturning circulation and shown that the theory works well when tested against laboratory experiments. We have also examined the nature of circulation changes that may occur when heat and freshwater fluxes across the ocean surface change, as expected owing to global warming. The global meridional overturning circulation of the oceans (otherwise known as the thermohaline circulation) is forced by density differences owing to heat and water fluxes at the sea surface, wind stress on the surface and injections of energy into turbulent mixing from the winds and tides. In our approach we examine the extent to which the density differences and interior turbulent mixing together, but in the absence of large-scale wind stresses, could force the overturning.

As outlined in a key paper last year (Hughes and Griffiths 2005) our calculations show that, after taking account of the behaviour of cold, dense currents sinking from localized surface regions to large depths in the oceans along gentle bottom slopes under the influence of Coriolis forces, the buoyancy-forced flow can account for a number of key features of the observed circulation: using the estimated poleward heat transport and the measured average interior vertical mixing rate we successfully predicted the top to bottom density difference, the dilution of dense currents by a factor of around three as they sink, the rate of formation of Antarctic Bottom Water (AABW) and North Atlantic Deep Water (NADW), and the thickness of the subtropical thermocline. Thus a simple model can provide powerful insights into the dynamics of the oceans. We concluded that substantially less energy than previously proposed for turbulent mixing is required for a convective circulation to be of the observed magnitude, partially as a result of turbulent entrainment into the dense sinking currents. This year we have modified the theory to describe laboratory experiments with this form of convective circulation (often termed "horizontal convection" by virtue of the forcing at only the horizontal sea surface). A detailed comparison of our own laboratory data from previous years with this theory has been outstandingly successful and provides a new explanation for the heat flux-Rayleigh number relationship, boundary layer thickness and overturning rate in terms of inviscid dynamics of the sinking currents and interior flow (Hughes *et al* . 2006).

One remaining difficulty is that the model in its simplest form predicts an abyssal ocean density gradient much smaller than measured. A PhD student, Ms Coman, has used further experiments to examine the possibility that dual sinking regions, one in either hemisphere and generating waters of different density (the AABW and NADW) may produce a larger abyssal gradient (figure 3). This notion is born out by the results, but the effect is apparently not large enough to explain the ocean stratification and other factors will be explored in the coming year.

In other experiments the convective circulation was brought to its equilibrium (steady) state and then the surface boundary conditions were changed, so as to mimick climate changes such as a warming or increased freshwater inflow in high latitude oceans, or a change in the radiative heat input in the subtropics. These changes disturb the balance within the circulation. For example, a cooling in the subtropical ocean leads to a temporary strengthening of the overturning, more vigorous sinking of colder water and an exponential adjustment to a new equilibrium much the same as the initial state (figure 4). 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 around twice the thickness of the thermocline (figure 3). This state of shallow overturning is temporary. After a long period (several times the exponential timescale mentioned above) the circulation evolves through a period of large oscillations in the depth of convection, to the initial state of full-depth overturning.

All of this work examines the fundamental dynamics of convective overturning, and ultimately examines the role of such convection in the global circulation. An important role for convection has not always been accepted, in part because it was ruled out by Sandstrom's theorem, a postulate drawn from experiments carried out at the beginning of the twentieth century and still referred to today. However, this theorem is in conflict with modern experiments. We therefore re-created those early experiments (Coman *et al*. 2006) and concluded that Sandstrom's report, hence the theorem, are incorrect: heating and cooling sources on the same geopotential surface do drive a persistent recirculation. Most of our experiments have been carried out in non-rotating tanks. However, the role of Coriolis accelerations is being studied in a series of runs in which the carefully designed convection apparatus sits on a precision rotating platform. The flow with rotation is far more complicated and three-dimensional, and is rich in wave and vortex motions, but is less readily scaled to ocean conditions.

Figure 1. A photograph of dye in the convective overturning when a larger heat flux is applied to the left hand side of the base of a box, a weaker heat flux is applied to the right hand side of the base, and the central section of the base is cooled such that there is no net heat input. I this example the right hand plume drives a shallow cell, and its water (blue) is eventually entrained into the stronger plume at left and cycled throughout the box.

Figure 2. Overturning driven by heating the left half of the base of a box and cooling the right half of the base. The photograph was taken shortly after the temperature of the heating base was increased by a small amount.

Figure 3. Photographs of the evolution of overturning as in figure 2, but after the temperature of the base at the right was decreased. The flow evolves through a period of shallow convection before returning to a state of full-depth overturning.

References: Hughes, G.O. and Griffiths, R.W. (2005) A simple convective model of the global overturning circulation, including effects of entrainment into sinking regions. *Ocean Modelling* 12 , 46-79 (doi:10.1016/j.ocemod.2005.04.001).

Hughes, G.O. Griffiths, R.W., Mullarney, J.C. and Peterson, W.H. (2006) A theoretical model for horizontal convection at large Rayleigh number. *J. Fluid Mech* ., in press, accepted July 2006.

Coman, M.A., Griffiths, R.W. and Hughes, G.O. Sandstrom's experiments revisited. (2006) *J.Marine Res* ., in press, accepted October 2006.

How does the Southern Ocean respond to changes in wind forcing?

Andrew McC. Hogg 1 , Michael P. Meredith 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET , UK

The Southern Ocean is characterised by turbulent flow associated with the world's strongest ocean current, the Antarctic Circumpolar Current (ACC). This turbulence is dominated by mesoscale eddies – vortices which are small (~50km) compared with the size of the Southern Ocean. Mesoscale eddies play a variety of roles in the dynamics of the Southern Ocean: they help to balance the forces contributing circulation in this region, thereby controlling the zonal momentum balance of the ACC, and are responsible for carrying heat across the Southern Ocean.

We can measure the energy contained in the ocean eddy field using satellite observations. These measurements show that there was a strong peak in the eddy energy between 2000 and 2002 (Meredith & Hogg, 2006). The spatial distribution of the excess eddy kinetic energy, as shown in Figure 1, are distributed around the Southern Ocean, and are not confined to a single region. These observations imply that variations in the eddy field are due to a spatially distributed source; the primary candidate for these variations is the strong westerly wind field that drives the ACC.

Analysis of the westerly winds in the Southern Ocean reveal a peak in the wind stress in 1998, 2-3 years before the peak in the eddy field. This observation is compared with numerical simulations using an eddy resolving ocean model. The model indicates that a 2-3 year lag in the eddy field is to be expected, and also demonstrates the dynamics which cause this lag – the energy resides in the potential energy field before being converted into eddy energy through baroclinic instability (Meredith & Hogg, 2006). It is notable that standard ocean-climate models, which do not resolve small scale eddies, predict a completely different response to wind variability. This is of particular concern, given that the response of the circulation to changes in wind forcing has a number of other consequences, including the poleward heat transport, which may have feedbacks on the climate system.

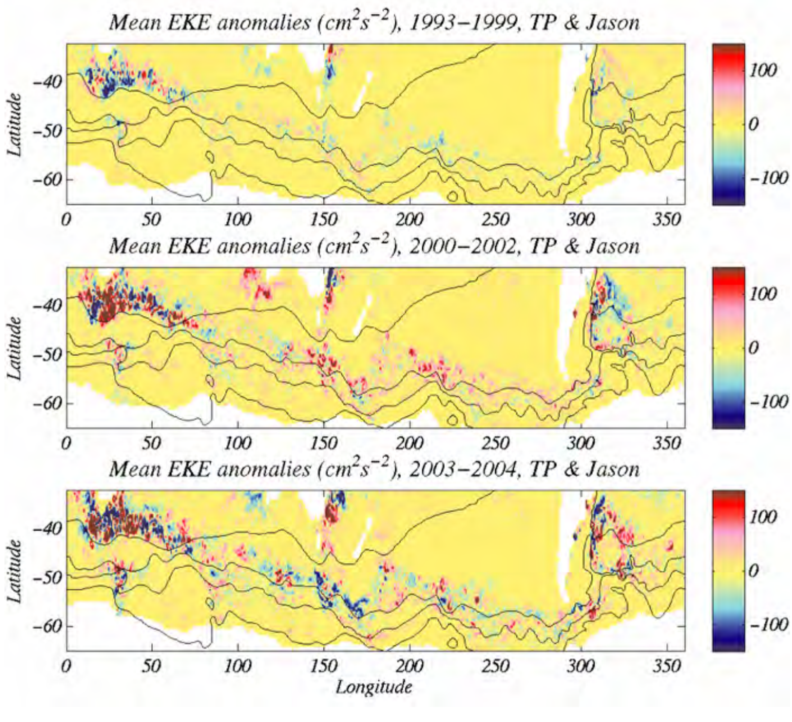


Figure 1. The eddy kinetic energy anomalies in the Southern Ocean for three different periods: 1993-1999, 2000-2002 and 2003-2004.

References: Meredith M. P., and Hogg A. McC. (2006) Circumpolar response of Southern Ocean eddy activity to a change in the Southern Annular Mode. *Geophys. Res. Lett.* 33 , L16608, doi:10.1029/2006GL026499.

The Propagation and Morphology of Lava Flows

Ross C. Kerr 1 , Ross W. Griffiths 1 , Aaron W. Lyman 1 , Katharine V. Cashman 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Geological Sciences, University of Oregon, Eugene, OR 97403-1272, USA

Using a powerful combination of laboratory experiments and theoretical analyses, we have investigated the propagation and morphology of basaltic and silicic lava flows. In one set of experiments, molten polyethylene glycol wax was released at a constant flow rate under cold water on a sloping plane (Figure 11). Initially, the wax spreads both down and across the slope at the same rate in an early-time viscous regime, before undergoing a transition to a long-time viscous regime where downslope flow is faster than lateral flow. Eventually, the lateral flow is stopped by the yield strength of the growing surface crust, and the flow then travels downslope in a channel of constant width. Using scaling analysis, we have derived expressions for the final channel width in both the early-time and long-time flow regimes, as a function of the flow rate, the slope, the density difference driving the flow, the lava viscosity, the thermal diffusivity, and the strength of the surface crust. We have also found a dimensionless flow morphology parameter that controls whether the subsequent channel flow occurs with a 'mobile crust' morphology (involving lots of exposed melt and consequent high heat loss) or in a 'tube' morphology (involving a complete solid roof and relatively small heat loss from the melt). The theory has been successfully applied to understand the formation of a basaltic sheet flow lobe in Hawaii, for which we estimated the crust strength of 60kPa. Our results provide important insight into conditions that promote lava tube formation, which is in turn responsible for greatly increasing the length of individual flows.

In a second set of experiments, we rapidly released a fixed volume of molten polyethylene glycol wax , which propagated as a two-dimensional flow down a sloping channel under cold water. We found that four dynamical flow regimes can arise: an inertial slumping regime, a horizontal viscous regime, a sloping viscous regime, and a surface crust regime that finally stops the flow. With this dynamical understanding, we analyzed the flow of blocky andesite lava from the 1988-1990 eruption of Lonquimay Volcano, Chile. We found that the surface crust regime, for a crust strength of 2 MPa, is able to predict the entire propagation of the lava flow (figure 2). This discovery is very exciting, because it offers the prospect of being able to predict the evolution of future blocky lava flows, without the almost impossible task of predicting the rheology of the interior lava as a function of position and time. We hope that our work will encourage volcanologists to very carefully monitor both the erupted volume and flow length as a function of time in future flows, as such early detailed observations are crucial to allow dynamical models to be used to understand or predict the propagation of lava flows.

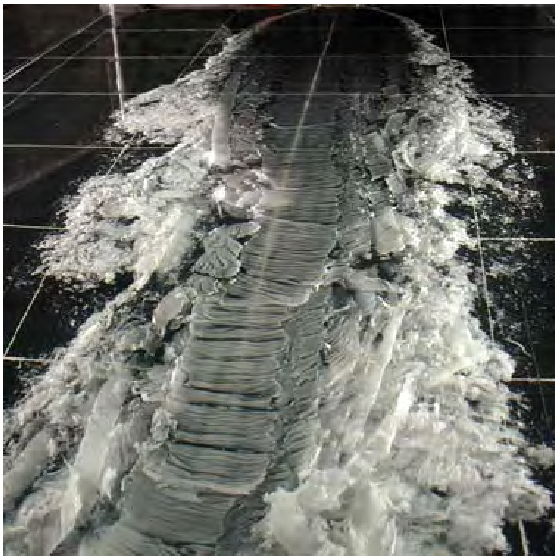


Figure 1. The formation of channelized lava flows, modeled using molten polyethylene glycol wax flowing down a wide uniform slope under cold water. The flow shown is in the mobile crust morphology. Molten wax is transparent, solid wax is white, and the base of the tank is black with a 20 cm grid.

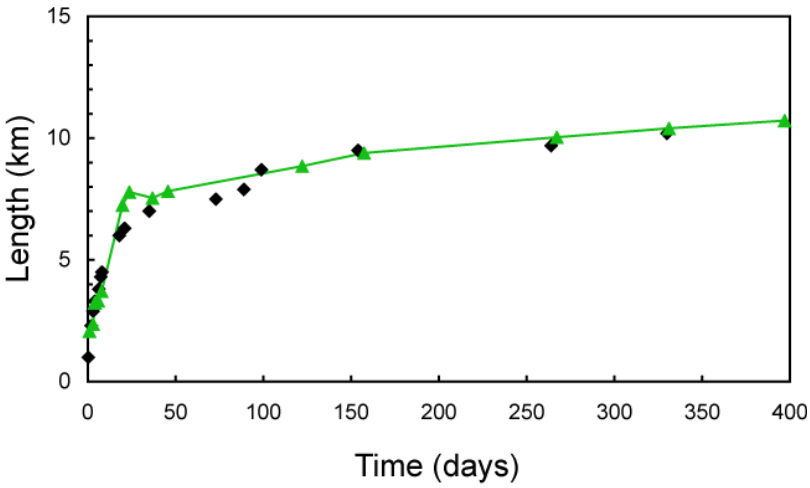


Figure 2. Flow length as a function of time (diamonds) for the 1988-1990 andesite lava flow of Lonquimay Volcano , Chile . The triangles show the predicted propagation in the crust strength regime, for a surface crust yield strength of 2 MPa.

References: Kerr, R. C., Griffiths, R. W. and Cashman, K. V. (2006) The formation of channelized lava flows on an unconfined slope. *Journal of Geophysical Research* **111** , B10206, doi:10.1029/2005JB004225.

Kerr, R. C. and Lyman, A. W. (2007) The importance of surface crust strength during the flow of the 1988-1990 andesite lava of Lonquimay Volcano, Chile. *Journal of Geophysical Research* , in press.

Lyman, A. W. and Kerr, R. C. (2006) The effect of surface solidification on the emplacement of lava flows on a slope. *Journal of Geophysical Research* **111** , B05206, doi:10.1029/2005JB004133.

Interaction of coherent eddies with headland wake flows

Melanie J. O'Byrne 1 , Ross W. Griffiths 1 , Jason H. Middleton 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 School of Mathematics, University of New South Wales, Sydney, NSW 2052, Australia

Flow around islands and headlands can trap suspended particles, bring nutrients up from deeper waters, influence the distribution of sediments and provide favourable environments for marine biota.

As few islands or headlands are isolated bodies, it is important to understand how unsteady incident flow affects wake structure and behaviour.

In 2006 we continued laboratory investigations into the effects that perturbations in the oncoming flow have on the wake of an idealised headland, using ultrasonic Doppler techniques to measure the velocity field.

We have completed a series of experiments in a one-metre diameter rotating cylindrical tank. The headland, seafloor (base) and coast (sidewall) were impulsively set in motion relative to the still water. Thus, in a headland reference frame, there is oncoming flow.

We find that for Reynolds numbers above approximately 1000, coherent incident eddies 'lock-on' to shedding in the headland wake, resulting in a train of vortex dipoles downstream of the obstacle. This finding is potentially relevant to engineering applications such as design of offshore platforms, power cables or bridge pylons.

Rotating experiments also reveal an interesting phenomenon analogous to classic amplitude modulation. For some Reynolds numbers between 800 and 1500, the wake from an upstream disturbance acts as a high-frequency carrier signal, modulating the amplitude of the signal from the headland wake.

We aim to identify flow regimes and geometries where these behaviours may be observed, how they are triggered and thus whether they may be predicted.

The limited flow time in a single revolution of the rotating table results in a transient headland wake, as shown in Figure 1. These still images, from two experiments with a Reynolds number of 1000, compare the unperturbed or natural flow (left column) with the perturbed flow (right column) around an idealised headland. The recirculating headland wakes look similar in both cases nine seconds after impulsively starting rotation. Twenty-four seconds later, the perturbed wake is considerably mixed and coherent eddies from upstream are clearly visible, while the natural headland wake is clear. Thereafter, the wake structure is lost regardless of upstream conditions, in part due to the presence of the curved wall and its thickening boundary layer.

In order to ensure an established wake flow, we have begun studies using a new 3-metre flume in which the working fluid continually recycles through a series of pumps. This permits a typical flow time of 20 minutes. Preliminary results at low Reynolds numbers reveal that incident disturbances can significantly extend the length of the wake bubble. In future experiments, we will study the residence time and amount of leakage of fluid trapped in the headland wake.

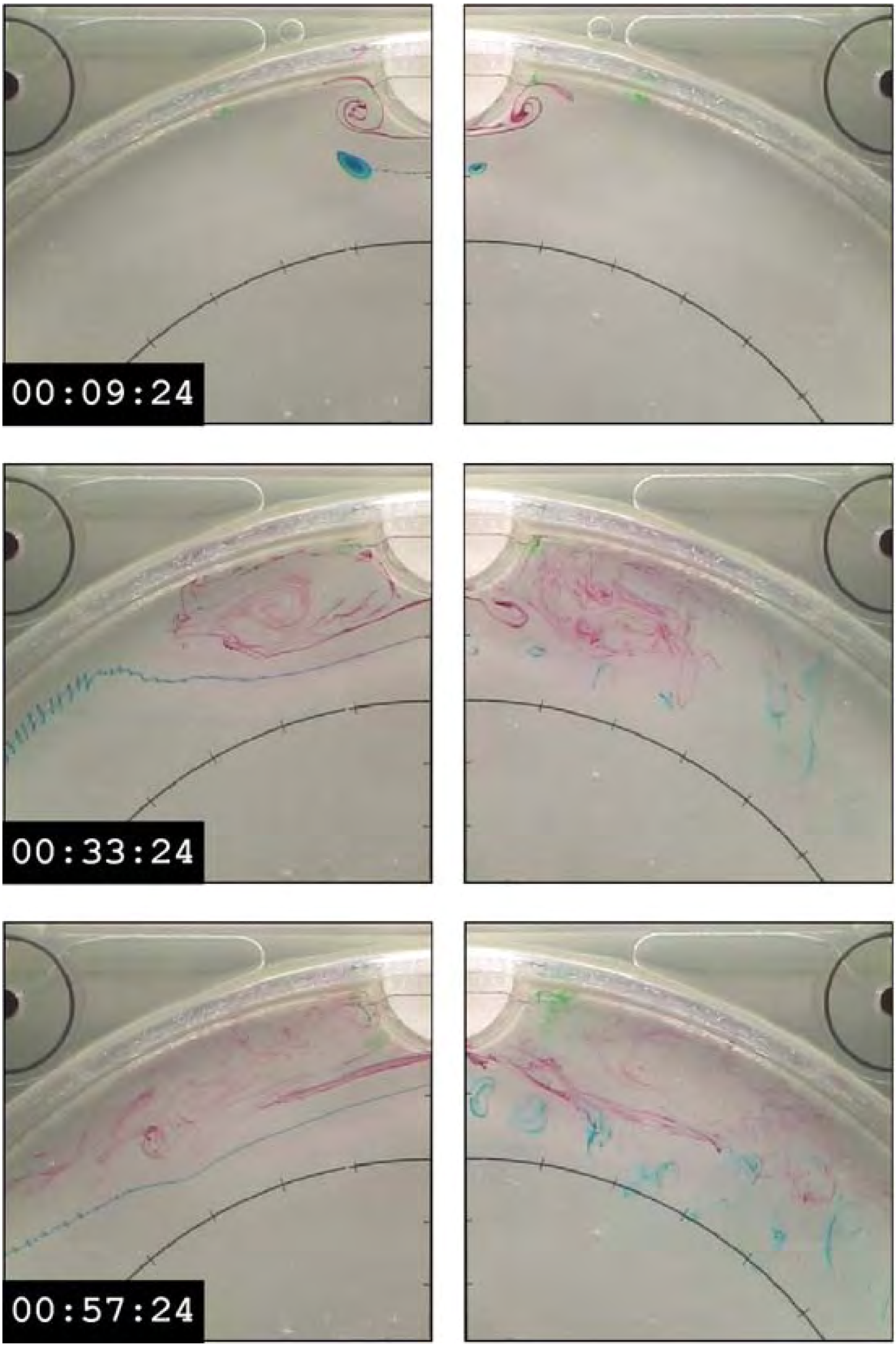


Figure 1. Still images of two experiments at a headland Reynolds number of 1000, without (left) and with (right) oncoming flow perturbations, reveal the transient wake structure in our experiments with an impulsively started flow. The idealised headland and coast (a vertical wall) are at the top of each image.

Mixing in ocean straits and overflows

Tjipto J. Prastowo 1 , Ross W. Griffiths 1 , Graham O. Hughes 1 , Andrew McC. Hogg 1

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

We have measured the amount of mixing that occurs when two fluids of different density exchange in opposite directions through a constriction or over a sill. Such exchange flows commonly occur through ocean straits and over bottom sills. The constrictions control the rate of transport of water into or out of estuaries and marginal seas and between abyssal ocean basins. Analytical methods are frequently used to estimate exchange flows through these constrictions; we have focused on extending the simple analytical solutions to more realistic cases. Exchange flows involve strong velocity and density gradients between the two layers flowing in different directions, and this flow can become 'critical' (i.e. reach the speed of gravity waves on the density interface) so that there is a hydraulic control point in the strait or above the sill.

We have observed that mixing occurs readily between the two layers by shear instability (figure 1). The mixing produces a large volume of water having mixed properties, and it also modifies the mass flux through the constriction. This year we have examined in a series of experiments the role of the constriction geometry. The results have been included in a paper (Prastowo *et al* . 2006) that concentrates on the amount of mixing and the effect of the mixing on the exchange rates through a horizontal constriction. We find that mixing in the flow reduces the exchange rate by approximately 16% relative to that predicted by inviscid hydraulic theory, and that sidewall friction leads to a further reduction. The reduction increases with constriction length and decreases with minimum constriction width. The mixing can be described in terms of a efficiency – the proportion of the available potential energy (released by the flow over a given time) that is used to raise the centre of mass by vertical mixing. We find that the mixing efficiency depends only upon a Reynolds number based on the constriction length (figure 8). For Reynolds numbers in excess of 5×10^4 the efficiency takes a constant value of $11 \pm 1\%$. These measurements are in agreement with our previously developed scaling theories that predict both the observed exchange rate and the measured mixing efficiency. We have also completed this year a series of closely related experiments on exchange flows over sills. Ongoing work is now concentrating on interpreting the data and applying our theories to these cases.

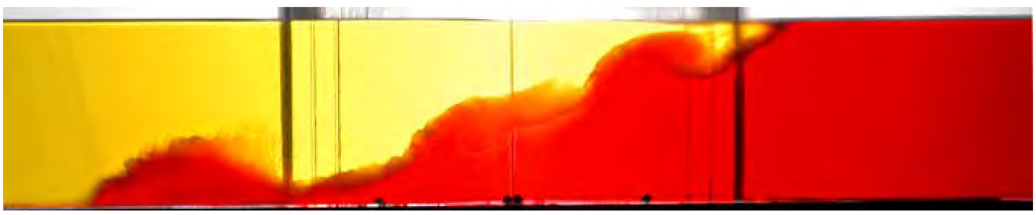


Figure 1. Shear instability and mixing in an hydraulically-controlled exchange flow through a short constriction.

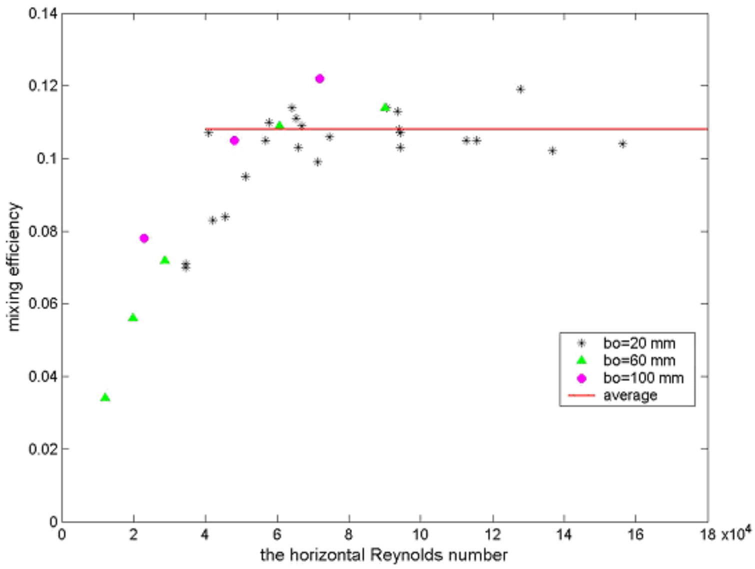


Figure 2. The mixing efficiency (the proportion of potential energy released that goes into raising the centre of mass through mixing) computed from measurements of density profiles after the flow has proceeded for a given time.

References: Prastowo, T. J., Griffiths, R. W., Hughes, G. O. and Hogg, A. McC. (2006) Mixing due to exchange flows through a horizontal constriction. *J. Fluid Mech* ., submitted.

Subduction kinematics and dynamics in 3D space: Insight from laboratory and numerical modelling

W. P. Schellart 1 , J. Freeman 1 , D. R. Stegman 2 , L. Moresi 2 & D. May 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 School of Mathematical Sciences, Monash University, Melbourne, VIC 3800, Australia

During development of the plate tectonic theory in the 1960's and 1970's it was soon realized that the motion of the tectonic plates, which cover the Earth's surface, is primarily driven by dense subducted slabs located in the mantle. Subducted slabs form along convergent plate boundaries where an oceanic plate is thrust underneath an overriding plate into the Earth's mantle. The slabs are denser than the ambient mantle, forcing the slab to sink and pulling the trailing plate at the surface into the mantle, thus driving plate motion at the surface and flow in the Earth's mantle. The kinematics and dynamics of this sinking process and the flow that is induced by the sinking has been investigated extensively in two-dimensional space, but three-dimensional investigations are still in their infancy . Three-dimensional investigations are important, because subduction zones on Earth are limited in trench-parallel extent (~200-7000 km) and most are curved. We have recently attempted to address this deficiency by doing laboratory and numerical simulations of progressive subduction in 3D space [Schellart, 2004; Stegman et al., 2006]. These works have shown that in self-consistent dynamic models, where plate motions and trench migration are not imposed but evolve naturally, subducting slabs and associated trenches predominantly retreat oceanward, inducing flow in the mantle that is toroidal in nature and located exclusively around the lateral edges of the slab. We observed no poloidal flow around the slab tip, as was suggested by previous workers. The (non-) existence of poloidal flow around the slab tip is important for understanding the relationship between slab width and trench velocity. Current and previous works have shown that there is an inverse relationship between slab width and trench retreat velocity: the wider the slab, the slower the trench retreat velocity [Schellart, 2004; Stegman et al., 2006; work in progress]. Such a relationship is most easily explained if in fact, there is no (or negligible) trench rollback-induced poloidal flow around the slab tip. To address this issue in more detail, new laboratory and numerical models have been run to study the subduction-induced flow patterns in the mantle. Our models confirm previous observations that rollback-induced flow of the mantle occurs in a toroidal fashion and occurs exclusively around the lateral edges of the slab (Figs. 1, 2).

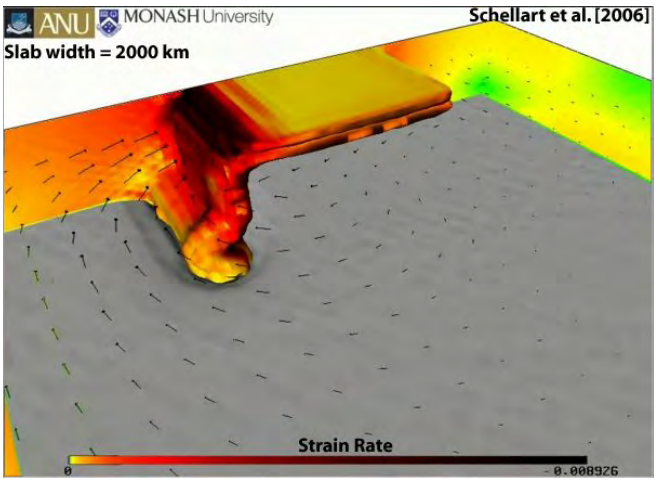


Figure 1. 3D view of numerical simulation of subduction illustrating slab geometry and toroidal flow patterns in the mantle (arrows) at 200 km depth.

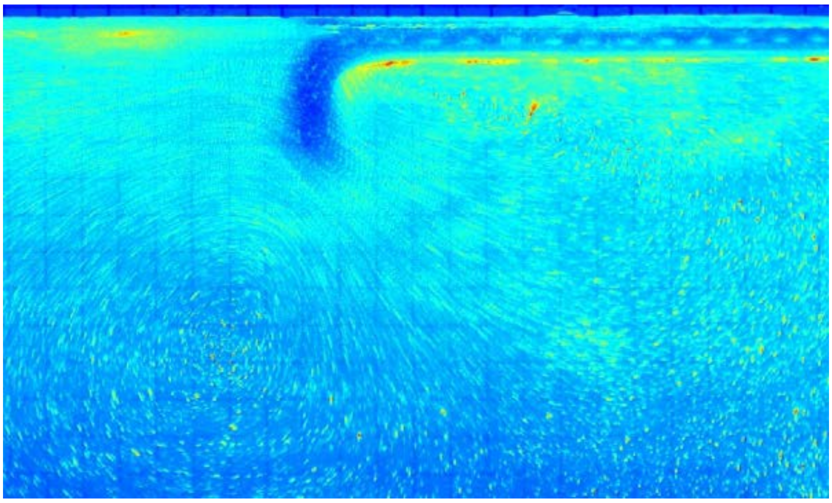


Figure 2. Side view of laboratory simulation (composite image of nine photographs) of subduction illustrating slab geometry and poloidal flow patterns in the mantle in the centre of the subduction zone.

References: Schellart, W.P., Kinematics of subduction and subduction-induced flow in the upper mantle. ***Journal of Geophysical Research*** **109** , B07401, doi:10.1029/2004JB002970, 2004.

Stegman, D., J. Freeman, W.P. Schellart, L. Moresi and D. May, Influence of trench width on subduction hinge retreat rates in 3-D models of slab rollback. ***Geochemistry Geophysics Geosystems*** **7** , Q03012, doi:10.1029/2005GC001056, 2006.

Laboratory Modelling of 3-D Flow and Temperatures in Subduction Zones with Back-arc Spreading and Plumes

Chris Kincaid 1 , Ross Griffiths 2 , John Foden 3 , Charles Langmuir 4 , Richard Carlson 5 , David James 5

1 Graduate School of Oceanography, University of Rhode Island , Narragansett , RI , USA
2 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
3 School of Earth and Environmental Sciences , University of Adelaide , Adelaide , SA 5005, Australia
4 Department of Earth and Planetary Sciences, Harvard University , Cambridge , MA , USA
5 Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC , USA

Subduction of lithospheric plates back into the mantle at subduction zones (ocean trenches) provides the dominant driving force for plate tectonics and causes thermal and chemical exchange with the Earth's interior. We have developed a laboratory apparatus for modeling 3D aspects of flow in subduction zones in response to various modes by which plates move and subduct into the mantle. These include both slab rollback, when the slab sinks with a backward retreating or horizontal component of motion, and periods where the angle of descent (slab dip) either increases or decreases with time. Previous work has documented the importance of these modes of plate motion on 3D shallow mantle return flow and both slab and mantle wedge temperatures (Kincaid and Griffiths, 2003; 2004). During a recent visit to RSES, Kincaid has been studying the role of back-arc spreading (BS) on slab/mantle evolution and the interaction between subduction and buoyant mantle upwellings (plumes). A series of experiments started in 2004 and completed here in 2006 (with collaborator C. Langmuir) characterize spatial and temporal patterns in slab and mantle wedge temperatures for various modes of plate sinking and back-arc spreading, including extension produced by slab/arc retreat versus motion of the overriding plate. Parameters explored include subduction style, width of the BS center, extension rate and the BS center–to–trench separation distance. Results show dramatic differences in the plate and overlying mantle wedge evolution depending on conditions. For example, BS due to trench/plate rollback produces very shallow flow trajectories in the wedge (which are unfavorable for decompression melting) but extreme lateral variations in slab heating and shallow back-arc temperatures (Figure 1). Extension produced by retreat of the overriding plate away from the arc/trench produces laterally uniform slab/wedge temperatures and steep return flow trajectories (favorable for decompression melting). Results are being related to recent data sets collected by C. Langmuir in the Tonga-Lau system.

During his 2006 visit to the GFD facility at RSES, Prof Kincaid (with ARC collaborator J. Foden) has considered what temporal changes in plate motions (slab and BS) allow material from a hydrated boundary layer above the downgoing slab to be brought up into the melting zone beneath either the arc or the back-arc. Results are being related to geological data on the spatial and temporal distributions of Boninite magmas in subduction environments. This work is related to another long term NSF funded project involving a multidisciplinary, multi-institutional approach to studying the continental evolution of the northwestern USA (http://www.dtm.ciw.edu/research/HLP). The project includes geological and geochemical field work (T. Grove, MIT; A. Grunder & R. Duncan, OSU; W. Hart, Miami; R. Carlson, Carnegie), seismic imaging (D. James, Carnegie; M. Fouch, Arizona; R. Keller, UO; S. Harder, UTEP) and geodynamic modeling (Kincaid/Griffiths). We have added to the existing apparatus the ability to introduce plumes (with a controlled location, temperature and buoyancy flux) to model how both plume heads and tails are deformed by extreme three-dimensional shear flows that are produced in subduction zones with rollback and back-arc extension. Both generic cases to document basic plate-plume interaction modes and experiments with parameters (e.g., plate motion histories) specific to the Cascades-Yellowstone system will be run.

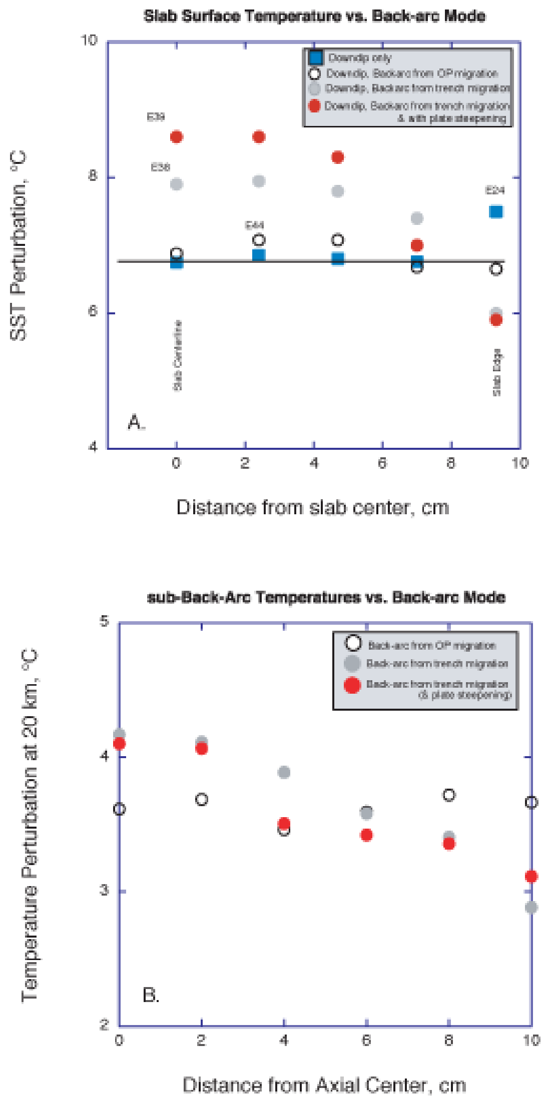


Figure 1. Plots of temperature perturbations produced along the surface of the subducting slab (A) and beneath the back-arc spreading center. Values are plotted as a function on distance from either the center of the slab or the back-arc spreading axis. Values are laboratory perturbations, produced by subtracting off initial reference values (5°C for the slab, ~15°C for the back-arc). Slab surface temperatures are from a scaled depth of 160 km after ~30 Ma of subduction. Sub-back-arc values are from a scaled depth of 20 km after 30 Ma of extension for cases with a 250km trench - back-arc separation. (OP=overriding plate)

Figure 1

References: Kincaid, C., and R. W. Griffiths (2003) Thermal evolution of the mantle during rollback subduction, *Nature* , 425 , 58-62

Kincaid, C. and R. W. Griffiths (2004) Variability in mantle flow and temperatures within subduction zones. *Geochem. Geophys. Geosyst.* , 5, Q06002, doi:10.1029/2003GC000666

Strengthening International Science and Science Commons - IAGA and *e* GY

Charles Barton 1

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

Charles Barton served throughout the year as President of the International Association of Geomagnetism and Aeronomy (IAGA www.iugg.org/IAGA), Chair of the International Committee for the Electronic Geophysical Year, 2007-2008 (*e* GY www.egy.org), and as a member of two National Committees of the Australian Academy of Science: Earth Science and Space Science. Duties involved two months working at the University of Colorado (Laboratory for Atmospheric and Space Physics) and participation in meetings and international conferences in Boulder (*e* GY) , Vienna (EGS), Canberra (White Conference on Data Explosion), Singapore (AOGS), Beijing (COSPAR), Brussels (European Commission; Global Science Commons), and Beijing (CODATA). IAGA continues to serve as the pre-eminent international body for coordinating, promoting, and communicating the science of geomagnetism and aeronomy. Our growing dependence on space systems and manned space exploration has led to keen interest in space weather. IAGA is one of the seven Scientific Associations of the International Unipon of Geodesy and Geophysics (www.iugg.org). *e* GY was initiated by IAGA to mark the 50-year anniversary of the highly successful International Geophysical Year. It joins with the three other international science year programs: the International Polar Year, the International Year of Planet Earth, and the International Heliophysical Year. *e* GY adopts the IGY principles of promoting better science by sharing and providing ready access to data and information – but by using the power of modern information and communication technologies. *e* GY provides a common theme linking all the international science year programs as well as the ambitious Global Earth Observing System of Systems initiative that arose from the Earth Observation Summits. On the home front, a case is being prepared for Australia to rejoin CODATA (the International Council for Science's Committee on Data for Science and Technology) as a means of providing a focus for informatics and science commons developments in Australia .

Thermo-chemical Evolution of the Australian Continent

Justin Freeman 1 and Jean Braun 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Department of Earth Science, University of Rennes , France

A new view of regional and global scale tectonics is emerging in which chemistry has a very strong influence on the dynamics and evolution of planetary surfaces. That is, while thermal buoyancy is largely responsible for driving plates and generating plumes, small variations in chemistry (or phase) introduce compositional buoyancy that drastically adjust, and sometimes dominate, the dynamics. The strength and evolution of continents is known to require compositional buoyancy to explain their longevity and geology. Furthermore, the evolution of descending slabs in the mantle is affected by the well-known pressure-induced phase changes at 410 km and 660 km depth. A fundamental aspect of thermo-chemical convection is the entrainment that occurs at the chemical interface, strongly influencing the stability and evolution of plumes, and yet this is largely unaccounted for in current models. Whether continents, slabs, or plumes, these features have almost exclusively been studied in 2-D and yet, time and time again, studies have shown that the third dimension is essential for understanding their behavior. With widespread advances in computational resources and techniques, it is no longer necessary to continue working under the false assumption that the geometry of the system may be simplified. We have developed a 3-D geodynamic computational code for the modeling of thermo-chemical convection and are currently applying this state-of-the-art software to problems in the Earth and planetary sciences. One such example is the current investigation of the thermal structure of the Australian continent. Currently, the structure of the upper mantle of the Earth is constrained through seismic tomography models, regional geological models and the interpretation of geochemistry. The combination of such data sets allows for a picture of the interior to be built up and the processes governing such details may be inferred. Recent developments (Faul and Jackson, 2003; Priestley and McKenzie, 2006) have provided a method for determining upper mantle temperatures from shear wave tomography (Figure 1). Through combining such upper mantle temperature estimates with geophysical, geochemical and geological data sets, a picture of the Australian continent as well as the continental lithosphere and the upper mantle structure beneath Australia may be constructed. A natural extension of such a model is to incorporate these data sets into a 3-D thermo-chemical convection model of the Australian continent. Continental volumes may be represented as chemically distinct regions, including variable heat source distributions and thermodynamic properties (such as thermal diffusivities).

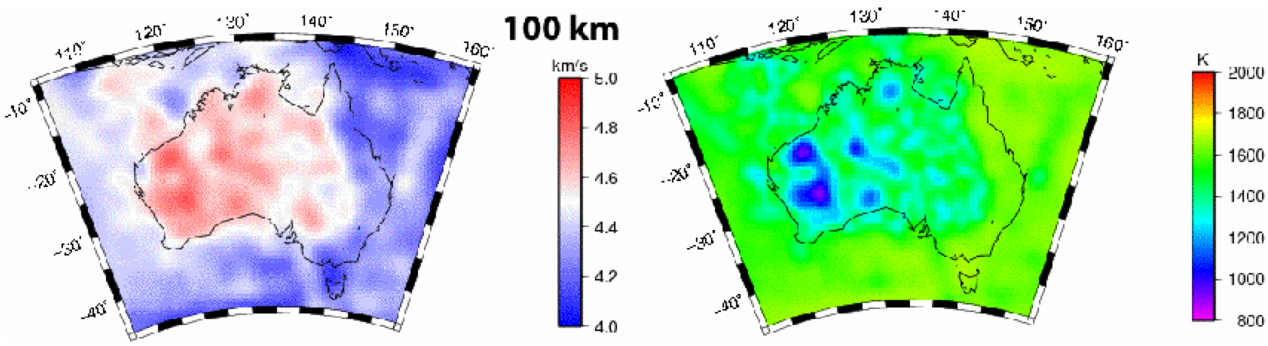


Figure 1. Shear wave tomography (left) at a depth of 100 km beneath the Australian continent. Red regions correspond to fast velocities and blue is slow. Calculated upper mantle temperature

(right) derived from the tomography model. The method to determine temperature from *V s* is from Priestly and McKenzie (2006). At this depth, hot upper mantle temperatures are observed in the east whilst the west shows regions with cooler temperatures. From Freeman et al. (in preparation).

References:

Faul, U. H. and Jackson, I., The seismological signature of temperature and grain size variations in the upper mantle EPSL, 234, 119-134, 2005.

Priestley, K. and McKenzie, D., The thermal structure of the lithosphere from shear wave velocities EPSL, 244, 285-301, 2006.

Quantitative infra-red absorption spectroscopy

Malcolm Sambridge, Istvan Kovacs, Joerg Hermann, Hugh O'Neill, John Fitzgerald

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

A new collaboration with members of the Earth materials area of the school was initiated this year in the area of I nfra-red (IR) spectroscopy. IR spectroscopy involves the measurement of light absorbance by anisotropic crystals. Important mineralogical applications include the quantification of water content of minerals like olivine and pyroxenes. The technique may also provide clues on the crystallography of water substitution. The governing physics requires solutions to Maxwell's equations for light propagation in media where both refractive index and absorption vary anisotropically, and these can become rather complicated. As a result this has largely neglected by modern practitioners in favour of empirically determined relationships between various quantities. In the present collaboration the fundamental physics (developed mostly in the latter part of the 19 th and early 20 th Centuries) has been re-examined. It has been possible to derive expressions for the distribution of polarized and unpolarized absorbance of linearly polarized light travelling in an arbitrary direction in weakly absorbing media.

The figure shows the predicted and observed angular variation of absorbance as a function of the polarization angle of the incoming light. Each polar plot is for a different incoming light direction. The consistency between predictions and observations shows that the new theory is a good match to the data. Using the new theory it's possible to estimate total absorbance (and hence water concentration) in minerals from unpolarized light at random directions. From an experimental viewpoint use of unpolarized light avoids many of the difficulties encountered with polarized light, which widens the range of minerals to which the technique can be applied.

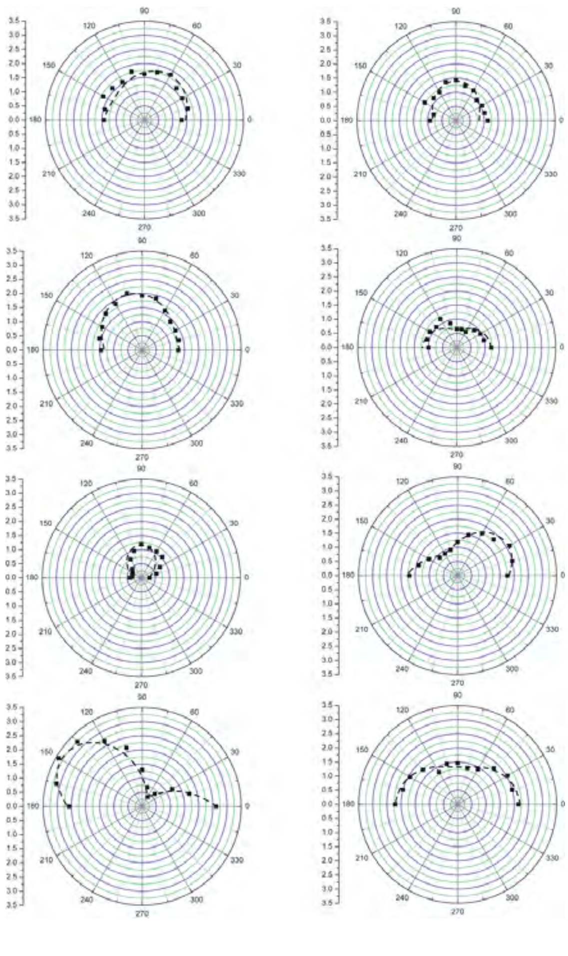


Figure 1: Angular variation of integrated absorbance for random light directions. The dashed line shows the prediction from the new theory the dots show the observations.

Constraining source location and mechanism using coda wave interferometry

David Robinson 1 , Roel Snieder 2, Malcolm Sambridge 1

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 Centre for wave phenomena, Colorado School of Mines, Golden , Colorado , USA .

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. An example of such a PDF is shown in Figure 1. 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. The mechanism perturbation is a simple function of the change in strike, dip and rake of the double couple. Applicability of the theory is tested using synthetic waveforms generated from a 3D finite difference solver for the elastic wave equation. Perturbations in strike, dip and rake are tested independently and simultaneously. In each case a cross-over point is identified such that the estimated source change is within one standard deviation of the actual change for all perturbations below the cross-over. After the cross-over the CWI estimates represent a lower bound for the change in mechanism. Cross-over points of 30, 62 and 56 degrees are observed when the strike, dip and rake are varied independently. When all angles are varied by the same perturbation simultaneously the cross-over point is 17 degrees. The new theory creates the potential for joint relative location and focal mechanism determination using information from seismic coda, a component of the waveform that is often discarded. We anticipate the publication of this work in 2007.

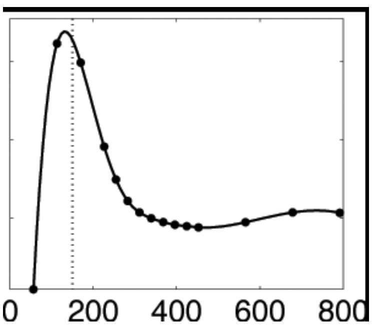


Figure 1: Probability density function for the actual separation between two double couple events given a CWI estimate of 150 m. The vertical dashed line represents an actual separation of 150 m.

References: 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

High resolution seismic imaging of southeast Australia using multiple array deployments

Rawlinson, N. and Kennett, B. L. N.

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

The Tasman Orogen, or "Tasmanides" occupies the eastern third of the Australian continent, and is distinct from the Precambrian cratonic terrane to the west both in terms of its subduction accretion style of emplacement, and its Phanerozoic age. Over the last decade up to 10 separate temporary seismic arrays have been deployed to target the southern half of this region of the Australian continent (see Figure 1). In most cases, vertical component short period seismometers have been used, with 3-D P-wave teleseismic tomography being the primary tool of analysis. Beginning with SETA in southeast Tasmania , a new generation of seismic equipment featuring 3-component short period sensors is now being used. One of our current goals is to combine data from all available experiments in a single inversion for the 3-D seismic structure of the upper mantle beneath this region.

The EVA array (see figure), which covers much of eastern Victoria , comprises 50 short period vertical component seismometers, and was deployed in September 2005. After continuously recording for a period of approximately 8 months, the array was removed in May 2006. Considering the rugged terrain and significant forestation that characterizes much of eastern Victoria , the data is generally of high quality, with a large number of teleseisms detected. A preliminary teleseismic tomography model has been generated using arrival time information from 90 distant earthquakes, and the resultant images exhibit significant lateral variations in wavespeed. Of particular interest is a strong velocity contrast at 50-100 km depth between northern Victoria (higher wavespeed) and southern Victoria (lower wavespeed). Further work is required to properly understand the geological implications of these results.

In early October 2006, an array of 40 3-component short period seismometers was deployed in southeast Tasmania as part of the SETA experiment. The array will be in place for a period of approximately 8 months to record large distant earthquakes. In addition, our collaborator Dr. Michael Roach from the University of Tasmania , will detonate several explosive sources to improve crustal path coverage. The use of 3-component seismometers should allow additional information on seismic structure to be inferred from techniques such as crustal receiver functions and S-wave tomography. In February 2007, the SEAL2 array will be deployed in NSW in a collaborative project with the NSW geological survey. Additional array deployments are expected to take place to the east and north of SEAL2 in late 2007 and early 2008.

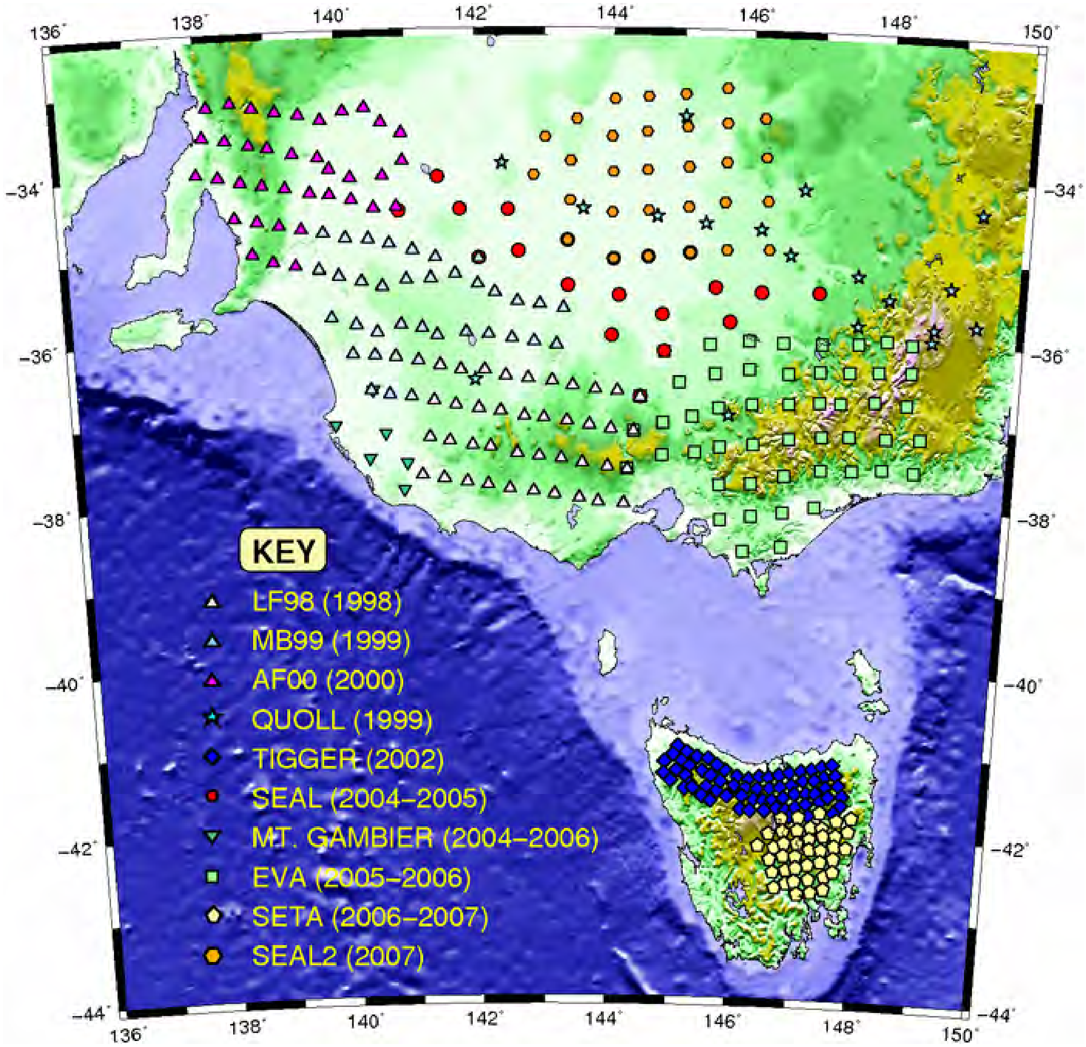


Figure 1: Distribution of temporary passive seismic arrays in southeast Australia over the last decade.

Simultaneous inversion of active and passive source datasets for 3-D seismic structure

N. Rawlinson and M. Urvoy

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

Seismic body wave tomography is a well established tool for imaging subsurface seismic structure at a variety of scales, but most applications involve a single type of dataset, such as local earthquake, teleseismic, or refraction and wide-angle reflection. However, with ongoing seismic deployments around the world, it is becoming increasingly common for multiple datasets to span a common region of the Earth. Rather than treat each dataset separately, a combined inversion would in many cases be preferable, as the increased path coverage should result in a better constrained model.

We have developed an innovative new tool for combining a variety of body wave data types in a simultaneous inversion for seismic structure and source location. The forward problem of traveltime prediction is solved using a new grid based scheme known as the multi-stage fast marching method, which can track phases comprising any number of reflection or refraction branches in 3-D heterogeneous media containing undulating interfaces. The inverse problem of adjusting velocity, interface and source location parameters is solved using an efficient subspace inversion method. The new iterative non-linear tomography scheme is capable of combining multiple overlapping body wave datasets of different geometry in a single inversion for velocity structure, interface geometry and/or hypocenter location.

The new scheme has been applied to refraction, wide-angle reflection and teleseismic arrival time data from Tasmania in a simultaneous inversion for 3-D lithospheric P-wavespeed and Moho geometry. A total of 6520 teleseismic arrival time residuals from the 2002 TIGGER experiment and 3172 crustal refraction and reflection (Pn, PmP and Pg phases) traveltimes from the 1995 TASGO experiment are used to constrain 3-D seismic structure. The crossing path coverage of the teleseismic dataset is extensive in the lower crust and upper mantle, but virtually non-existent in the mid-upper crust. In contrast, the path coverage of the active source dataset is almost exclusively crustal, with some penetration of the uppermost mantle. As a result, the two datasets are highly complimentary, and their combined inversion holds the promise of properly resolving both crustal and upper mantle structure.

The figure shows several several slices through the Tasmanian tomography solution model. In contrast to previous results from separate inversions of the active and passive source datasets, the new images reveal a zone of elevated wavespeed beneath the Cambrian Mt. Read Volcanics, and indicate that both crustal thinning and elevated wavespeeds occur beneath northeast Tasmania , which supports the case for the existence of a prior passive margin. Otherwise, most major inferences from the previous studies, including evidence for a remnant subduction and rustal shortening, are supported by the new results.

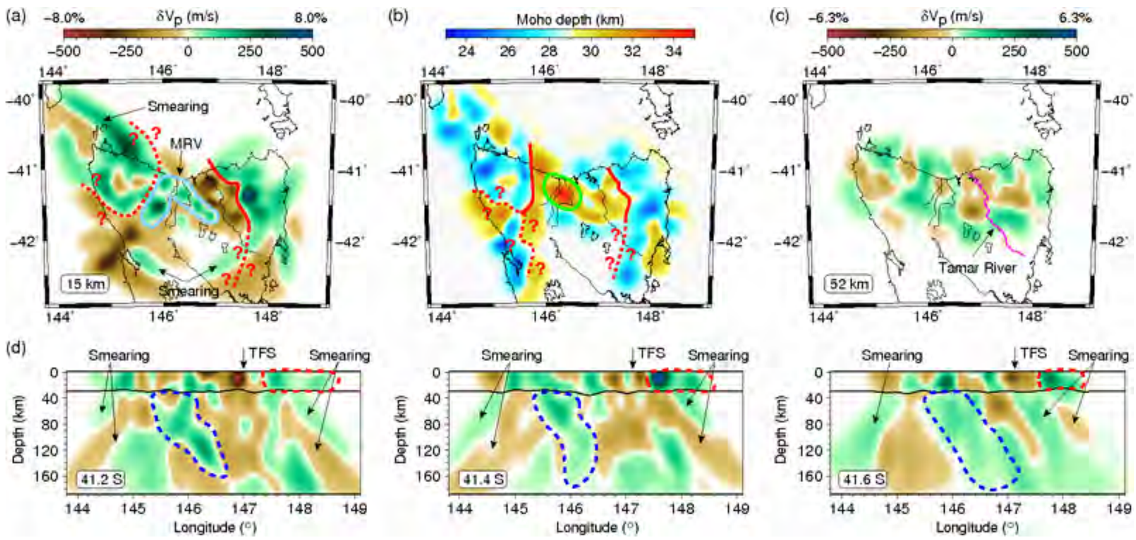


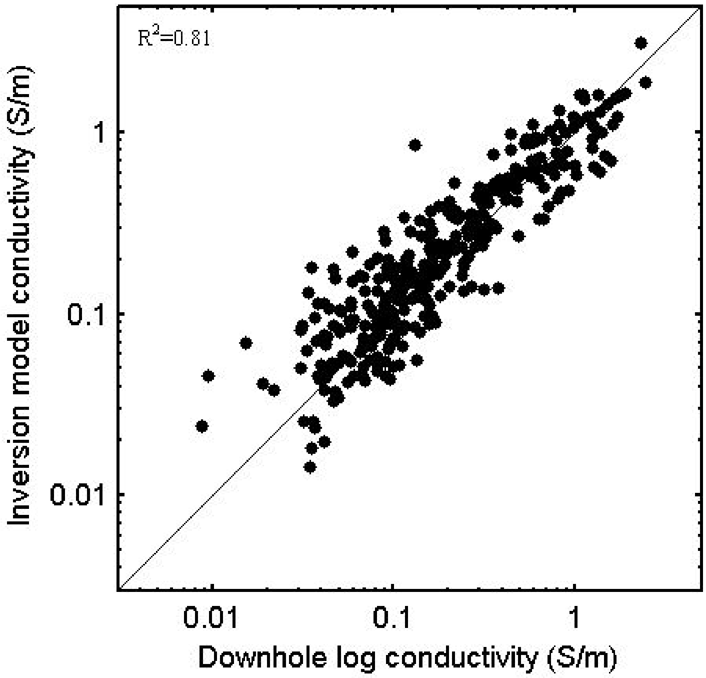
Figure 1: Summary of Tasmania tomography results. (a) Crustal section at 15 km depth; (b) Moho structure; (c) upper mantle section at 52 km depth; (d) three east-west cross-sections. Several features of interest have been highlighted. TFS = Tamar Fracture System; MRV = Mt. Read Volcanics.

Calibration and Inversion of Airborne Geophysical Data

R. Brodie and M. Sambridge

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

Prior to 2006, holistic inversion http://rses.anu.edu.au/cadi/ar/ar05/cadi5.html of frequency-domain airborne electromagnetic data had been successfully applied in situations where there was considerable prior knowledge of the geology and conductivity structure of the survey area to constrain the inversion (Brodie and Sambridge, 2006a). Over the last year we have investigated how well the method works when there is a lack of prior information. To simulate this scenario we inverted the same datasets without the use of a sophisticated prior reference model, downhole conductivity logs, or watertable depth constraints, all of which had been used in our previous work. We adopted a generalised multi-layer fixed layer thickness inversion model and used a homogenous reference model. To compensate for the lack of hard constraints we imposed vertical smoothness regularisation on the conductivity model to stabilise the inversion. is possible to extract information from the subsurface along the connecting path between two stations by just using Earth's ambient seismic noise field. Due to the inter-station distance and spectrum characteristics of the noise field, the extracted signal is mainly the Green's function of Rayleigh wave type surface wave for vertical components. The seismic broadband data was compiled from the temporary and permanent stations across the Australian continent from 1992 to 2006. The data was used to calculate the Green's function between each possible station pairs which resulted in a coverage of the continent as in earthquake tomography studies with over 1000 individual raypaths. Then seismic tomography was set to construct the group velocity image for Australian crust with frequency dependency. The image which was obtained from the seismic tomography, clearly maps the major geological units in the crust. The geologically older parts of the continent in the west have higher group velocities. In contrast to this, the relatively younger Phanerozoic belts are marked with lower group velocities Figure 1. A comparison of downhole log conductivity measurements and holistic inversion model conductivities. Although the downhole log data were not actually used in the inversion the correlation between the inversion model conductivities and downhole log data was high, as is demonstrated in Figure 1.



Each point on this figure relates to the average conductivity over 5 m intervals for all the 44 available downhole logs. We have also found that gain and bias calibration parameters were similar to those we had estimated by other methods that had incorporated substantial information.The extracted wavefield which is the Rayleigh wave component of the Green's function, from the correlations of permanent station CTAO with other stations. Figure 2: The map in A shows the raypath distribution used in the group velocity tomography. Group velocity anomalies for two different frequencies are given in B for 0.2 Hz and C for 0.08 Hz.

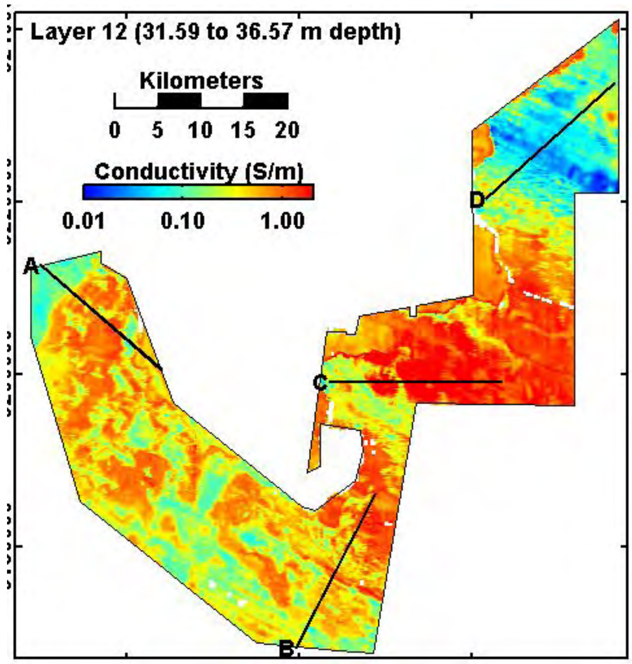


Figure 2 shows the conductivity of layer 12 of the holistic inversion model. Figure 3 shows an example of a section through the inversion models. It can be seen that the top of the conductive zone at around 15-20 m elevation is coincident with the elevation of the known depth of a saline watertable. Our research has led us to concluded that the holistic inversion can be successfully applied in cases where little or no prior information is available (Brodie and Sambridge, 2006b).

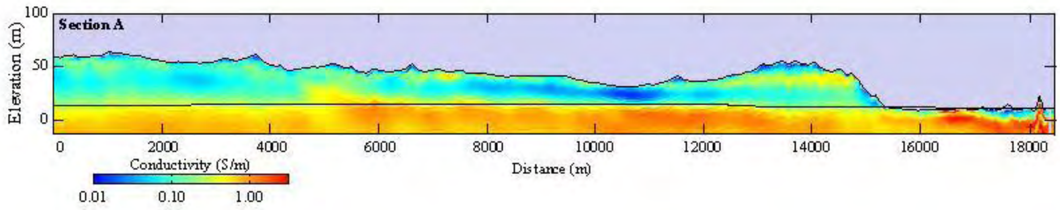


Figure 3. A conductivity section through holistic inversion model along the profile labelled A on Figure 2. The top of the watertable surface is shown by the black line at approximately 15-20 m elevation.

Since the multi-layer inversion requires many more inversion parameters we had to parallelise the holistic inversion code. For this we used the MPI paradigm implemented mainly via the PETSc code for distributed sparse matrix algebra. Parallelisation has allowed us to invert whole datasets, rather than subsets, for multi-layer models. We have run inversions with up to 8.07 million data and 3.40 million parameters on 64 nodes of the Terrawulf Cluster.

References:

Brodie, R. and Sambridge, M., 2006, A holistic approach to inversion of frequency-domain airborne EM data: Geophysics, 71, G301-G312.
Brodie, R. and Sambridge, M., 2006, Holistic inversion without prior information: Australian Earth Science Convention 2006 - Melbourne , Australia , ASEG, Extended Abstracts.

Geomagnetism

F. E. M. Lilley

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

Work has continued in 2006 bringing a number of contributions to publication stage. These are concerned particularly with electromagnetic induction in the Earth and its oceans. Contact has been maintained with Professor J.T. Weaver of Canada , regarding the analysis of magnetotelluric data for local geological distortion, and regional geological dimensionality. Discussion has continued with other Australian geophysicists pursuing research based on electromagnetic induction by natural source fields, and related topics .

Volcano-tectonic earthquakes and magma reservoirs; their roles in volcanic eruptions at Rabaul Caldera

Itikarai 1 , B.L.N. Kennett 1 , C. Sinadinovski 1 , N. Rawlinson 1

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

Since seismic monitoring began in the late 1960s the seismicity in Rabaul caldera has been marked by intra-caldera high frequency volcano-tectonic earthquakes. The hypocentral distribution of these earthquakes defines an outward-dipping elliptical ring-fault in shallow depths (Mori et al., 1987). Before the 1994 eruption other prominent seismicity includes a swarm of earthquakes that occurred in May 1992 away from the caldera in a northeasterly direction.

After the eruption the intra-caldera seismicity decreased significantly. The locatable events have been sparsely distributed within the caldera with majority of them located on the southern section of the ring-fault. These events have been overshadowed by a group of earthquakes that occurred northeast of the caldera. Observations between the ongoing eruptions at Tavurvur and the periodic episodes of northeasterly earthquakes between 1995 and 2005 show interesting correlations. Notable episodes of northeasterly earthquakes have been followed by intensified or renewed eruptive activity. The lead-time between earthquakes and either one of the types of eruptive activity is between few and several months. We speculate that the northeast earthquakes mark episodes of intrusions of a second magma source into the caldera magma reservoir allowing magma mixing to occur, hence resulting in the ongoing eruption at Tavurvur.

P-wave traveltime tomography using the Fast Marching Method (Rawlinson and Sambridge, 2004) was used to map low velocity anomalies in and around Rabaul Caldera. 541 regional and local earthquakes detected by 20 seismic stations of the Rabaul Harbour Network, operating at different times, and giving rise to 3744 raypaths were used. The results suggests up to three possible magma reservoirs. One is the shallow caldera reservoir (Finlayson et al., 2003) and the other two, the first slightly deeper beneath the caldera and the second northeast of the caldera, are new finds (this study and Bai and Greenhalgh, 2005). The proximity of the northeast earthquakes to the north-northeasterly low velocity anomaly, evidence of magma mixing in Tavurvur eruptives, but not Vulcan, (Patia et al., 2002) and other information strongly suggests this anomaly is a magma reservoir, most likely basaltic in composition, and is the source of magma injected into the caldera reservoir.

The above information, particularly the reasonable correlation between the northeast volcano tectonic earthquakes and the ongoing eruptions at Tavurvur between 1995 and 2005, could be useful for future eruption forecasting and disaster mitigation in Rabaul.

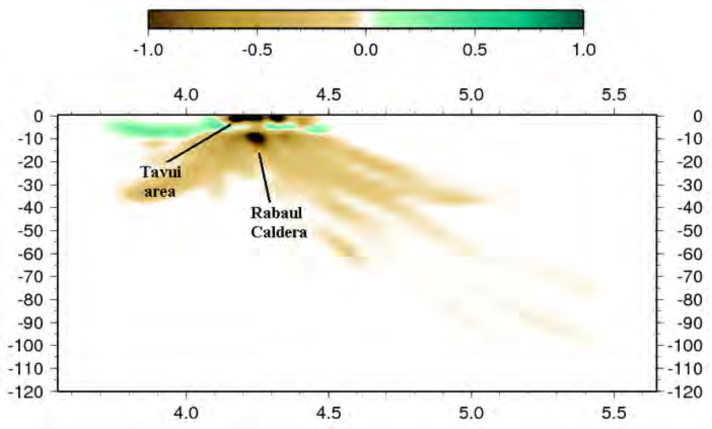


Figure. 1 : Velocity perturbation (in %) from the 1- D reference velocity model for a N-S cross-section passing through the centre of Rabaul Caldera and the Tavui region.

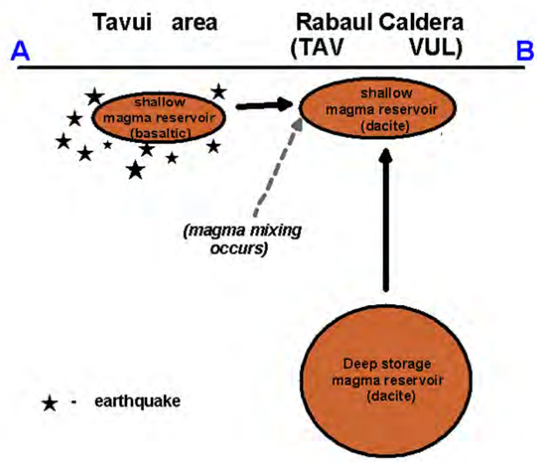


Figure. 2: Model for magma interactions in and around Rabaul Caldera.

References

Bai, C., and Greenhalgh, S., 2005. 3D multi-step travel time tomography: Imaging the local, deep velocity structure of Rabaul volcano, Papua New Guinea . Physics of the Earth and Planetary Interiors, 151, 259-275.

Mori, J., and McKee, C. O., 1987. Outward-dipping ring fault structure at Rabaul caldera as shown by earthquake locations, Science, 235, 193-195.

Patia, H., Eggins, S., McKee, C. O., and Johnson, R. J., 2002. The 1994 to 2001 eruption at Rabaul , Papua New Guinea : Evidence of repeated basaltic magma influx into a sub-caldera dacitic magma reservoir, 16th Australian Geological Convention, Adelaide , Abstract.

Rawlinson, N., and Sambridge, M., 2004. Wavefront evolution in strongly heterogeneous layered media using the fast marching method, Geophysical Journal International, 156, 631-647.

Roggensack, K., Williams, S. N., Schaefer, S. J., and Parnell Jr., R. A., 1995. Volatiles from the 1994 Eruptions of Rabaul: Understanding large caldera systems, Science, 273, 490-493.

Historical earthquakes: A case study for Adelaide 1954 earthquake

Cvetan Sinadinovski 1 , Stewart Greenhalgh 2 and David Love 3

1 Research School of Earth Sciences, Australian National University, Canberra 0200 ACT
2 Physics Department, Adelaide University, Adelaide 5000 SA
3 Primary Industries and Resources, South Australia, Adelaide 5000 SA

The accuracy of a seismic risk assessment is related to the time span of the data base. The longer the seismicity of an area is observed, the better the ability to predict future activity. Historical records of earthquakes stretch back more than four times the period of instrumentally recorded earthquakes, so the value of historical earthquakes and isoseismal maps (for example Fig. 1) is of great importance for calibration of ground motion models. Building type is taken into account during assigning of the intensity values and such maps reflect the local geology and soil characteristics.

Of interest to the insurers are also interrelated aspects of risk calculation such as the expected earthquake occurrences, maximum magnitudes and intensities, and anticipated damage. We have used a well documented case of the Adelaide 1954 earthquake to address these aspects and tried to compare the MM intensities with the damage ratios for the purposes of loss calculation. Our estimates are about 1% of the effective loss of the replacement value of insured dwellings in Adelaide. Earlier results of the Probable Maximum Losses studies based on aggregation of losses for several regions of MMI produced estimates in the range of 2 to 5% for a shallow earthquake with magnitude 5.6 below postcode 5000, with uncertainties in the results attributed to the modelling of the subsoils and choice of attenuation function.

By 1957 most of Adelaide Plains had been urbanised with expansion of low density housing after WW-II with the growth of outer centres and southwards along the coast. With the southerly development of Adelaide's suburbs an event of similar size recurring today might be expected to cause significantly higher loss.

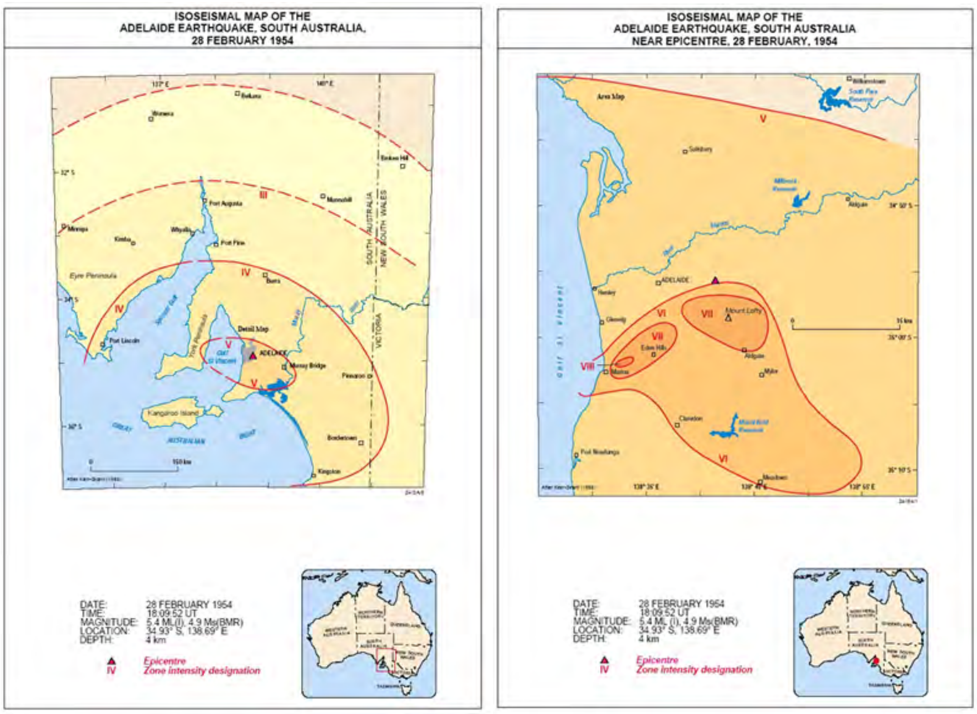


Figure 1: Isoseismal map of Adelaide 1954 earthquake

P Wave Tomography of Western Australia

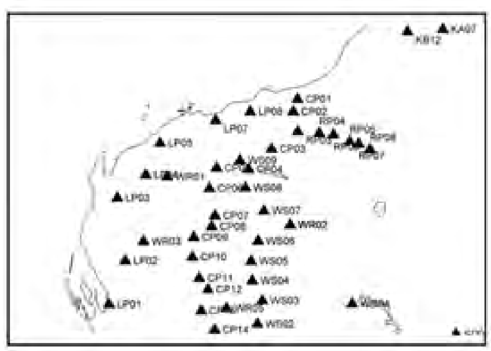
Agus Abdulah, Cvetan Sinadinovski and B.L.N. Kennett

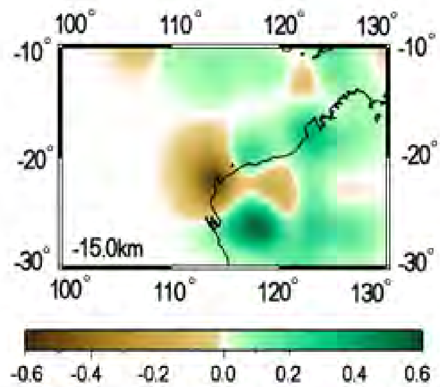
1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

Geologically, Western Australia is characterized by four main geologic features: Pilbara, Bangamall, Capricorn and Yilgarn Cratons. Pilbara in the north and Yilgarn in the south are Achaean Cratons. These two cratons are separated by two younger sediments, they are Bangamall 'Grenvillean' basin and Capricorn (early proterozoic orogen) [Betts et al., 2002]. This research is carried out to image the 3D structure of these geological features by using P-wave tomography technique.

There are about 45 seismic stations across Western Australia (Figure 1) which record local and broadband earthquakes with magnitudes between 3.0 and 7.0mb and depth between 1.0 and 600 km. This station-event pairs produce nearly 600 raypaths.

600 P wave traveltimes were hand picked and store it as data input for our tomography work. The tomography routine and the Fast Marching Method of Rawlinson et al. (2004 are used to trace seismic path in 1D model of ak135. Our area of study was discretised using grid node configuration with number of propagation grids are 30 x 46 x 55 for depth, latitude and longitude respectively.





The preliminary result of the tomography image at -15km of Western Australia is shown in Figure 2. The color represents P wave perturbation in percent relative to the ak135 model. Green represents high seismic speed and brown represents low seismic speed. The Achaean Cratons of Pilbara in the north and Yilgarn in the south are associated with high seismic speed anomaly, while the Bangamall and Capricorn are associated with low seismic speed.

Reference:

Betts P. G., D. Giles, G.S. Lister and L. R. Frick. 2002. Evolution of the Australian lithosphere, *Australian Journal of Earth Sciences*, **49** , 661–695

Rawlinson, N., and Sambridge, M., 2004. Wavefront evolution in strongly heterogeneous layered media using the fast marching method, Geophysical Journal International, 156, 631-647

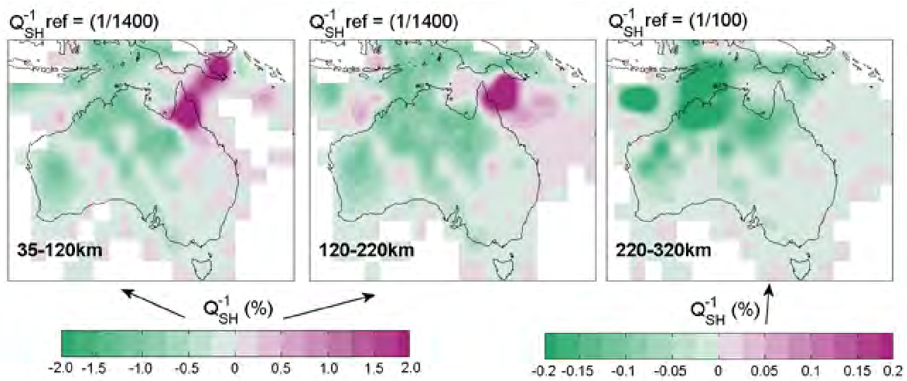
Attenuation Tomography of Australia

A. Abdulah & B.L.N. Kennett

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

The strategic position of the Australian continent in the middle of seismicity belts which extend from Java to Sumatra and the mid-ocean ridge to the south of the continent provides a wealth of events at suitable distances to be used as probes into the seismic structure of the upper mantle. The extensive deployments of portable broadband seismic stations across the Australian Continent and Tasmania since 1993 offers robust seismological data with a dense coverage at distances from 5° to 45°. Over the last two decades, a wide range of studies have been used to gain information on one-dimensional and three-dimensional structure in the mantle which exploits different aspects of seismograms. *P* and *S* wave seismic traveltimes from nearly 4000 three-component seismic dataset from the record have been hand picked. The wave ratio method is then applied to estimate the spectral ratio between shear and compressional waves. Seismic spectra are estimated using the multitaper method with 512 points in window range of 30s to 45s and frequency range of 0.25Hz to 1.00Hz.

Three-dimensional *P* and *S* wave speed tomography is conducted by inverting a kernel matrix obtained from a quasi three dimensional ray tracing which respect to *P* and *S* wave seismic traveltime residuals from the ak135 model. The study area from latitude 22° N to 65S° and longitude 78° to 189° and 0-1240km depth is discretised into 11100 cells with a cell size 3°x3° and depth increments of 35 or 200km. Both *P* and *S* -wave speed information from the seismic wave speed tomography are then utilised as data input for 3-D seismic attenuation tomography. In this inversion, it is assumed that *QP=2.3QS*. The seismic attenuation anisotropy in terms of the ratio between seismic attenuation derived from *SV* and *SH* component is also presented.



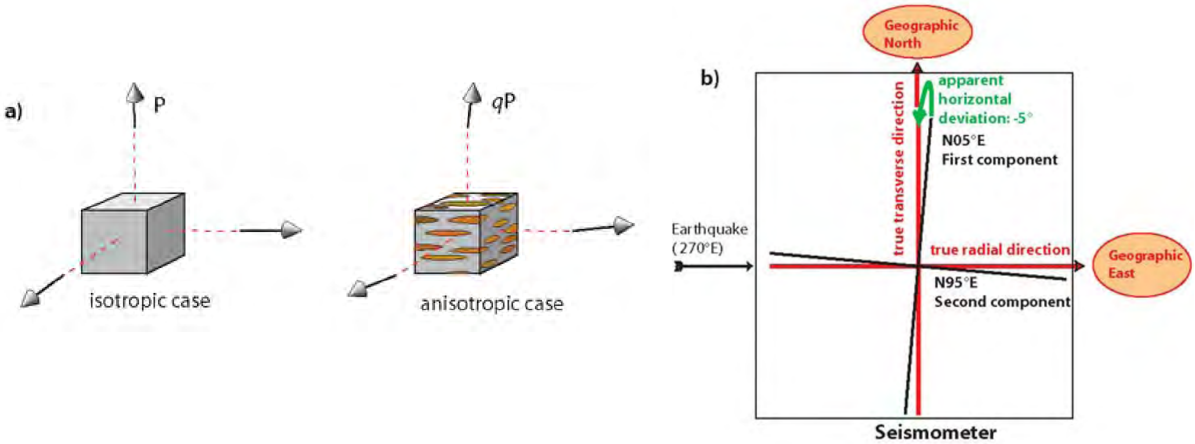
The major feature that is revealed from the both seismic wave and seismic attenuation studies is a strong contrast in deep structure between central Australia and the eastern seaboard (as can be seen in the Figure). Further representation of seismic attenuation anisotropy suggests that in the region where seismic coverage is good, transverse component (*SH*) wave is less attenuated than radial component (*SV*). The Archaean and the Proterozoic rocks in the west and in the middle of the continent point to a high seismic wave speed anomaly and low seismic attenuation and the Phanerozoic rocks and the presence of recent volcanism and region of high heat flow in the east are associated with low seismic wave speed anomaly and high seismic attenuation.

Earthquake location and upper mantle structure from *P* wave polarization in French Polynesia and Australia

Fabrice R. Fontaine 1 , Guilhem Barruol 2 , Brian L.N. Kennett 1 , Götz H. Bokelmann 2 , Dominique Reymond 3

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Laboratoire de Tectonophysique, Université Montpellier II, CNRS, ISTEEM, Montpellier, 34095 France
3 Laboratoire de Géophysique, CEA, Pamatai, Faaa, 98702 French Polynesia

We realized measurements of long-period *P* wave polarization in French Polynesia and in Australia. The 3D character of particle motion of *P* waves provides complementary and independent constraints on the upper mantle structure beneath a given station to that from shear-wave splitting. Analysis of the deviation of horizontal polarization and the vertical polarization angle as a function of event backazimuth are used to obtain information about: i) sensor misorientation, ii) seismic anisotropy, and iii) velocity heterogeneities. The measurements are realized with a method proposed by Schulte-Pelkum *et al.* (2001). We propose an alternative technique for temporary deployed seismic stations. Despite the availability of 15 years of data, the two permanent stations on Tahiti do not show any evidence of shear-wave splitting (Fontaine *et al.* , submitted) whereas *P* wave polarization observations do. Using the latter technique the fast axis azimuth is oriented N72°E close to the orientation of the ancient fracture zones . This direction is consistent with the observed fast axis orientation within the upper lithosphere from surface wave tomographic model by Maggi *et al.* (2006). This suggests that *SKS* waves sample either a complex upper mantle structure induced by the recent magmatism on Tahiti or a vertical mantle upwelling, while *P* waves identify an azimuthal anisotropy in the lithosphere at somewhat larger horizontal distance from the station, since the incidence angles are much larger than the *SKS* waves. Australia is ideally located for *P* wave polarization analysis due to the favourable distribution of seismicity around this continent. Moreover, some relatively dense networks of broadband seismometers were installed throughout the Australian region during the last decade that may give the possibility to discriminate between velocity perturbations and seismic anisotropy beneath some stations. We propose the existence of a dipping structure beneath some stations to explain our observations. In Tahiti, the tsunami warning centre uses only one seismic station in real-time to determine the earthquake location. The horizontal polarization of *P* waves deviates up to 10° depending on the backazimuth of the event. The introduction in the automatic earthquake location of a term for correction of the deviation of the direction of particle motion would improve the precision of the location and thus the accuracy of the tsunami warning system.



c)

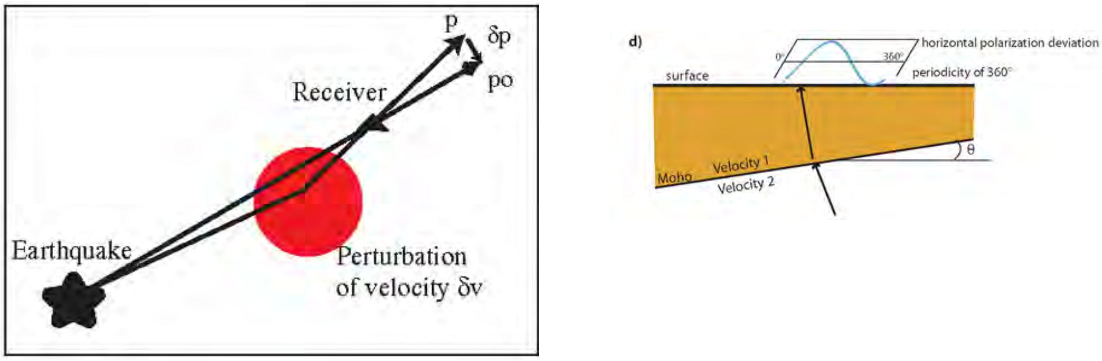


Figure 1. The deviation of polarization of *P* waves can be the result of several causes: a) seismic anisotropy of the medium, b) the sensor misorientation, c) a velocity anomaly, and d) a dipping seismic discontinuity.

References:

Fontaine F. R., Barruol G., Tommasi A., and Bokelmann G. H. R. (2006) Upper mantle flow beneath French Polynesia from shear-wave splitting, *submitted in Geophys. J. Int* .

Maggi A., Debayle E., Priestley K., and Barruol G. (2006) Azimuthal anisotropy of the Pacific region, *Earth Planet. Sci. Lett.* , doi:10.1016/j.epsl.2006.07.010.

Schulte-Pelkum V., Masters G., and Shearer P. M. (2001) Upper mantle anisotropy from long-period P polarization, *J. Geophys. Res.* , 106, 21 917-21 934.

Tracking later arrivals in heterogenous velocity models

Juerg Hauser, Nick Rawlinson, , Malcolm Sambridge

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

Continuous and discontinuous variations in seismic waves peed can cause a wave to travel to a receiver by more than one path. In such a situation Lagrangian wavefront tracking in reduced phase space can be used to calculate multivalued travel times. Source receivers ray paths can be estimated a posteriori by exploiting the connectivity between points on the wavefronts for all time steps. Our scheme currently allows calculation of later arrivals for a two dimensional velocity model with interfaces. In Figure 1 later arrivals for the reflected wave are generated due to the low velocity anomalies and the shape of the interface. This means that for some of the receivers up to 5 arrivals can be observed. However the travel time alone is not sufficient in order to identify potential later arrivals in observations. We therefore use the extracted ray paths for the calculation of synthetic seismograms. In the Gaussian beam method a synthetic seismogram is computed for a given ray path by shooting a fan of rays in the vicinity of the ray path and solving the dynamic ray equations for each ray. The seismogram is then given by a summation over those rays. In the figure synthetic seismograms are plotted for three receivers. For the receiver at 175 km the waveform is fairly complex due to the superposition of the five arrivals. For the receiver at 125 km the amplitude of the second arrival in the seismogram is larger than the one for the first arrival. This is due to a superpositon of the second and third arrival. The second and third arrival for this receiver have similar travel times. This is also visible in the ray paths of the second and third arrival being close to each other.

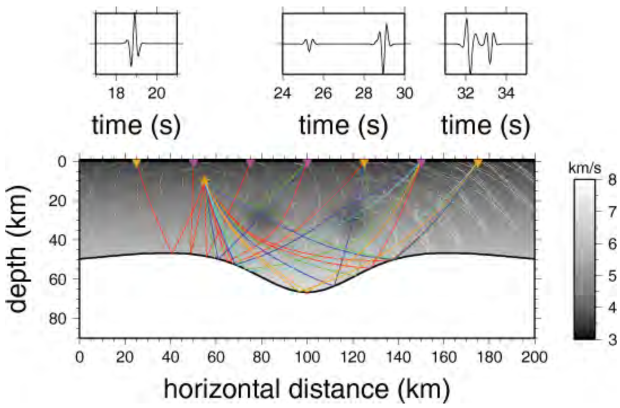


Figure 1: Synthetic seismograms, wavefronts and ray paths for the reflected wave generated by a source above an interface. First arrival ray paths are plotted in red, second in blue, third in green, fourth in light blue and fifth in orange. For the orange receivers a normalized synthetic seismogram is plotted in the box above them.

Lithospheric structure, past and present tectonics in Central East Antarctica

Anya M. Reading

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

The multi-year SSCUA experiment (seismic structure of the continenent under Antarctica) resulted in the successful collection of a unique seismic data set (2002-2004) from the previously unexplored region of Central East Antarctica, surrounding the Lambert Glacier Region (Fig. 1). In previous work, receiver function techniques were used to model the depth and the character of the seismic S-velocity profile beneath stations deployed across the region (Reading , 2006) which lies at the probably junction of three major plates in the assembly of the supercontinent of Gondwana. More recent analysis has focused on the splitting of shear waves. This indicates that the seismic energy, on its path between the Earth's core and the recording station, has encountered a region, or regions of past or present strain within the lithosphere.

Shear-wave splitting results for stations across the Lambert Glacier are shown (Fig. 2). The stations closer to the coast show fast directions parallel to the general west-east direction of the Antarctic coast-line. The strain in the deep lithosphere may be related to the rifting of the southern ocean when India and Australia broke away from this part of Antarctica . Stations furthest inland show strain in the deep lithosphere that is more likely to be related to relict structure in the most ancient blocks of the continent. New deployments associated with the International Polar Year (2007/08) are likely to provide additional seismic data to further investigate the remote interior of East Antarctica .

Figure 1. Downloading data from a station of the multi-year SSCUA seismic deployment.

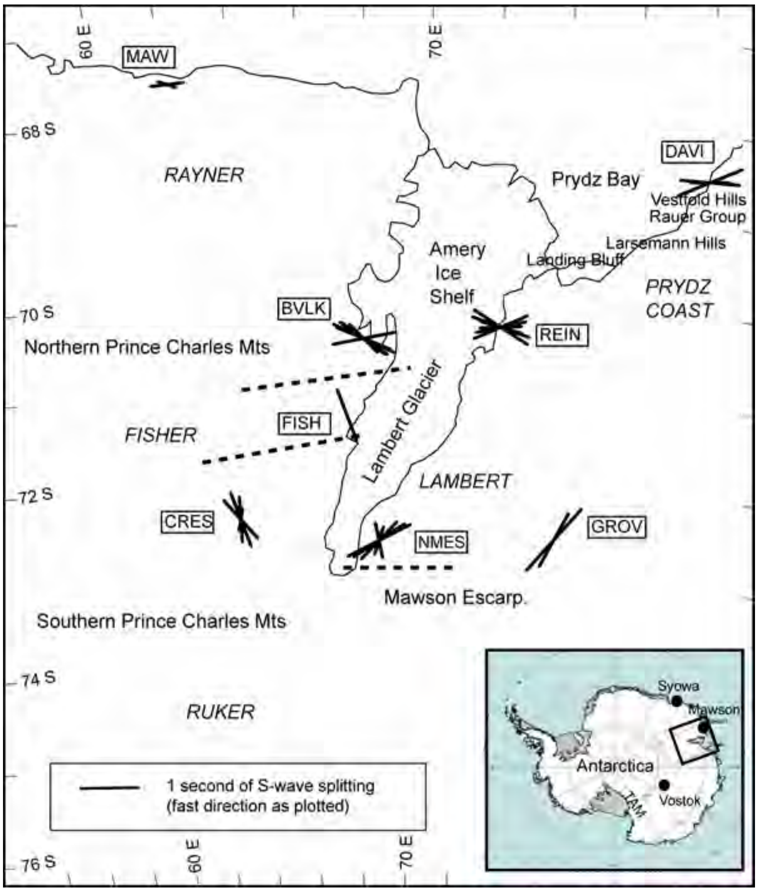


Figure 2. Shear-wave splitting results from stations of the SSCUA seismic deployment, surrounding the Lambert Glacier, East Antarctica .

References: Reading , A.M., 2006. The seismic structure of Precambrian and early Palaeozoic terranes in the Lambert Glacier region, East Antarctica . *Earth and Planetary Science Letters* , 244, 44-57.

Group Velocity Tomography of Australian Continent from Ambient Seismic Noise

Erdinc Saygin, Brian L.N. Kennett, Anya M. Reading

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

It is possible to extract information from the subsurface along the connecting path between two stations by just using Earth's ambient seismic noise field. Due to the inter-station distance and spectrum characteristics of the noise field, the extracted signal is mainly the Green's function of Rayleigh wave type surface wave for vertical components. The seismic broadband data was compiled from the temporary and permanent stations across the Australian continent from 1992 to 2006. The data was used to calculate the Green's function between each possible station pairs which resulted in a coverage of the continent as in earthquake tomography studies with over 1000 individual raypaths. Then seismic tomography was set to construct the group velocity image for Australian crust with frequency dependency. The image which was obtained from the seismic tomography, clearly maps the major geological units in the crust. The geologically older parts of the continent in the west have higher group velocities. In contrast to this, the relatively younger Phanerozoic belts are marked with lower group velocities.

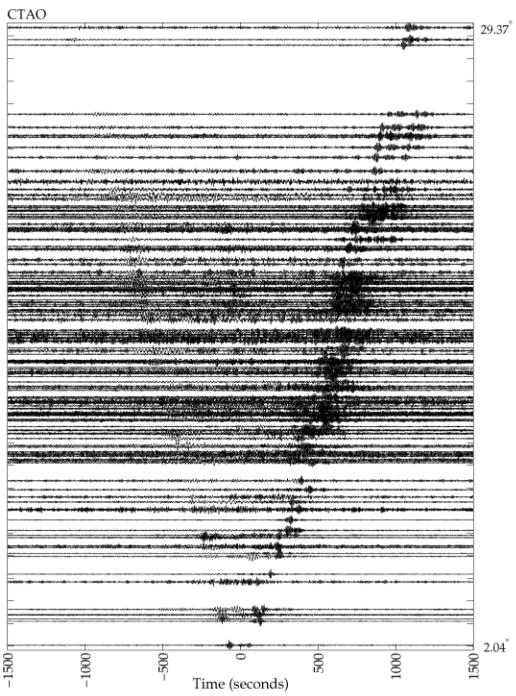


Figure 1: The extracted wavefield which is the Rayleigh wave component of the Green's function, from the correlations of permanent station CTAO with other stations.

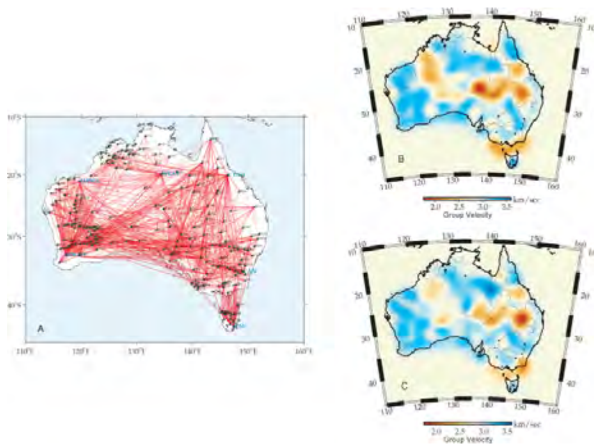


Figure 2: The map in A shows the raypath distribution used in the group velocity tomography. Group velocity anomalies for two different frequencies are given in B for 0.2 Hz and C for 0.08 Hz.

Guided Seismic Waves from the Indonesian Subduction Zone to the Australian Craton

1, B.L.N. Kennett, 2, T. Furumura

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
2 Earthquake Research Institute, University of Tokyo

Seismic wave propagation from the Indonesian subduction zone into the ancient lithosphere of the Australian cratons produces seismograms with a characteristic of low frequency onsets followed very quickly by a long duration high frequency coda for both P and S waves. Such effects are observed at the permanent array WRA and at portable stations across northern Australia . The propagation of high frequencies for up to 1500 km from the source requires very low attenuation of seismic waves along the path.

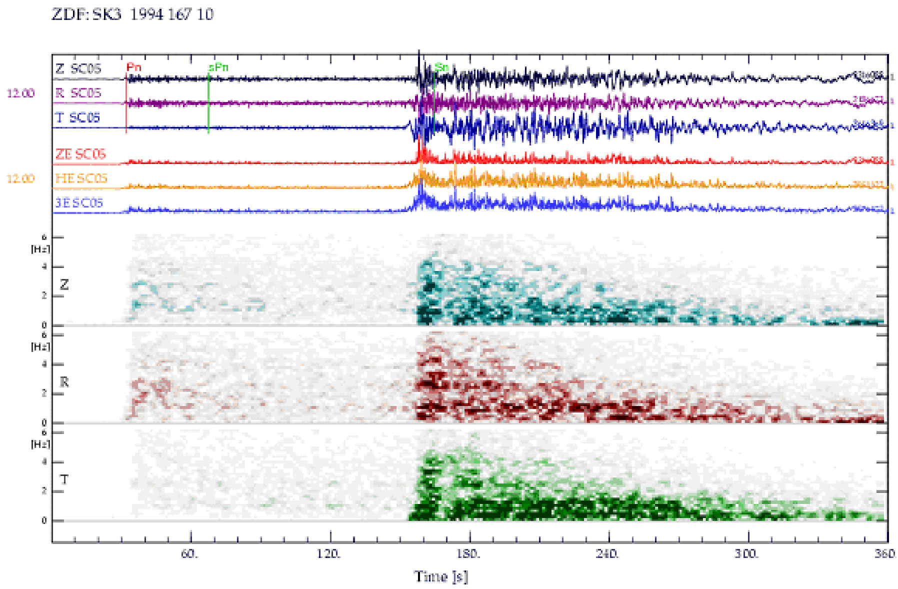


Figure 1

The example shows a seismogram for a station in the Northern Territory from a source at 35 km depth near 125 E. The upper three traces are the 3-component records with rotation along the great circle between source and receiver: Z is the vertical component, R the radial component along the path and T the transverse component to the path. The seismograms are shown without any filtering. The next set of three traces shows the energy on the vertical component (ZE), in the horizontal plane (HE) and the total energy (3E). The lower three panels show frequency-time analysis of the 3-component seismograms and display the persistence and slow decay of the high frequency components.

The detailed character of the seismograms recorded in northern Australia depends on the source position along the subduction zone system and appears to be related to the nature of the transition between the thick Australian Lithosphere and the subduction zone. The duration of coda increases and the rate of coda decay decreases for sources further to the east where the thick lithosphere abuts

To understand the structural factors controlling the appearance of the seismograms a range of numerical simulations have been carried out on the Earth Simulator supercomputer in Tokyo .

The calculations have been carried out using 2-D finite difference calculations in media with stochastic random heterogeneity. The calculation domain is 1500 km long by 400 km deep, and the grid spacing is 62.5m in both the horizontal and vertical direction. A 16 th order staggered grid method is used with a parallel code and frequencies up to 16 Hz are included. Thses very large models involving propagations over hundreds of wavelengths require 5 hours of computation each on 32 nodes of the Earth Simulator.

Based on prior experience with stochastic waveguides in subduction zones, the heterogeneity had much long scale lengths in the horizontal direction than the vertical and smaller scales in the crust than the mantle. The distribution of heterogeneity in the lower crust plays an important role in the development of the character of the seismograms but there is also a significant contribution from the structure in the mantle.

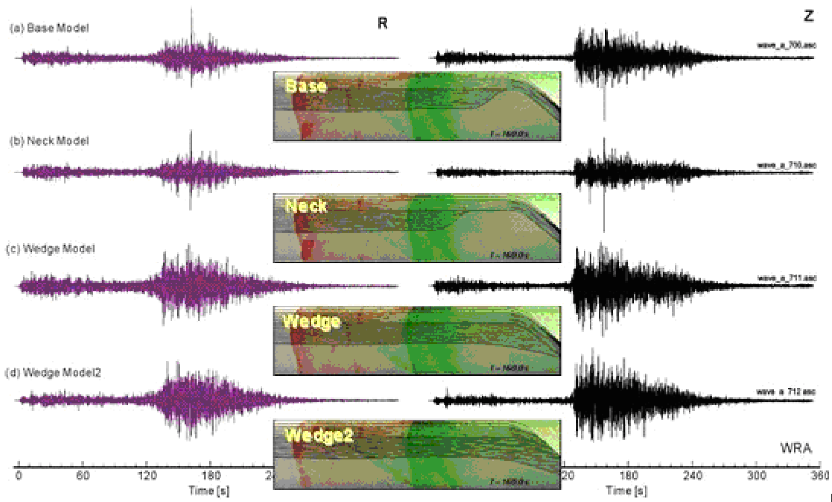


Figure 2

A suite of models of the transition between the thick lithosphere of the Australian Craton and the oceanic material in the subduction zone have been constructed based on tomographic imaging for the Indonesian region by Widiyantoro & van der Hilst (1997).

The resulting 2-D numerical simulations to high frequency capture many of the characteristics of the observed seismograms, and indicate that the nature of the transition structure from the subduction zone to the Australian craton has a significant influence on the character of the arrivals. The differences are apparent in the figure where calculated vertical (Z) and radial (R) component seismograms are shown for the epicentral distance to WRA from the Banda Sea .

The successful simulations include a quasi-laminated structure in the lower crust and mantle lithosphere on length scales well below those that can be directly imaged, whose origin is not yet understood. The stochastic waveguide acts to duct high frequency energy to large distances and the crustal heterogeneity helps to homogenize the energy between the three components.

Terrawulf projects in 2006

Malcolm Sambridge, Peter Rickwood, Justin Freeman and Yin Shan

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

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Terrawulf cluster

As the Terrawulf computational Facility reaches its fourth year of operation, it has been used for a range of new and continuing projects. Some of these are featured below. As in previous years the projects have involved staff and students across the school as well as collaborators nationally (e.g. Geoscience Australia) and overseas (e.g. University of Grenoble in France). This year we said farewell to Peter Rickwood who has looked after the Terrawulf and its users for the past two and half years. Peter leaves us to take up Ph.D study in the Univ. of Technology Sydney . Peter remains a welcome regular visitor to the floor and has continued his research collaborations with staff. New appointments have been Drs. Justin Freeman and Yin Shan. Justin is engaged in several lines of research in computational geoscience. Yin has taken up Peter's position and assumed responsibility for the Terrawulf cluster and support of its users.

The Terrawulf is now showing its age. Its warranty has expired and we have begun to loose nodes (primarily due to motherboard failure). This process is likely to continue, with node failure becoming more frequent over the next year. In 2007 we hope to be able to start building a replacement for the Terrawulf (funding permitting). Plans for Terrawulf II are underway. Watch this space…

Inferring earthquake source properties from coda wave interferometry

D. Robinson, M. Sambridge, R. Snieder The Terrawulf has been used to generate synthetic seismograms for assessing the applicability of coda wave interferometry theories for source separation and source variation. The systematic simulation of seismic waveforms in 3D complex media has provided an invaluable synthetic dataset for testing the theories. We have used these waveforms to determine probability density functions for source separation directly from the cross correlation of coda between displaced earthquake pairs. The data have also been used to demonstrate the applicability of a newly derived theory that relates the variation in source properties between two events to the interference pattern of their coda waves.

Estimation of earthquake source parameters from InSAR

J. Dawson, P. Tregoning

The Terrawulf was used to assess the accuracy of earthquake source parameters inverted from simulated Interferometric Synthetic Aperture Radar (InSAR) data. Using focal mechanisms of Australian earthquakes (1959 to the present), we simulated synthetic two-pass InSAR observations with realistic spatial noise derived from the characteristics of actual ERS-2 and ENVISAT InSAR data observed over Australia. The precision of two-pass satellite SAR interferometry with ERS2 and ENVISAT SAR data in the Australian region can approach ±2 mm (1 sigma) and is routinely at the ±4 mm level. The use of spatially uncorrelated observational weights has minimal impact on the accuracy of earthquake source parameters inverted from InSAR data. Invalid a priori assumptions of the dimension of the earthquake rupture plane can bias depth estimates by up to 0.4 km. In most cases single geometry (i.e. ascending or descending) InSAR observations can be used to accurately determine earthquake source parameters, although typically a combined geometry reduces the source parameter uncertainties by a factor of 1.5. In general, earthquakes of magnitude < 4.8 are unlikely to be observable by InSAR although very shallow events would be detectable. InSAR is insensitive to magnitude 6.2 earthquakes deeper than 10 km, and magnitude 5.5 deeper than 6 km. For earthquakes magnitude > 5.8 (average depth 6.5 km) we could estimate the epicentre of the rupture with an average accuracy of 0.25 km, depth to within 0.5 km and the fault orientation to better than 2 degrees.

Airborne frequency domain inversion

R. Brodie, M. Sambridge

The Terrawulf facility has been used to further enhance the "holistic" inversion of frequency-domain airborne electromagnetic. Before this development holistic inversions could only be run on subsets of airborne datasets, primarily due to the memory limitations of standalone processors.

In 2006 the holistic inversion code was parallelised via MPI to allow inversion of whole datasets at appropriate resolutions. Inversion of complete datasets (at once) ensures consistency of resolved calibration parameters over the whole survey. Parallelisation also allowed the move to more generalised vertically smooth multi-layer conductivity inversion models, which require many more model parameters to be solved for, but are generally more suitable when there is little prior information about the survey area.

The parallel code enabled the holistic inversion of a large (11,500 line kilometres) airborne electromagnetic survey involving 8.07 million data and 3.40 million parameters on 64 nodes of the Terrawulf in 8.22 hours using 51Gb of memory in total (Brodie and Sambridge, 2006).

References:

Brodie, R. and Sambridge, M., 2006, Holistic inversion without prior information: Australian Earth Science Convention 2006 - Melbourne , Australia , ASEG, Extended Abstracts.

A Probabilistic approach to ground motion estimation

R. Ruddick, M. Sambridge, T. Allen

The development of Australian-specific ground-motion models is fundamental to assessing the risk to Australian communities from earthquakes. A Bayesian approach has been developed for Earthquake source and path inversion, based on the Neighbourhood algorithm. All development work was carried out on the Terrawulf cluster, and subsequent runs were carried out on a cluster at Geoscience Australia . This calculation requires significant computing time. Here we inverted for 45 parameters (including the magnitudes of the 36 events). It took 382 hours to generate 712,500 models using 20 nodes on a cluster of Linux PCs with a Portland group F90 compiler. In comparison the same inversion took 65 hours using 100 nodes of a Linux cluster with the Intel FORTRAN comiler. Details of the method and preliminary results are reported on elsewhere.

GPS data processing

P. Tregoning

A multi-cpu cluster like the Terrawulf is ideally suited to ensemble data processing tasks such as that required in use of GPS data. In 2006 the Terrawulf was used to investigate

1) the effects of a priori hydrostatic delay errors on height and zenith delay estimates (For more details of this work see Tregoning, P . and T. A. Herring, 2006.)

2) the effects of atmospheric pressure loading and mapping functions on the uplift rate estimates of tide gauges in the southwest Pacific (manuscript in preparation).

3) reprocessing of a decade of GPS data in Papua New Guinea for present-day crustal motion studies.

References: '*Impact of a priori zenith hydrostatic delay errors on GPS estimates of station heights and zenith total delays'* . Tregoning, P . and T. A. Herring, *Geophys. Res. Lett.* , *in press* , 2006.)

Extracting denudation and relief history from thermochronological age-elevation profiles

Peter van der Beek 1 , Jean Braun 2 , Cristina Persano 3 , Frederic Herman 4* , and Erika Labrin

1 *Laboratoire de Géodynamique des Chaînes Alpines, Université Joseph Fourier, BP 53, 38041 Grenoble Cedex , France*
2 *Géosciences Rennes, Université de Rennes I, 35042 Rennes Cedex , France*
3 *Department of Geographical and Earth Sciences, University of Glasgow , Glasgow G12 8QQ , UK*
4 *Research School of Earth Sciences, Australian National University , Canberra ACT 0200, Australia*
** Present Address: Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena , CA 91125 , USA .*

We explore the capacity of low-temperature thermochronology data, in particular thermochronological age-elevation profiles, to provide joint constraints on the denudation and relief history of mountain belts. Thermochronological age-elevation profiles have been widely used to infer regional denudation histories but, in general, these analyses have considered the problem as one-dimensional, neglecting potential effects of topography or laterally varying denudation rates on age-elevation profiles. Although the influence of temporally steady-state topography on thermochronological age-elevation profiles is well understood, the potential effects of transient topography have not as yet been addressed in detail. To answer the question whether we can differentiate regional changes in exhumation rate from relief changes by analyzing thermochronological age-elevation profiles, we combine a three-dimensional thermal-kinematic model to predict thermal histories and thermochronological ages from an input denudation and relief history with an inversion scheme based on the neighborhood algorithm. We explore both synthetic data and a new thermochronological (zircon and apatite fission-track, apatite (U-Th)/He) dataset collected along an age-elevation profile in the French western Alps , a region that has experienced modest tectonic activity but intense glaciation during the last few myr. Our results suggest that multiple thermochronometers are required along an elevation profile to discriminate between different denudation and relief history scenarios, and that relief has increased significantly in our study area over the last few myr, possibly resulting from focused glacial valley erosion during Quaternary glaciations.

PRISE Introduction

PRISE operates as a unique entity within the Research School of Earth Sciences, with the principal charter being to provide external access to the Research School 's specialised equipment and expertise in areas of geochronology, isotope geochemistry and trace- and major element geochemistry. It is thus the Research School 's preferred vehicle for commercial and "commercial collaborative" projects in these areas.

The specialised expertise of the *PRISE* staff sees them involved in wide ranging collaborative research projects with academic colleagues throughout the world, as well as providing their research and analytical expertise to industry and Government agencies on a commercial basis. During 2006 *PRISE* hosted 23 visitors from Australia and overseas. Most undertook collaborative projects utilising the SHRIMP, Laser ablation- and solution ICPMS, electron microprobe and TIMS analytical facilities. PRISE staff also participated in, and led, a number of field-orientated studies in Australia , Africa , South America and Norway .

As members of a self-funded research group, *PRISE* scientists also undertake their own research projects and have been involved in successful Australian and international research grant proposals. During 2006 Dr Greg Yaxley was awarded an ARC Linkage grant with industry partner AMIRA International to develop new tools for the interpretation of diamond indicator minerals. The *PRISE* group maintains a high publication record and 2006 was no exception, with 42 papers being published in international journals and books
(http://rses.anu.edu.au/prise/pubs_2006.htm).

Some areas of current research activity

- A new high pressure empirical calibration of the exchange reaction for Ni and Mg between olivine and pyrope garnet at mantle pressures (3.0-4.5 GPa) was determined using the piston-cylinder apparatuses at RSES. This reaction is the basis of "Ni-in-garnet" thermometry, an important exploration tool used by the diamond industry in estimating thermal conditions and probable diamond stability in the lithospheric upper mantle. The key finding was that, as well as being temperature dependent, the reaction is also pressure dependent, casting doubt on previous calibrations which did not include any pressure dependence. This research is kindly funded by de Beers.

- The ultimate test of the Neoproterozoic "Snowball Earth" hypothesis is to accurately determine the ages of the various glaciogenic deposits around the world. This is possible by U-Pb dating of zircons from volcanic ashes from within these deposits, but complications caused by inheritance and mixed populations of zircons make this a difficult exercise. A sampling and analytical strategy (using the SHRIMP) has been developed to maximise the chances of successfully dating the correct material. This procedure is being applied to better constrain the timing of world-wide glacigene events.

- Sulphur isotope studies are fundamental to the understanding the origin and conditions of formation of the metal sulphides. One of the keys to discovering and deciphering complex histories within sulphide minerals is to use the spatial resolving power of the SHRIMP. Together with the Earth Chemistry group, analytical protocols for sulphur isotope analyses have been developed using the multi-collectors of the SHRIMP II. Testing of various potential standards has been successfully completed and reconnaissance studies on two ore deposits have been carried out.

- Sedimentary basin evolution is being studied through combined studies of oxygen isotopes and fluid inclusions in quartz cements, K-Ar ages of diagenetic illite, and Re-Os isotopes and trace elements in late-stage sulfides. The work has direct application to understanding the quality of petroleum reservoirs. In the next phase of the project the geochemical and petrographic data will be linked with regional tectonic models to improve predictive capabilities of the geochemical and geophysical datasets.

- Field work was conducted on the Almklovdalen peridotite-dominated body in the Western Gneiss Region, Norway . This is a large slice of upper mantle material, tectonically emplaced into the crust, which largely consists of fertile peridotite with abundant relatively refractory garnet clinopyroxenite and eclogite layers. All lithologies were extensively sampled for future petrological and geochemical studies aimed at investigating high pressure interactions between partial melts of eclogite or pyroxenite, and peridotite. These field based studies complement on-going high pressure experimental investigations of melting of heterogeneous upper mantle.

Research Projects

Rapid emplacement of the one of the world's greatest continental magmatic provinces - precise age constraints on the Bushveld Complex	Richard A. Armstrong
U-Pb and Lu-Hf isotopic constraints on the provenance of Permian detritus in turbidites from Patagonia and Livingston Island, Antarctica ; implications for plate reconstructions.	Fanning, C.M
Impact clusters on the Moon from 40Ar-39Ar ages of Apollo 16 melt breccias	Marc D. Norman
Exploring the melting behaviour of the Earth's heterogeneous upper mantle.	Anja Rosenthal
Experimental calibration of Ni partitioning between garnet and olivine at upper mantle pressures – implications for diamond exploration.	Gregory M. Yaxley

Rapid emplacement of one of the world's greatest continental magmatic provinces - precise age constraints on the Bushveld Complex

Richard A. Armstrong 1 , Sandra Kamo 2 , R.E. Harmer 3

1 Research School of Earth Sciences. The Australian National University , Canberra 0200, Australia
2 Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto , Toronto , Ontario , M5S 3B1 , Canada
3 African Platinum, Building 4 (Greystone), Fourways Golf Park , 2 Roos Street , Fourways 2191, South Africa .

The Bushveld Complex (*sensu lato*) in southern Africa represents one of the largest examples of continental magmatism on Earth. If the precursor felsic volcanic rocks of the Rooiberg Group are included, the volume of magma generated is estimated to be up to a staggering 1,000,000 km 3 . The layered mafic phase of the Bushveld Complex is the largest such igneous intrusion on Earth, with estimates of magma volume as high as 400,000 km 3 . Geophysical evidence also shows that the mantle beneath the Kaapvaal Craton still records a possible Bushveld-related seismic anomaly today (Fouch, et al., 2004). The timing and the origin of the various components of the complex are, however, poorly constrained with some work suggesting thermal activity could have continued for up to a billion years (McNaughton, et al., 1993). This research is aimed at determining a precise chronology of events covering the entire history of the Bushveld Complex, using combined TIMS and SHRIMP zircon U-Pb dating, with the aim at establishing some constraints on the possible origin of this massive and economically important event.

In the broadest sense, the Bushveld Complex is generally considered to include the intermediate to felsic volcanic rocks of the Rooiberg Group, the mafic layered rocks of the Rustenburg Layered Suite, the felsic intrusive rocks of the Lebowa Granite Suite, plus the enigmatic Rashoop Granophyres. Representatives of all these major components were sampled for dating (note that some of the dates quoted below are still subject to a final assessment once the last analyses are completed, but it is anticipated that this should not affect the absolute ages, but might affect the final precision quoted). TIMS dating of felsites of the roofing Rooiberg Group show that these precursors to the main phase of the Bushveld Complex were emplaced 2059.9 ± 1 Ma ago. This is significantly prior to intrusion of the main phase of the complex – as shown by dates obtained on zircons from the famous PGE-bearing Merensky Reef, and from a late-stage basic pegmatoid. These gave statistically identical ages of 2055.3 ± 1.2 Ma and 2056.3 ± 0.7 Ma respectively. Dating of granites of the Lebowa Suite that demonstrably intrude and post-date the mafic rocks, shows they were intruded at 2054 ± 2 Ma (a mean of several dates obtained on a variety of granites from this suite). A date of 2054 ± 4 Ma recently published by Dorland et al., 2006 on a rhyolite within the overlying sedimentary sequence of the Waterberg Group shows that the Bushveld Complex had cooled and had undergone significant erosion short time after intrusion of the mafic phase.

This high-precision geochronological study established for the first time that the whole event occurred over a very short time interval of approximately 4 Ma. The emplacement of the mafic Rustenburg Layered Complex and the felsic Lebowa Granite Complex was within 1-2 Ma, a time interval similar to that measured for large igneous volcanic provinces such as the Karoo or Deccan . Extensive recent geochronological investigations of large parts of southern Africa have shown that Bushveld-aged igneous rocks occur over a vast region of the subcontinent. These are currently the focus of a larger study aimed at discovering the full areal extent of rocks of this age and to establishing a possible causal link between the Bushveld Complex and a larger regional event. It certainly seems probable that the Bushveld Complex, unique as it is, was a part of some larger "Bushveld event", rather than an isolated igneous event of unknown origin. Certainly some origins can now be discounted – it is unlikely that an extraterrestrial (impact) origin can be reconciled with the distinctly different ages now established for the Rooiberg and Bushveld events. The origin of this enormous and economically important complex is still uncertain, but the rapid emplacement and erosion does provide some clues. Further research on the age of the late-stage cassiterite-bearing granites associated with the Bushveld Complex is in progress.

References: Dorland, H.C., Beukes , N.J. , Gutzmer, J., Evans, D.A.D and Armstrong, R.A. (2006) Precise SHRIMP U-Pb zircon age constraints on the lower Waterberg and Soutpansberg Groups, South Africa . *South African Journal of Geology* , 109, 139-156.

Fouch, M.J., James, D.E., Vandecar, J.C., van der Lee, S and Kaapvaal Seismic Group (2004). Mantle seismic structure beneath the Kaapvaal and Zimbabwe Cratons. *South African Journal of Geology* , 107, 33-44.

McNaughton, N.J,, Pollard. P.J., Groves , D.I. and Taylor , R.G. (1993). A long-lived hydrothermal system in Bushveld Granites at the Zaaiplaats Tin Mine: lead isotope evidence. *Economic Geology* , 88. 27-43.

U-Pb and Lu-Hf isotopic constraints on the provenance of Permian detritus in turbidites from Patagonia and Livingston Island, Antarctica ; implications for plate reconstructions.

Fanning, C.M 1 , Hervé, F. 2 , Yaxley, G.M 1 . and Pankhurst, R.J. 3

1 Research School of Earth Sciences , The Australian National University , Canberra ACT 0200, Australia
2 Departamento de Geología, Universidad de Chile, Casilla 13518, Correo 21, Santiago , Chile
3 NERC Isotope Geosciences Laboratory, Keyworth, Nottingham NG12 5GG , UK

The provenance of sedimentary rocks has been revolutionised through application of isotopic methods, in particular U-Pb detrital zircon dating. Such studies reveal not only the age spectrum for the source of zircon, but invariably a young age component that places significant constraints on, and sometimes redefines, the time of deposition. In many cases this young age component is derived from a magmatic source that is coeval with deposition. Laser ablation, multi-collector ICP MS Lu-Hf analyses of previously U-Pb dated zircon can further constrain isotopic sources. The Hf isotope signature of an individual zircon age component will provide a characteristic signature of the protolith and information as to crustal residence time, thereby enabling more refined correlations and reconstructions.

Within the Late Palaeozoic accretionary wedge of the western margin of Patagonia and Antarctic Peninsula there are packages of metasedimentary rocks that lie outboard of the southern Patagonian and Antarctic Peninsula batholiths. Detrital zircons in turbiditic sandstones from both areas indicate a similar source characterized by an abundance of Permian-age detrital zircons. Previously it has been suggested that these have come from a Permian arc, possibly the Choiyoi province of southern South America . Hf isotopic data for Permian-age detrital zircons from turbidites in a N to S transect from 50°S to 60°S yield dominant initial epsilon Hf values between -5 and -10. This indicates that the source for these Permian zircons had a significant crustal residence time and that they were not derived from a juvenile magmatic arc. Other grains record even more enriched Hf isotope signatures indicating derivation from yet older crustal sources.

The Hf isotopes reinforce communality of the detrital zircon source and further indicates that juvenile crust was not dominant, but that there may have been mixing between older sources of, say, Pan African (Brasiliano) and Grenville ages, together with a minor but significant subduction-related magmatic input. This supports the proposal that recently recognised but widespread Permian magmatism in Patagonia represents crustal melting in response to subducted slab break-off, ie the inferred Permian arc is not juvenile. The data is consistent with the premise that the Antarctic Peninsula was side by side with Patagonia during the Jurassic, receiving detritus from the same source.

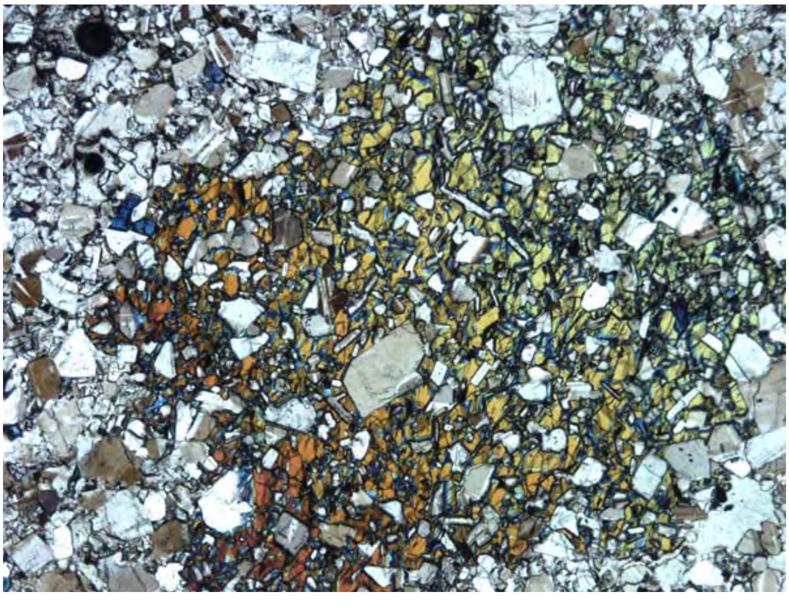
Impact clusters on the Moon from 40Ar-39Ar ages of Apollo 16 melt breccias

Marc D. Norman 1 , Robert A. Duncan 2 , and John J. Huard 2

1 Research School of Earth Sciences, Australian National University, Canberra, ACT 0200 Australia
2 College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331 USA

The upper crust of the Moon records an integrated history of impact events extending from soon after the main accretionary phase of planet formation to the present day. Lunar impact breccias provide a record of the timing and frequency of events that occurred prior to the development of a significant rock record on Earth. One of the most unexpected discoveries obtained from the Apollo expeditions to the Moon is the predominance of impact melt breccia ages between 3.8 and 4.0 billion years. This clustering of ages corresponds to an episode of intense crustal metamorphism defined by whole rock U-Pb isotopic compositions of lunar anorthosites, a coincidence that suggests a cataclysmic bombardment of the Moon at that time.

The idea that the Earth and Moon experienced a major spike of incoming planetesimals at ~3.9 Ga is controversial. An event of this magnitude would have significant implications for crust formation and biologic evolution on Earth, for establishing absolute timescales of geological events on other planets, and for understanding planetary dynamics in the Solar System. As a test of the cataclysm hypothesis, we measured 40Ar-39Ar ages on 25 samples of Apollo 16 impact melt breccias using a continuous laser heating system on sub-milligram fragments. Twenty-one samples produced multi-step plateaus that we interpret as crystallization ages, with 20 of these ages falling in the range 3.75 to 3.96 Ga. The ages cluster into at least four groups, allowing us to recognise several different impact events within the Apollo 16 melt breccia suite. This shows that numerous large impact events occurred on the lunar surface within a relatively narrow time interval, providing additional evidence of a heavy bombardment of the Moon during the crucial period when biology was emerging and early continental crust was forming on the Earth.



Photomicrograph of a crystalline lunar impact melt rock with a poikilitic texture. The yellow-orange mineral is pyroxene enclosing euhedral crystals of plagioclase. Cross-polars, field of view about 1 mm wide.

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

Anja Rosenthal 1 , Gregory M. Yaxley 1 , David Green 1 and Carl Spandler 2

1 Research School of Earth Sciences, Australian National University , Canberra , ACT 0200, Australia
2 Institute of Geological Sciences, University of Bern , Bern , Switzerland

This project forms part of an ARC-funded project, which aims to determine solidus temperatures, phase relations and partial melt compositions during partial melting of upwelling eclogites (oceanic crust composition), residual garnet-bearing and garnet-free pyroxenites and refertilised lherzolites over the upper 150-200 km of the mantle, 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 often used to explain the heterogeneity of mantle-derived magmas.

The primary technique for this research is high pressure experimental petrology, in conjunction with a range of cutting edge micro-analytical techniques (electronprobe microanalysis, laser-ablation ICP-MS). Techniques of high pressure and temperature experimental petrology are necessary to define the melting behaviour of postulated mantle materials as functions of pressure (P), temperature (T) and composition. High pressure experiments can be used to establish equilibrium melt and residual phase compositions. Careful experimental design can also constrain and clarify other melting models such as continuous melting and melt extraction, channel flow and melt pooling, etc.

A high-pressure experimental investigation of several eclogitic compositions (Res-2 to Res-5) is nearly complete, in which the effects of Na/Ca+Na and other compositional features on the phase relations and partial melt compositions have been delineated. The preparation of compositions and experimental techniques followed established procedures. High pressure experiments have been conducted over a temperature range from 1200 to 1500°C, and a pressure range form 3.0 to 5.0 GPa in a standard 1.27 cm piston-cylinder apparatus. Run products were polished and examined by reflected light microscopy, and by scanning electron microscopy (SEM) and electronprobe microanalysis (EPMA), using a JEOL 6400 SEM with EDS facility to analyse major element of the mineral assemblages (garnet and clinopyroxene) and glass.

A second essential component of the project is to assess whether evidence of processes of heterogeneous melting, melt migration and mantle refertilisation exists in natural mantle samples. Accessible for such investigation due to tectonic emplacement from upper mantle into the crust are peridotitic bodies of the Western Gneiss Region (WGR) of Norway . For example, at Almklovdalen, a range of relatively refractory pyroxenite-rich lithologies are surrounded by fertile garnet peridotite and dunite. These may be natural examples of high pressure interactions between partial melts of pyroxenites and enclosing peridotites.

Fieldwork was conducted in the Nordfjord-Stadlandet part of the Western Gneiss Region in Norway in June-July to sample these pyroxenites and peridotites, which The region is known for its excellent outcrops, making possible the compilation of spatial, temporal and genetic relationships of the layered peridotite masses, and determination and mapping of key textures in mm to m scale available.

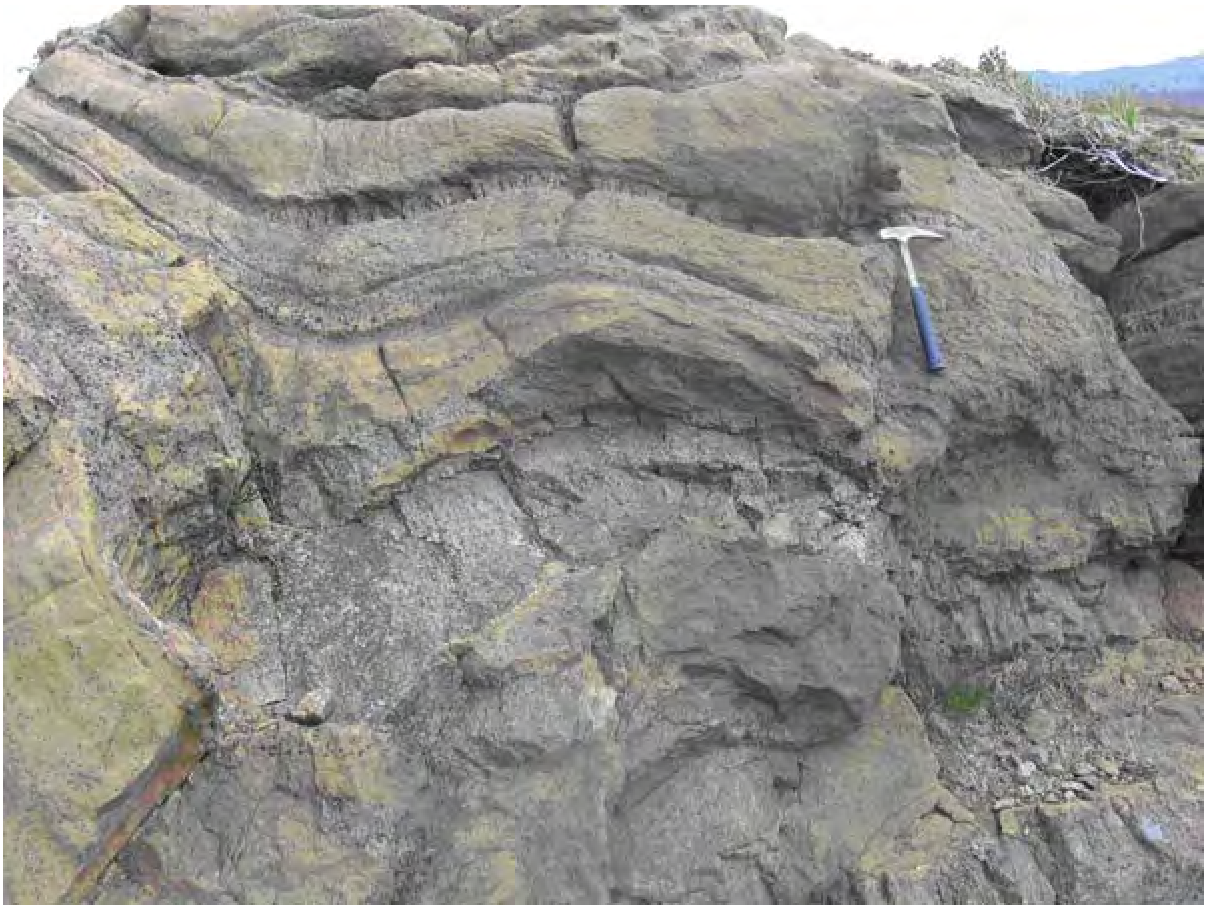


Figure 1. Layers of garnet pyroxenite and peridotite at Alklovdalen, Western Gneiss Region.

Experimental calibration of Ni partitioning between garnet and olivine at upper mantle pressures – implications for diamond exploration.

Gregory M. Yaxley 1 and Hugh St.C. O'Neill 1

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

The chemical compositions of lithosphere-derived pyrope garnet, often recovered from heavy mineral concentrates (HMC) obtained during diamond exploration programs, contain a record of the temperature at which the grains equilibrated with olivine in peridotite in the lithosphere.

This information is extremely useful in guiding diamond exploration programs. If the local cratonic geotherm at the time of kimberlite emplacement can be estimated independently (e.g. from studies of multiphase mantle-derived garnet peridotite xenoliths), then temperature information obtained from single-phase thermometry can be fitted to the geotherm allowing estimation of the mantle depth interval sampled by the kimberlite during its ascent to the surface. This is important in assessing the extent of entrainment by kimberlites of material from pressure – temperature conditions within the diamond stability field. This clearly has implications for the diamond prospectivity of individual pipes.

Temperature information is preserved in garnet and olivine major, minor and trace element chemistry. For example, garnet and olivine participate in T dependent exchange equilibria, such as the following for Ni:

$3Ni^{2+}{}_2SiO_4 + 2Mg_3Al_2Si_3O_{12} = 2Ni^{2+}{}_3Al_2Si_3O_{12} + 3Mg_2SiO_4$ (1)

olivine garnet garnet olivine

If the temperature and pressure dependence of exchange equilibrium (1) can be calibrated, then in principal the chemical compositions of garnet and olivine coexisting in the upper mantle can be used to determine the temperature at which they equilibrated.

A new empirical calibration of the reaction for Ni-Mg exchange between olivine and garnet at mantle pressures has been conducted at 3.0-4.5 GPa, using piston-cylinder high-pressure experimentation at the Research School of Earth Sciences. This research was kindly funded by de Beers.

An important new finding of this study, is that when our data is combined with an earlier, higher pressure calibration (6-7 GPa) (Canil 1994), the reaction has a resolvable and significant pressure effect of approximately 6-8°C/kbar. This agrees with thermodynamic predictions based on molar volume estimates (Canil 1994). This seriously compromises the validity of a former empirical calibration of Ryan et al. (1996), which does not include pressure effects in the Ni exchange reaction, nor in the Fe-Mg olivine garnet thermometry, which was used in its original formulation. Application of this thermometer to single grain Cr-pyrope garnet may artificially extend the range of temperatures obtained from any given Ni-in-garnet data set, thereby implying a falsely large sampling depth interval for individual kimberlites pipes.

References: Canil D. (1994) An experimental calibration of the nickel in garnet geothermometer with applications. *Contributions to Mineralogy and Petrology* **117** , 410-420.

Ryan C.G., Griffin W.L. and Pearson N.J. (1996) Garnet geotherms: Pressure-temperature data from Cr-pyrope garnet xenocrysts in volcanic rocks. Journal of Geophysical Research **101** , 5611-5625.

Electronics Group

The Group enjoyed a stimulating year, venturing into contemporary technologies, engaging with complex diagnostic and maintenance issues, and contributing to school and university administration. The tradition of engagement with research programs has continued, morale and cohesion are high, members support each other, and there is a strong sense of worth and identity within the group.

Demand for Electronics support remained strong during the year, with resources allocated as shown:

	Budgeted	Actual	Comment
Total hours worked	10395 (12 Months)	9537 (11 Months)	December figures not yet available. (ca 10300 with Dec. projection)
Hours billed	6965 (12 Months)	6459 (11 Months)	December figures not yet available. (ca 6973 with Dec. projection)
Billable	67%	67.7%	

Human resources were utilized as follows:

Task:	Percentage of total hours:
Development	51.1%
Maintenance	20.4%
Administration and Group Support. (Inc. Study Leave, Union/EBA work, Software support)	28.5%

Despite greater than expected staff losses due to retirement, long service leave and illness, the group met its working hours target for 2006, through extended working days and unused flextime. The group will carry a budget surplus into 2007 because of external work largely undertaken in 2005, but invoiced in 2006.

Training expenditure and overheads were minimal during 2006 (but extensive in 2005), however considerable progress was made in upgrading both capital and non-capital equipment, in line with the groups structured plan. This action has largely addressed the under spending caused by budget uncertainties of recent years.

The Group commenced work on the SHRIMP SI project during 2006, as well as a range of smaller projects and renovations.

Notable developments undertaken included:

- Development of a prototype precision Magnetic Field Control system (FC4) for the SHRIMP SI, incorporating fuzzy logic control implemented on an FPGA platform, and high resolution (24 bit) measurement and control. (A Latimore, D Cassar, D Cummins, A Forster).
- Detailed testing of the prototype Iflex electrometer project (SHRIMP SI), and design of the production version. (N.Schram, D. Corrigan, D Cummins).
- Debugging of the renovated PG61 Mass Spectrometer, various diagnostic tasks addressing data inconsistency issues. (A. Latimore, D. Corrigan, N. Schram).
- Specification development and technology assessment for a Distributed Vacuum (Management) System (DVS) for application to all SHRIMP instruments (D. Cassar).
- Preliminary design and HV supply purchasing for the SHRIMP SI High Voltage System (work in progress) (A Welsh, N Schram).
- Completion of Power-Mode upgrade to the "Multi Anvil Press" for Earth Materials (D.Cassar).
- Assembly of the filament degasser system to support the Triton mass spectrometer (D. Corrigan)
- Upgrade and commissioning of sample manipulation motor-drive electronics on SHRIMPs II and RG (A. Welsh, P.Lanc [Earth Chemistry]).
- Fabrication and testing of 4 "*Low Field Tesla Tamer*" precision magnetic field probes for the SHRIMP group. (J Arnold).

• Assembly and testing of a remote GPS monitoring station (AntPAC 2007) for deployment in Antarctica in 2006/7 for Earth Physics (Geodynamics) (A Welsh, N Schram).
• Fabrication of 8 "LDL Safe Lights" for the Earth Environment thermoluminescence laboratory (D.Cummins).
• An upgrade to the "1 Atmosphere Furnaces" in use by Earth Materials (A Forster).
• Fabrication and Commissioning of a "Pneumatic Sample Crusher Controller" for The University of Melbourne. (D Cummins).
• Design and fabrication of a *Floating Beam Monitor* for the SHRIMP Ion Optical test bench (J. Arnold, N.Schram)
• Design and fabrication of a "Tsukuba Furnace Controller" for the Imperial College London. (J Arnold, A Forster).
• Development of a 'prototype' STE-processor board as a replacement for boards deployed in all SHRIMP instruments (A Latimore).

Staffing:

For most of the year the group comprised an Electronics Engineer and five Technical Officers supplemented by two Trainee Technical Officers.. D Corrigan continued to specialise in engineering design, working closely with both Engineering and Electronics staff. His primary task for 2006 was the construction of the Triton filament degasser. J. Arnold retired in October, followed by A. Welsh in November. . From January the 'electronics' staff will be reduced to 3.8 posts (excluding Corrigan), as Forster retires in January, and Schram moves to part time employment. The group appointed two Trainee Technical Officers in 2003, in anticipation of the retirements now occurring.

Recruitment:

The group has been very fortunate and successful in its training endeavours of recent years. We propose the recruitment of 2 Trainee Technical Officers as a 'long term' solution to staffing needs. In addition, we may attempt to recruit a mid-career technician as an interim measure to narrow the experience-gap we currently face.

Leadership:

The current leader (Schram) will move to part time work in 2007, leading to retirement later in the decade. The group requires a full time leader, so this role will pass to Latimore.

Outlook:

2007 promises to be very challenging. The group has a very large development workload, which includes the SHRIMP SI. Maintenance tasks have increased through the ageing and expansion of the RSES instrument base. The group no longer has the resources (manpower and obsolete spare parts) to support much of the aged equipment deployed throughout the school, particularly obsolete vacuum system electronics. Group members have withdrawn from broader university, college and school roles in order to concentrate on core business.

We anticipate that project delays will occur within 2007, and it may prove essential to quarantine selected staff from 'general' duties, on a rotational basis, in order to progress the SHRIMP SI project. The group has a core of skilled and talented staff, upon which it can be reconstructed, and we approach the challenges of 2007 with vigour and enthusiasm.

Engineering Group

Engineering Workshop time was in high demand this year.

59% of total hours for the year were devoted to charged RSES internal work. The total work done for clients outside RSES accounted for 12% of our time and 29% of our time was uncharged.

Internally the main commitments were:

- SHRIMP SI- Multicollector and ESA internal components (Mr G. Woodward, Mr C. Were, Mr D. Thomson, Mr B. Buttler, Mr B. Taylor, Mr A. Wilson)
- SHRIMP 1 Refurbishment (Mr G. Woodward, 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, Mr D. Thomson, Mr B. Taylor)
- Secondary Column test bench (Mr G. Woodward, Mr L. Williams)
- Filament Degasser for Prof M. McCulloch's Finnegan mass spectrometer (Mr G. Woodward, Mr B. Taylor)
- New and refurbished pressure vessels for Prof H. O'Neill (Mr G. Woodward, Mr C. Were)
- Helium Tanks and Pipette system for Dr J. Dunlap (Mr B. Taylor, Mr C. Were)
- Field work equipment for Dr M. Gagan (Mr C. Were, Mr A. Wilson, Mr D. Thomson, Mr L. Williams)
- Fitment of Lead doors to circular radiation shields for Prof R. Grün (Mr C. Were, Mr L. Williams)
- Field work equipment for Prof M. McCulloch (Mr C. Were)
- Precision diamond grinding of samples and pistons for use in high pressure/ temperature experiments in the Rock Physics laboratories (Mr C. Were, Mr B. Taylor, Mr A. Wilson, Mr G. Woodward)
- Continued design and development of vacuum crushing vessels for Dr M. Honda (Mr D. Thomson, Mr C. Were, Mr A. Wilson, Mr B. Buttler, Mr B. Taylor)

Two large external projects were taken on this year:

A Vacuum Sample Crusher was built for the University of Melbourne's Argon and Noble Gas laboratory run by Dr D. Phillips. (Mr B. Buttler, Mr B. Taylor)

SHRIMP 2 ESA assemblies (Quadrupole Lens and Alpha Slit) for "Australian Scientific Instruments". (Mr G. Woodward, Mr C. Were, Mr D. Thomson, Mr B. Buttler, Mr B. Taylor, 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:

- 39%. 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.
- 3%. Other- Sydney engineering exhibition, unloading deliveries.

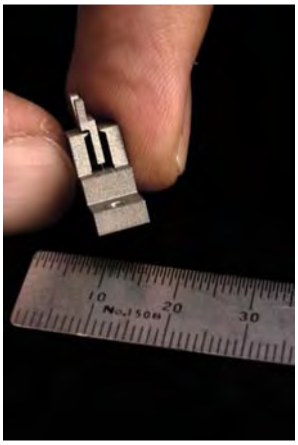
Staffing

Early this year Mr Link Williams was chosen as the College of Science apprentice fitter and machinist. Link was the first College of Science appointment at the ANU and will serve his apprenticeship under the guidance of workshop staff at RSES, Faculty of Physics, RSC and RSPhysSE.

Mr JP. Robbie, who left early in the year, was replaced by Mr Brent Buttler. Brent is a skilled tradesman with prior experience in Computer Numeric Control in the tool making industry.

Other Developments

Every effort has been made this year to ensure maximum use of the schools computer controlled machines. We have invested time in learning SolidCAM- the Computer Aided Manufacturing (CAM) software package by Solid Works. This program allows more efficient use of the 3D part files generated by Solid Works which now seems to be the preferred package among designers at ANU.



Optomechanical Flexture for students
at the College of Engineering
and Information Technology

2006 Publications by Author (Listed alphabetically within research areas)

Earth Chemistry

Allen, C.M., Barnes, C.G., (2006) Ages and some cryptic sources of Mesozoic plutonic rocks in the Klamath Mountains , California and Oregon . In Snoke, A.W. and Barnes, C.G. eds. Geological studies in the Klamath Mountains province, California and Oregon : A volume in honor of William P Irwin: Geological Society of America Special Paper Vol 410, 223-245.

Barnes, C.G., Allen, C.M., (2006) Depth of origin of late Middle Jurassic garnet andesite, southern Klamath Mountains , California . In Snoke, A.W. and Barnes, C.G. eds. Geological studies in the Klamath Mountains province, California and Oregon : A volume in honor of William P Irwin: Geological Society of America Special Paper Vol 410, 269-286.

Buick, I.S., Allen, C., Pandi, M., Rubatto, D., Hermann, J., (2006) The Proterozoic magmatic and metamorphic history of the Banded Gneiss Complex, central Rajasthan , India : LA-ICP-MS U-Pb zircon constraints. Precambrian Research, 151, 119-142.

Buick, I.S., Allen, C., Pandit, M., Rubatto, D., Hermann, J., (2006) The Proterozoic magmatic and metamorphic history of the Banded Gneiss Complex, central Rajasthan , India : LA-ICP-MS U-Pb zircon constraints, Precambrian Research 151, 119-142.

Buick, I.S., Hermann, J., Williams, I.S., Gibson, R., Rubatto, D., (2006) A SHRIMP U-Pb and LA-ICP-MS trace element study of the petrogenesis of garnet-cordierite-orthoamphibole gneisses from the Central Zone of the Limpopo Belt, South Africa, Lithos 88, 150-172.

Campbell , I.H., and Davies, G.F., (2006) Do mantle plumes exist? Episodes, Vol 29, 162-168.

Carosi, R., Montomoli, C., Rubatto, D., Visona, D., (2006) Normal-sense shear zones in the core of the Higher Himalayan Crystallines (Bhutan Himalayas): evidence for extrusion? Law, R. D., Searle, M. P. Godin, L. (eds.), Channel Flow, Ductile Extrusion and Exhumation of the Lower-mid Crust in Continental Collision Zones, London Journal of the Geological Society, London, 425-444.

Clift, P. D., Carter, A., Campbell, I.H., Pringle, M.S., Van Lap, N., Allen, C.M., Hodges, K.V., and Tan, M.T., (2006) Thermochronology of mineral grains in the Red and Mekong Rivers, Vietnam: Provenance and exhumation implications for Southeast Asia. *G 3* , Vol 7, doi:10.1029/2006GC001336.

Cross, A.J. and Crispe, A.J., (in press) SHRIMP U–Pb analyses of detrital zircon: a window to understanding the Paleoproterozoic development of the Tanami Region, northern Australia . Mineralium Deposita. Online .

Dobrestov, N.L., Buslov, M.M., Rubatto, D., Safonova, I.Y., (2006) Shalkar Ophiolite Complex, northern Kazakhstan : structural setting, age, geochemistry and genesis. Russian Geology and Geophysics 47, 475-484.

Fonseca, R.O.C., Mallmann, G, O'Neill, H.St.C. and Campbell , I.H., (2006) How chalcophile is rhenium? An experimental study of the solubility of Re in sulphide mattes. In review, Earth and Planetary Science Letters EPSL-D-06-00825.

Gómez-Pugnaire, M.T., Galindo-Zaldívar, J., Rubatto, D., Gonzalez-Lodeiro, F., López Sánchez-Vizcaíno, V., and Jabaloy, A., (2004, published in Jan 2006) A reinterpretation of the Nevado-Filábride and Alpujárride complexes (Betic Cordillera): field, petrography and U-Pb ages from orthogneisses (western Sierra Nevada, S Spain), Schweizerische Mineralogische und Petrographische Mitteilungen 84, 303-322.

Grether, D., Lineweaver, C.H., (2006) How Dry is the Brown Dwarf Desert?: Quantifying the Relative Number of Planets, Brown Dwarfs and Stellar Companions around Nearby Sun-like Stars, Astrophysical Journal 640, 1051, astro-ph/0412356.

Grether, D., and Lineweaver, C.H., (2006) The Metallicity of Stars with Close Companions, Astrophysical Journal (submitted).

Gutjahr, M., Bradshaw, J.D., Weaver, S., Münker, C., and Ireland , T.R., (2006) Provenance of Cambrian conglomerates from New Zealand : implications for the tectonomagmatic evolution of the SE Gondwana margin. J. Geol. Soc., London , Vol 163, 997-1010.

Hermann, J., Rubatto, D., Korsakov, A., and Shatsky, V.S., (2006) The age of metamorphism of diamondiferous rocks determined with SHRIMP dating of zircon, Russian Geology and Geophysics 47, 513-520.

Hermann, J., Rubatto, D., and Trommsdorff, V., (2006) Sub-solidus Oligocene zircon formation in garnet peridotite during fast decompression and fluid infiltration (Duria, Central Alps), Mineralogy and Petrology 88, 181-206.

Ireland, T.R., Holden, P., Norman, M.D., and Clarke, J., (2006) Isotopic enhancements of 17 O and 18 O from solar wind particles in the lunar regolith, Nature, Vol 440, 776-778.

Kim, S.W., Oh, C.W., Williams, I.S., Rubatto, D., Ryu, I.-C., Rajesh, V.J., Kim, C.-B., Guo, J., and Zhai, M., (2006) Phanerozoic high-pressure eclogite and intermediate high- pressure granulite facies metamorphism in the Gyeonggi Massif, South Korea : implications for the eastward extension of the Dabie-Sulu continental collision zone. Lithos 92, 357-377.

Liang, H.Y, Campbell . I.H., Allen, C., Sun, W.D., Liu, C.Q., Yu, H.X,. Xie Y.W., and Zhang, Y.Q. , (2006) Zircon Ce4+/Ce3+ ratios and ages for Yulong ore-bearing porphyries in eastern Tibet, Mineralium Deposita, Vol 41, 152-159.

Lineweaver, C.H., (2006) Can a Biosphere be Selfish? The Gaian Challenge to Darwinism. Review Essay of "Scientists Debate Gaia: The Next Century", Ed. S.H. Schneider, J.R. Miller, E. Crist and P.J. Boston, Astrobiology Magazine, in press, on-line at http://www.astrobio.net .

Lineweaver, C.H., (2006) Finding Earths, Life and Intelligence in the Universe, The Explorer, Special Edition 2006, Finding Earths Life and Intelligence in the Universe published by the SETI Institute, p 7.

Lineweaver, C.H., (2006) Increasingly Overlapping Magisteria, "Divine Action and Natural Selection: Questions of science and faith in biological evolution'', ed. J. Seckbach, Vol. 11 of a series on Cellular Origin, Life in Extreme Habitats and Astrobiology, Springer, Dordrecht, in press.

Lineweaver, C.H., (2006) We Have Not Detected Extraterrestrial Life, Or Have We?, "Life As We Know It'', ed. J. Seckbach, Vol. 10 of a series on Cellular Origin, Life in Extreme Habitats and Astrobiology, Springer, Dordrecht pp 445-457, ISBN 1-4020-4394-5.

Lineweaver, C.H. and Grether, D., (2006) Quantifying the Short-Period Brown Dwarf Deserts, American Astronomical Society Meeting 207, No. 77.05; Bulletin of the American Astronomical Society, Vol. 37, p.1292.

Lineweaver, C.H. and Robles, J., (2006) The range of geochemistries of terrestrial planets in the universe, Geochimica et Cosmochimica Acta Supplement, v. 70, issue 18, p. 360.

Lineweaver, C.H. and Robles, J., (2006) Towards a Classification System of Terrestrial Planets in Australian Space Science Conference Series: 6th Conference Proceedings NSSA (ed) National Space Society of Australia Ltd Full, conference held in Canberra, Australia July 19-21, 2006, ISBN 0-9775740-0.

McNamara, G. and Lineweaver, C.H., (2006) Towards Omega, chapter in "In Search of Dark Matter'', G. McNamara and K. Freeman, Praxis Publishing, Chichester, UK Chapter 14, p 141-146.

Minier, V., and Lineweaver, C.H., (2006) A search for water masers toward extrasolar planets V. Minier, C.H. Lineweaver, Astronomy and Astrophysics, 449, 805-808.

Mohapatra, R. K., Honda, M., (2006) "Recycled" volatiles in mantle-derived diamonds- Evidence from nitrogen and noble gas isotopic data, Earth and Planetary Science Letters, Vol 252, 215-219.

Norman M. D., Yaxley, G.M., Bennett, V.C., Brandon , A.D., (2006), Magnesium isotopic composition of olivine from the Earth, Mars, Moon, and pallasite parent body, Geophys. Res. Lett., 33, L15202, doi:10.1029/2006GL026446.

Nutman, A.P., Bennett, V.C, Friend, C. L. R., (in press) 3.85 Ga tonalites in the Nuuk region, West Greenland : Geochemistry and reworking within an Eoarchaean gneiss complex, Contributions to Mineralogy and Petrology.

Phillips, G., Wilson, C.J.L., Campbell, I.H., and Allen, C.M., (2006) U-Pb detrital geochronology from the southern Prince Charles Mountains, East Antarctica – Defining the Archaean to Neoproterozoic Ruker Province, Precambrian Research , Vol 148, 292-306.

Piontkivska, H., Schwartzman, D. W., and Lineweaver, C.H., (2006) Hyperthermophilic biogenesis and early biospheric evolution, Geochimica et Cosmochimica Acta Supplement, v. 70, issue 18, p. 495.

Price, R.C., Ireland, T.R., Maas, R., Arculus, R.J. (2006) SHRIMP ion probe zircon geochronology and Sr and Nd isotope geochemistry for southern Longwood Range and Bluff Peninsula intrusive rocks of Southland, New Zealand. New Zealand Journal of Geology and Geophysics, Vol 49, 291-303.

Robles, J. and Lineweaver, C.H., (2006) Is the Sun a Random Star?, Australian Space Science Conference Series: 6th Conference Proceedings NSSA (ed) National Space Society of Australia Ltd Full, conference held in Canberra , Australia July 19-21, 2006 , ISBN 0-9775740-0.

Rubatto, D., Hermann, J., Buick, I.S., (2006) Temperature and bulk composition control on the growth of monazite and zircon during low-pressure anatexis (Mount Stafford , central Australia), Journal of Petrology 47, 1973-1996.

Squire, R.J., Campbell, I.H. Allen, C.M., and Wilson, C.J.L., (2006) Did the Transgondwanan Supermountain trigger the explosive radiation of animals on Earth? Earth and Planetary Science Letters , Vol 250, 116-133.

Earth Environment

Anderson, A ., Chappell, J ., Gagan, M.K ., and Grove, R . (2006) Prehistoric maritime migration in the Pacific islands: an hypothesis of ENSO forcing. Holocene Vol 16, 1-6.

Aubert, M., O'Connor, S., M., McCulloch M.T., Mortimer, G., and Richer-LaFlèche, M. (2006) Uranium-series dating rock art in East Timor , Journal of Archaeological Sciences.

Ayling, B., McCulloch, M., Gagan, M., Stirling , C., Andersen, M. and Blake, S. (2006) Sr/Ca d 18 O seasonality in a Porites coral from the MIS 9 339-303 ka_ interglacial, Earth and Planetary Science Letters, 248, 462-475.

Barker, S., Cox, S.F., Eggins, S.M., Gagan, M.K. (2006) Microchemical evidence for episodic growth of antitaxial veins during fracture-controlled fluid flow. Earth and Planetary Science Letters, Vol 250, Issue 1-2, 331-344.

Bernal, J.P., Eggins, S.M., McCulloch, M.T., Grün, R., and Eggleton, R.A. (2006) Dating of chemical weathering processes by in situ measurement of U-series disequilibria in supergene Fe-oxy/hydroxides using LAM-MC-ICPMS. Chemical Geology, Vol 235, Issue 1-2, 76-94.

Bostock, H.C., Opdyke, B.N., Gagan, M.K., Kiss, A.E. and L.K. Fifield (2006) Glacial/interglacial changes in the East Australian current. Climate Dynamics, Vol 26, Issue 6, 645-659.

Byrami, M.L., Newnham, R.M., Alloway, B.V., Pillans, B., Ogden , J., Westgate, J. & Mildenhall , D.C. (2005) A long early-mid Pleistocene pollen record from Auckland , New Zealand . In: Head, M.J. & Gibbard, P.L. (Eds.). Early-Middle Pleistocene Transitions: The Land-Ocean Evidence. Geological Society, London , Special Publication, Vol 247, 183-208.

Coutard, S., Lautridou, J.-P., Rhodes , E.J., and Clet, M. (2006). Tectonic, eustatic and climatic significance of raised beaches of Cotentin (Val de Saire, Normandy , France). Quaternary Science Reviews, Vol. 25, 595-611.

Chappell J., Zheng H., Fifield K. (2006). Yangtse River sediments and erosion rates from source to sink traced with cosmogenic 10 Be: sediments from major rivers. Palaeogeography, Palaeoclimatology, Palaeoecology, Vol 241, 79-94.

Ellwood, M.J., Kelly, M., Maher, W.A., De Deckker, P. (2006), Germanium incorporation into sponge spicules: Development of a proxy for reconstructing inorganic germanium and silicon concentrations in seawater, Earth Planetary Science Letters, Vol 243, 749-759.

Esat, T.M., Yokoyama Y., (2006) Variability in the uranium isotopic composition of the oceans over glacial–interglacial timescales, Geochimica et Cosmochimica Acta, Vol 70, 4140-4150.

Esat, T.M., and Yokoyama Y., (2006) Growth patterns of the last ice age coral terraces at Huon Peninsula , Global and Planetary Change, Vol 54, 216-224.

Feathers, J.K., Rhodes , E.J., Huot, S., and McAvoy, J.M., (2006) Luminescence dating of a pre-Clovis occupation at the Cactus Hill site, Virginia , USA . Quaternary Geochronology, Vol 1, 167-187.

Greenbaum, N., Porat, N., Rhodes , E.J., and Enzel, Y. (2006). Large floods during late Oxygen Isotope Stage 3, southern Negev desert, Israel . Quaternary Science Reviews Vol 25, 707-719.

Wells, R.T., Grün, R., Sullivan, J., Forbes, M., Dalgairns, S., Bestland, E., Spooner, N., Walshe. K., Rhodes, E., Eggins, S. (2006). Late Pleistocene megafauna site at Black Creek Swamp, Flinders Chase National Park, Kangaroo Island, South Australia. *Alcheringa Special Issue* 1 , 367-387.

Grün, R., Maroto, J., Eggins, S., Stringer, C., Robertson, S., Taylo,r L., Mortimer, G., and McCulloch, M. (2006) ESR and U-series analyses of enamel and dentine fragments of the Banyoles mandible. Journal of Human Evolution Vol 50, Issue 3, 347-358.

Grün, R. (2006) A simple method for the rapid assessment of the qualitative ESR response of fossil samples to laboratory irradiation. Radiation Measurements, Vol 41, 682-689.

Grün, R., (2006) Direct dating of human fossils. Yearbook of Physical Anthropology, 49, 2-48.

Grün, R. , Eggins, S., Wells, R.T., Rhodes , E., Bestland, E., Spooner, N., Ayling, M., Forbes, M., McCulloch, M. (2006) A cautionary tale from down under: Dating of the Black Creek Swamp megafauna site on Kangaroo Island , South Australia . Quaternary Geochronology, Vol 1, 142-150.

Hiemstra J. F., Evans D. J. A., Scourse J. D., Furze M. F. A., McCarroll D., and Rhodes E. J. (2006) The late Quaternary glacial landforms and sediments of the isles of Scilly. Quaternary Science Reviews, Vol 25, 299-309.

Jupiter, S.D., Phinn S.R., Duke, N.C., and Potts , D.C. (2006) Changing mangrove distributions in the Pioneer estuary (Queensland , Australia): evaluating a technique for monitoring mangrove health. Proceedings of the 10 th International Coral Reef Symposium, Okinawa , Japan , pp 1721-1731.

Lawrence, M.G., Jupiter, S.D., and Kamber, B.S. (2006) Aquatic geochemistry of the rare earth elements and yttrium in the Pioneer River catchment, Australia, Marine and Freshwater Research, Vol 57, 725-736.

Montagna, P., McCulloch, M., Taviani, M., Mazzoli, C., and Vendrell, B. (2006) Phosporus in cold-water Corals as a proxy for seawater nutrient chemistry, Science, 312: 23 June, 1788-1791

Nejman, L., Rhodes, E.J., and Grün, R. (2005) OSL dating. In: L. Kaminská, J.K. Kozlowski and J.A. Svoboda (eds) Pleistocene Environments and Archaeology of the Dzeravá Skala Cave, lesser Carpathians, Slovakia. Polska Academia Umiejetnosci, Kraków.

Norman, M.D., McCulloch, M.T., O'Meill, H. S., Yaxley, G. M. (2006) Magnesium isotopic analysis of olivine by laser-ablation multi-collector ICP-MS: composition dependent matrix effects and a comparison of the Earth and Moon. Journal of Analytical Atomic Spectrometry, 21(1), 50-54

Pandolfi, J.M., Tudhope A.W., Burr, G., Chappell, J., Edinger, E., Frey, M., Steneck, R., Sharma, C., Yeates, A., Jennions, M., Lescinsky, H., and Newton, A. (2006) Mass mortality following disturbance in Holocene coral reefs from Papua New Guinea. Geology, Vol 34, 949-952.

Pelejero, C., Calvo, E., McCulloch, M.T., Marshall, J.F., Gagan, M.K., Lough, J.M., Opdyke, B.N. (2006) Response to comment on "Preindustrial to modern interdecadal variability in coral reef pH. Science, Vol. 314, 595c.

Pillans, B. (2006). Chronostratigraphy. In: Elias, S.A. (Ed.). *Encyclopedia of Quaternary Science* , Elsevier, Amsterdam, pp. 2811-2818.

Pillans, B. (2006). Quaternary stratigraphy overview. In: Elias, S.A. (Ed.). *Encyclopedia of Quaternary Science,* Elsevier, Amsterdam, pp. 2785-2801.

Rhodes, E.J., Singarayer, J.S., Raynal, J.-P., Westaway, K.E., and Sbihi-Alaoui, F.Z. (2006) New age estimates for the Palaeolithic assemblages and Pleistocene succession of Casablanca, Morocco. Quaternary Science Reviews, Vol 25, 2569-2585.

Rhodes , E.J., Chappell, J., Fujioka, T., Fitzsimmons, K., Magee, J., Aubert, M. and Hewitt, D. (2006). The History of Aridity in Australia : Chronological Developments. In: Roach I. C. (ed.) Regolith 2005 – Ten Years of CRC LEME, CRC LEME, 265-268.

Schwenninger, J.-L., Rhodes , E.J., Bates, M.R., Briant, R.M., and Wenban-Smith F., 2006. Optically stimulated luminescence (OSL) dating of Quaternary deposits from the Sussex/Hampshire coastal corridor. English Heritage Archaeological Science Research Department Report Series no. 20/2006.

Treble, P.C., Schmitt, A.K., Edwards, R.L., McKeegan, K.D., Harrison, T.M., Grove, M., Cheng, H., and Wang, Y.J., (in press) High resolution Secondary Ionisation Mass Spectrometry (SIMS) d 18 O analyses of Hulu Cave speleothem at the time of Heinrich Event 1, Chemical Geology.

Tian, F., Frew, R.D., Sander, S., Hunter, K.A., Ellwood, M.J., (2006) Organic iron(III) speciation in surface transects across a frontal zone: the Chatham Rise, New Zealand, Marine and Freshwater Research, Vol 57, 533-544.

Trotter, J.A., and Eggins, S.M. (2006) Chemical systematics of conodont apatite determined by laser ablation ICPMS. Chemical Geology, Vol 233 (3-4), 196-216.

Wu, J.L., Lin, L., Gagan, M.K., Schleser, G.H., and Wang, S.M. (2006) Organic matter stable isotope (d 13 C, d 15 N) response to historical eutrophication of Lake Taihu , China . Hydrobiologia, Vol 563, 19-29.

Wysoczanksi, R., Wright, I.C., Gamble, J.A., Hauri, E.H., Luhr, J.F., Eggins, S.M., and Handler, M.R. (2006) Volatile contents of Kermadec Arc-Havre-Trough pillow glasses: fingerprinting slab-derived aqueous fluids in the mantle sources of arc and back-arc lavas. Journal of Volcanology and Geothermal Research, Vol 152, Issue 1-2, 55-73.

Yokoyama, Y., and Esat, T.M. (2006) Comment on "Extending the radiocarbon calibration beyond 26,000 years before present using fossil corals" by T.-C. Chiu, R.G. Fairbanks, R.A. Mortlock, A.L. Bloom (Quaternary Science Reviews 24 (2005) 1797–1808), Quaternary Science Reviews, Vol 25, 381-383.

Earth Materials

Barker, S.L.L., Cox, S.F., Eggins, S.M. and Gagan, M.K. (2006) Microchemical evidence for episodic growth of antitaxial veins during fracture-controlled fluid flow" Earth and Planetary Science Letters, Vol. 250, Issues 1-4, 331-344.

Barnhoorn, A., Jackson, I, Fitz Gerald, J. D., Aizawa, Y.,(2006) Mechanical spectroscopy of high-purity MgO, Proceedings 30th Annual Condensed Matter and Materials Meeting, Wagga Wagga, 7-10 February 2006, ISBN 1-920791-09-4, http://www.aip.org.au/wagga2006/WP4_Barnhoorn.pdf

Berly, T.J., Hermann J., Arculus R.J. and Lapierre H. (2006) Supra-Subduction Zone pyroxenites from San Jorge and Santa Isabel (Solomon Islands). J. Petrol. 47, 1531-1555.

Berry, A.J., O'Neill, H.St.C., Scott, D.R., Foran, G.J. and Shelley, J.M.G. The effect of composition on Cr2+/Cr3+in silicate melts. Am. Mineral., 91, 1901-1908, 2006.

Betts, P.G., Giles, D., Mark, G., Lister, G.S., Goleby, B.R. and Aillères, L. 2006. Synthesis of the Proterozoic evolution of the Mt Isa Inlier. Australian Journal of Earth Sciences 53, 187-211.

Brown, F.H., Haileab, B., McDougall, I. (2006) Sequence of tuffs between the KBS Tuff and the Chari Tuff in the Turkana Basin, Kenya and Ethiopia. Journal of the Geological Society, London , Vol 163, 185-204.

Buick I.S., Allen C., Pandit M., Rubatto D., and Hermann J.: The Proterozoic magmatic and metamorphic history of the Banded Gneiss Complex, central Rajasthan, India: LA- ICP-MS U-Pb zircon constraints. Precamb. Res., 151, 119-142.

Buick, I.S., Hermann J., Williams I.S., Gibson R.L., Rubatto D. (2006): A SHRIMP U-Pb and LA-ICP-MS study of the petrogenesis of garnet-cordierite-orthoamphibole gneisses from the Central Zone of the Limpopo Belt, South Africa. Lithos, 88, 150-172.

Evans, K.A., Phillips, G.N., and Powell, R. Rock buffering of auriferous fluids at Kalgoorlie gold deposit, Western Australia . *Economic Geology* 101, 805-817

Evans, K.A. and Powell, R. The thermodynamics of mixing in saline and mixed solvent solutions at elevated temperature and pressure: A framework for geological phase equilibria calculations. *Geochim. Cosmochim. Acta* 70, 5488 – 5506

Evans K.A. Redox decoupling and redox budgets: Conceptual tools for the study of earth systems. *Geology* 34(6), 489-492.

Evans K.A. and Banwart S. A. Rate controls on the chemical weathering of natural polymineralic material. I. Dissolution behaviour of polymineralic assemblages determined using batch and unsaturated column experiments. *Applied Geochemistry* 21(2), 352-376.

Evans K.A., Watkins D. C., and Banwart S. A. Rate controls on the chemical weathering of natural polymineralic material. II. Rate-controlling mechanisms and mineral sources and sinks for element release from four UK mine sites, and implications for comparison of laboratory and field scale weathering studies. *Applied Geochemistry* 21(2), 377-403.

Falus, Gy., Szabó, Cs., Kovács, I. , Zajacz, Z., (2006) Symplectite in spinel lherzolite xenoliths from the Little Hungarian Plain, Western Hungary : a principle key for understanding basin evolution. Lithos , doi:.10.1016/j.lithos.2006.06.017.

Fitz Gerald, J.D., Parsons, I. and Cayzer, N. (2006) Nanotunnels and pull-aparts: defects of exsolution lamellae in alkali feldspars. American Mineralogist, Vol 91, 772-783.

Fitz Gerald, J.D., Mancktelow , N.S. , Pennachioni, G. and Kunze, K. (2006) Ultrafine-grained quartz mylonites from high-grade shear zones: evidence for strong dry middle to lower crust. Geology, Vol 34, Issue 5, 369-372.

H. Fossen and W.J. Dunlap, 2006, Age constraints on the late Caledonian (Scandian) deformation in the Major Bergen Arc, SW Norway: Norsk Geologisk Tidskrift, v. 86, p. 59-70.

Giles, D., Betts, P.G., Aillères, L., Hulscher, B., Hough, M. and Lister, G.S., 2006. Evolution of the Isan Orogeny at the southeastern margin of the Mt Isa Inlier. Australian Journal of Earth Sciences 53, 91-108.

Gwanmesia, G., Jackson , I. , Liebermann, R.C., In search of the mixed derivative •^{2} M/•P•T (M = K, G): joint analysis of ultrasonic data for polycrystalline pyrope from gas- and solid-medium apparatus, Physics and Chemistry of Minerals (in press)

Hermann J., Fitz Gerald J., Malaspina N., Berry A.J. and Scambelluri M.: OH-bearing planar defects in olivine produced by the breakdown of Ti-rich humite minerals from Dabie Shan (China). Contrib. Mineral. Petrol., in press.

Hermann J., Rubatto D., Korsakov A. and Shatsky V. (2006): The age of metamorphism of diamondiferous rocks determined with SHRIMP dating of zircon. Russian Geol. Geophys. 47, 513-520

Hermann J, Rubatto D, and Trommsdorff V. (2006) Sub-solidus Oligocene zircon formation in garnet peridotite during fast decompression and fluid infiltration (Duria, Central Alps). Mineral. Petrol. 88, 181-206

Jackson, I., Faul, U.H., Fitz Gerald, J.D. and Morris, S. (2006) Contrasting viscoelastic behaviour of melt-free and melt- bearing olivine: implications for the nature of grain-boundary sliding. Materials Science and Engineering A. 442, 170-174.

Jackson, I., Faul, U.H., Fitz Gerald, J.D., Morris, S.J.S, (2006) Strain-energy relaxation mechanisms in geological materials, 30th Annual Condensed Matter and Materials Meeting, Wagga Wagga, 7-10 February 2006, http://www.aip.org.au/wagga2006/WP22_Jackson.pdf

Korsakov, A.V., and Hermann J. (2006): Silicate and carbonate melt inclusions associated with diamonds in deeply subducted carbonate rocks. Earth. Plant. Sci. Lett. 241, 104-118.

Li, C.P., Fitz Gerald, J.D. and Chen, T. (2006) Substitution reactions of carbon nanotube template. Applied Physics Letters, 88, 264622.

Lu, C., Jackson , I. , (2006) Low-frequency seismic properties of thermally cracked and argon-saturated granite, Geophysics, 71, F147-F159.

MacCready, T., Goleby, B.R., Goncharov, A., Drummond, B.J. and Lister, G.S. 2006. Shifts in the locus of crustal thickening during Mesoproterozoic orogenesis in the Mt Isa Terrane. Australian Journal of Earth Sciences 53, 41-53.

Malaspina N., Hermann J., Scambelluri M. and Compagnoni R. (2006): Polyphase inclusions in garnet– orthopyroxenite (Dabie Shan, China) as monitors for metasomatism and fluid-related trace element transfer in subduction zone peridotite. Earth. Planet. Sci. Lett. 249, 173-187.

Malaspina N., Hermann J., Scambelluri M. and Compagnoni R. (2006): Multistage metasomatism in ultrahigh-pressure mafic rocks from the North Dabie Complex (China). Lithos, 90, 19-42.

Mazur, S. Dunlap, W.J. K. Turniak, K., and Overc-Driedzic, T., 2006, 40 Ar/ 39 Ar age constraints for the thermal evolution and erosional history of the central European Variscan belt: new data from the sediments and basement of the Carboniferous foreland basin in western Poland : Journal of the Geological Society, London , v. 163(6), p 1011-1024

McDougall, I., Brown, F.H. (2006) Precise 40 Ar/ 39 Ar geochronology for the upper Koobi Fora Formation, Turkana Basin, northern Kenya. Journal of the Geological Society, London , Vol 163, 205-220.

McDougall, I. , Watkins, R.T. (2006) Geochronology of the Nabwal Hills: a record of earliest magmatism in the northern Kenyan Rift Valley. Geological Magazine, Vol 143, 25-39.

McFarlane, C.R.M. & Harrison, T.M. (2006) Pb-diffusion in monazite: constraints from a high-T contact aureole setting. Earth & Planetary Science Letters, 250, 376-384.

McFarlane, C.R.M. (2006) Palaeoproterozoic metamorphic evolution of the Challenger Au deposit, South Australia, from Monazite geochronology. Journal of Metamorphic Geology, 24, 75-87.

McFarlane, C.R.M., Connelly, J.N., Carlson, W.D. (2006) Contrasting response of monazite and zircon to a high-temperature thermal overprint. Lithos, 88, 135-139, special issue on compositional variation in metamorphic accessory phases.

Micklethwaite, S., and Cox, S.F., (2006) Progressive fault triggering and fluid flow in aftershock domains: Examples from mineralized Archaean fault systems. Earth and Planetary Science Letters, Vol 250, 318-330.

McLaren S. and Dunlap, W.J. 2006, Use of 40 Ar/ 39 Ar K-feldspar thermochronology in thermal history reconstruction: An example from the Big Lake Suite granites, Warburton Basin, South Australia: Basin Research, v. 18, p. 189-204.

Mortimer, N. Hoernle, K. Hauff, F. Palin, J.M. Dunlap, W.J. Wernerr, R. Faure, K. 2006, New constraints on the age and evolution of the Wishbone Ridge, Southwest Pacific Cretaceous microplates, and Zealanddia-West Antarctica breakup: Geology, v. 134, p. 185-188.

Mustard R., Ulrich T., Kamenetsky V., and Mernagh T. P. (2006) Gold and metal enrichment in natural granitic melt during fractional crystallization. *Geology* 34(2), 85-88.

Norman, M.D., McCulloch, M,T., O'Neill, H.St.C., and Yaxley, G.M. Magnesium isotopic analysis of olivine by laser-ablation multi-collector ICP-MS: composition dependent matrix effects and a comparison of the Earth and Moon. J. Anal. At. Spectrom., 21, 1, 50-54, 2006

O'Neill, H.St.C., Berry, A.J., McCammon, C.C., Jayasuriya, K.D., Campbell, S.J., Foran, G. An experimental determination of the effect of pressure on the Fe 3+ /?Fe ratio of an anhydrous silicate melt to 3.0 GPa. Amer. Mineral., 91: 2-3, 404-412, 2006.

O'Neill, H.St.C., and Berry, A.J. Activity coefficients at low dilution of CrO, NiO and CoO in melts in the system CaO-MgO-Al 2 O 3 -SiO 2 at 1400°C: Using the thermodynamic behaviour of transition metal oxides in silicate melts to probe their structure. Chem. Geol., 231: 77-89, 2006.

O'Neill, H.St.C., Free energy of formation of zircon and hafnon. Amer. Mineral., 91: 1134-1141, 2006.

Rubatto D., Hermann J., and Buick, I.S. (2006): Temperature and bulk composition control on the growth of monazite and zircon during low-pressure Anatexis (Mount Stafford, Central Australia). J. Petrol 47, 1973-1996.

Sandiford, M., Hansen, D.L., McLaren, S. Lower crustal rheological expression in inverted basins. In: Buiter, S.J.H. and Schreurs, G. (eds) Analyogue and Numerical Modelling of Crustal-Scale Processes. Geological Society, London , Special Publications, 253, 271-283.

Sandiford, M. and McLaren, S. Thermo-mechhanical controls on heat production distributions and the long-term evolution of the continents. In: Brown, M. and Rushmer, T. (Eds) Evolution and differentiation of the Continental Crust, Cambridge University Press, 67-92.

Satish-Kumar M., Hermann J., Tsunogae T. and Osanai Y. (2006) Carbonation of Cl-rich scapolite boudins in Skallen, East Antarctica: Evidence for changing fluid condition in the continental crust. J. Met. Geol, 24, 241-261.

Scambelluri M., Hermann J., Morton L. and Rampone B. (2006) Melt- versus fluid-induced metasomatism in spinel to garnet wedge peridotites (Ulten Zone, Eastern Italian Alps): clues from trace element and Li abundances. Contrib. Mineral. Petrol. 151, 372-394.

Schellart, W.P., Lister, G.S. and Toy, V.G. 2006. A Late Cretaceous and Cenozoic reconstruction of the Southwest Pacific region: Tectonics controlled by subduction and slab rollback processes. Earth Science Reviews 76, 191-233

Sinmyo, R., Hirose, K., O'Neill, H.St.C., Okunishi, E. Ferric iron in Al-bearing post-perovskite, Geophys. Res. Lett., 33: L12S13, doi: 10.1029/2006GL025858.

Spandler C. and Hermann J. (2006): High-pressure veins in eclogite from New Caledonia and their significance for fluid migration in subduction zones. Lithos 89, 135-153.

Tenthorey, E. and COX, S.F., 2006. Cohesive strengthening of fault zones during the interseismic period: An experimental study. Journal of Geophysical Research-Solid Earth,111, B09202, doi: 10.1029.2005JB004122.

Tenthorey, E and Fitz Gerald, J.D. (2006) Feedbacks between deformation, hydrothermal reaction and permeability evolution in the crust: experimental insights. Earth Planetary Science Letters, Vol 247, 117-129.

Ting,V., Liu, Y., Withers, R.L., Norén, L., James, M. and Fitz Gerald, J.D. (2006) A structure and phase analysis investigation of the "1:1" ordered A 2 InNbO 6 perovskites (A = Ca 2+ , Sr 2+ , Ba 2+). Journal Solid State Chemistry, Vol 179, 551-562

Trommsdorff V., Montrasio A., Hermann J., Müntener O., Spillmann P. and Gieré R. (2005) The Geological Map of Valmalenco. Schweiz. Mineral. Petrol Mitt. 85, 1-13.

Tulloch, A.J. and. Dunlap, W.J 2006, A Carboniferous 40Ar/39Ar amphibole emplacement age for the Au-bearing Sams Creek alkali-feldspar granite dike, west Nelson, New Zealand: New Zealand Journal of Geology and Geophysics, v. 49, p. 233-240.

Zhang, H., Yu, J., Chen, Y., and Fitz Gerald, J.D. (2006) Conical boron nitride nanorods synthesized via ball-milling and annealling method. Journal American Ceramic Society, doi: 10.1111/j.1551-2916.2005.00720.x, Vol 89, 675-679.

Zhang, H., Fitz Gerald, J.D., Chadderton, L.T., Yu, J. and Chen, Y. (2006) Growth and internal structure of prismatic Boron Nitride nanorods. Physical Review B, Vol 74, 045407.

Zhang, H.Z., Phillips, M.R., Fitz Gerald, J.D., Yu, J. and Chen, Y. (2006) Patterned growth and cathodoluminescence of conical boron nitride nanorods. Applied Physics Letters, Vol 88, 093117.

In Press

Berry, A.J., Hack, A.C., Mavrogenes, J.A., Newville, M. and Sutton, S.R., 2006, A XANES study of Cu speciation in high-temperature brines using synthetic fluid inclusions. American Mineralogist.

Dunlap, W.J. 2006, K-Ar and 40 Ar/ 39 Ar dating of K-Mn oxides: Regolith Geochronology and Landscape Evolution, Open File Report 189, ed. B. Pillans, CRC LEME, Australia. IN PRESS, September, 2006.

Evans K. A. and Powell R. DES-code: a metacode to aid calculation of the chemical potential of aqueous solutions at elevated temperatures and pressures. *Computers and Geosciences* .

Gwanmesia, G., Jackson , I. , Liebermann, R.C., In search of the mixed derivative •^{2} M/•P•T (M = K, G): joint analysis of ultrasonic data for polycrystalline pyrope from gas- and solid-medium apparatus, Physics and Chemistry of Minerals

Hack, AC, Hermann, J and Mavrogenes, JA, 2006. Mineral solubility and hydrous melting relations in the deep Earth: Continuous simple system topologies, fluid-melt relations and critical behavior. Accepted pending revision, American Journal of Science. Rubatto D., and Hermann J.: Zircon behaviour in deeply subducted rocks. Elements, in press.

Herman, F. Braun J. and Dunlap, W.J. Tectono-morphic scenarios in the Southern Alps of New Zealand , Journal of Geophysical Research (B).

Hermann J., Fitz Gerald J., Malaspina N., Berry A.J. and Scambelluri M.: OH-bearing planar defects in olivine produced by the breakdown of Ti-rich humite minerals from Dabie Shan (China). Contrib. Mineral. Petrol., in press.

Hermann J., Spandler C., Hack A., and Korsakov, A.V. Aqueous fluids and hydrous melts in high-pressure and ultra-high pressure rocks: implications for element transfer in subduction zones. Lithos,

Jackson, I., Faul, U. H., Fitz Gerald, J.D., Morris, S.J.S., Contrasting viscoelastic behaviour of melt-free and melt-bearing olivine: implications for the nature of grain-boundary sliding, Materials Science and Engineering. A, vol 442, (in press)

Jackson , I. , Physical Origins of Anelasticity & Attenuation in Rock, in Treatise on Geophysics, Volume 2 - Mineral Physics: Properties of Rocks & Minerals, Elsevier

Kovács I., Hidas K., Hermann J., Szabó C., Sharygin V., Theodoros Ntaflos T.: Fluid induced incipient melting in mantle xenoliths from the Minusinsk Region (Siberia, Russia) and some implications for the subcontinental lithospheric mantle. Geol. Carpath., in press.

Menzies, J. Davies, H. Dunlap W.J. and Golding, S. 2006, A possible early age for the Diprotodon (Marsupialia: Diprotodontidae) fossil from the Papua New Geuinea Highlands: Alcheringa, 2006.

Rolland, Y., Corsini, M., Rossi , M., COX, S.F., Pennacchioni, Mancktelow, G.N., Boullier, A.-M., Fornari, M., 2006. Comment on the dating of Alpine deformation by Ar-Ar on syn-kinematic mica in mid-crustal shear zones of the Mont Blanc Massif (paper by Leloup et al.), *Tectonics* .

Spandler C., Mavrogenes J., and Hermann J.: Experimental constraints on element mobility from subducted sediments using high-P synthetic fluid/melt inclusion. Chem. Geol.

Xi, L., O'Neill, H.St.C. Effects of P 2 O 5 and TiO 2 on the partial melting of spinel lherzolite in the system CaO-MgO-Al 2 O 3 -SiO 2 at 1.1 GPa, Canadian Mineralogist

Submitted

Beltrando, M., Hermann, J., Lister, G., Compagnoni, R. (2006) On the evolution of orogens: pressure cycles and deformation mode switches, EPSL, *Submitted*

Forster, M., Lister, G., (2006) Orogenic sequence diagrams and the evolution of the Otago Schist, New Zealand, Geology, *Submitted* .

Smith, M.L., Kurtz, J., Richards, S.W., Forster, M., Lister, G., (2006) Re-evaluating the breakup of the South America and Africa using deformable mesh reconstruction software, Journal of the Virtual Explorer, *Submitted* .

Earth Physics

Coman, M., Hughes, G., Kerr, R., Griffiths, R., (2006) The effect of a barrier on laminar convection in a box with differentially heated endwalls, International Journal of Heat and Mass Transfer, Vol 49, 2903-2911.

Coman, M.A., Griffiths , R.W.and Hughes, G.O., (2006) Sandstrom's experiments revisited. J. Marine. Res.64,783-796.

Coman, M., Griffiths, R., Hughes, G., (2006) Horizontal convection driven by two spatially separated regions of destabilising flux, Proceedings of the 6th International Symposium on Stratified Flows, Perth, 12-15 December 2006, 563-568.

Cashman, K., Kerr, R., Griffiths, R., (2006) A laboratory model of surface crust formation and disruption on irregular channelized lava flows, Bulletin of Volcanology, Vol 68, 753-770, doi:10.1007/s00445-005-0048-z.

Davies, G.F. (2006), Gravitational depletion of the early Earth's upper mantle and the viability of early plate tectonics, Earth Planet. Sci. Lett., 243, 376–382.

Davies, G.F. (2006), Mantle regulation of core cooling: a geodynamo without core radioactivity? Phys. Earth Planet. Interiors, in press.

Barruol G., Reymond D., Fontaine F. R., Hyvernaud O., Maurer V., and Maamaatuaiahutapu K., 2006, Characterizing swells in the southern Pacific from seismic and infrasonic noise analyses, vol 164, Geophysical Journal International, doi:10.1111/j.1365-246X.2006.02871.x

Fontaine F. R., Barruol G., Tommasi A., and Bokelmann G. H. R., 2006, Upper mantle flow beneath French Polynesia from shear-wave splitting, Geophys. J. Int. (Submitted)

Griffiths, R., Hughes, G., (2006) Adjustment Processes and Timescales in Horizontal Convection, Proceedings of the 6th International Symposium on Stratified Flows, Perth, 12-15 December 2006, 545-550 .

Huang, J.S. and Davies, G.F. (2006), Stirring in Three-Dimensional Mantle Convection Models and Implications for Geochemistry I: Passive tracers, *Geochemistry Geophysics Geosystems* , in press.

S. Zhong, M. Ritzwoller, N. Shapiro, W. Landuyt, J.S. Huang, P. Wessel (2006) , Seafloor Topography for the Pacific and Its Implications for Thermal Evolution of Lithosphere and the Mantle Dynamics, *Journal of Geophysical Research* , in press.

Hogg, A.McC. & Blundell, J.R., (2006) Interdecadal variability of the Southern Ocean, J. Phys. Oceanogr., 36, 1626-1645.

Hogg, A.McC., Dewar, W.K., Killworth, P.D. & Blundell, J.R., (2006) Decadal variability of the midlatitude climate system driven by the ocean circulation, J. Climate , 19, 1149-1166.

Hogg, A.McC. & Hughes, G.O. 2006 Shear flow and viscosity in single-layer hydraulics. J. Fluid. Mech. 548, 431–443.

Hogg, A., Hughes, G., (2006) Viscous hydraulic control: A reduced gravity model, Proceedings of the 6th International Symposium on Stratified Flows, Perth, 12-15 December 2006, 62-67.
Hughes, G., Griffiths, R., Mullarney, J., Peterson, W., (2006) A theoretical model for 'horizontal convection', Proceedings of the 6th International Symposium on Stratified Flows, Perth, 12-15 December 2006, 551-556 .

Hughes, G.O., Griffiths, R.W. (2006) A simple convective model of the global overturning circulation, including effects of entrainment into sinking regions. Ocean Modelling 12, 46–79.

Rawlinson N., Reading A.M. & Kennett B.L.N. (2006) Lithospheric structure of Tasmania from teleseismic tomography: implications for Phanerozoic evolution of Eastern Australia, Journal of Geophysical Research, Vol 111, B02301, doi:10.129/2005JB003803.

Miller M.S., Kennett B.L.N. & Toy V. (2006) Spatial and temporal evolution of the subducting Pacific plate structure along the western Pacific margin, Journal of Geophysical Research, Vol 111, B02401, doi:10.129/2005JB003705.

Miller M.S., Kennett B.L.N., Gorbatov A. (2006) Morphology of the distorted subducted Pacific slab beneath the Hokkaido corner, Physics of the Earth and Planetary Interiors, Vol 156, 1-11.

Miller M.S., Kennett B.L.N. (2006) Evolution of mantle structure beneath the Northwest Pacific: evidence from seismic tomography and paleogeographic reconstructions. Tectonics, Vol 25, TC4002, doi: 10.1029/2005TC001909.

Miller M. S., Gorbatov A., Kennett B. L. N. (2006) Three-dimensional visualization of a near-vertical slab tear beneath the southern Mariana arc, Geochem. Geophys. Geosyst., Vol 7, Q06012, doi:10.1029/2005GC001110.

Prastowo, T., Griffiths, R., Hughes, G., Hogg , A., (2006) Mixing in Exchange Flows Through a Contraction , Proceedings of the 6th International Symposium on Stratified Flows, Perth, 12-15 December 2006, 68-73.

Rawlinson N., Kennett B.L.N., Heintz M. (2006), Insights into the structure of the upper mantle beneath the Murray Basin from 3-D teleseismic tomography, Australian Journal of Earth Sciences, Vol 53, 595-604.

Kennett B.L.N. (2006), Nonlinear methods for seismic event location in a global context, Physics of the Earth and Planetary Interiors, Vol 158 , 46-54.

Kennett B.L.N. (2006), On seismological reference models and the perceived nature of heterogeneity, Physics of the Earth and Planetary Interiors, Vol 159, 129-139.

Heintz M. & Kennett B.L.N. (2006), The apparently isotropic Australian upper mantle, Geophys. Res. Lett., 33, L15319, doi:10.1029/2006GL026401

Kennett B.L.N. (2006) Developments in passive seismic techniques through the ANSIR National Research Facility, Exploration Geophysics, December issue

Antonioli, F., Ferranti, L., Lambeck, K., Kershaw, S., Verrubbi, V., Pra, G.D., (2006) Late Pleistocene to Holocene record of changing uplift rates in southern Calabria and northeastern Sicily (southern Italy, Central Mediterranean Sea), Tectonophysics, Vol 422, Issue 1-4, 23-40.

Lambeck, K., Purcell, A., Funder, S., Kj æ r, K., Larsen, E., M ö ller, P., (2006) Constraints on the Late Saalian to early Middle Weichselian ice sheet of Eurasia from field data and rebound modelling, Boreas, Vol 35, Issue 3, 539-575.

Lambeck, K., Sivan, D., Purcell, A., (2006) Timing of the last Mediterranean Sea – Black Sea connection from isostatic models and regional sea-level data, in *The Black Sea Flood Question: Changes in Coastline, Climate and Human Settlement* , V. Yanko-Hombach, A.S. Gilbert, N. Panin (eds), Springer, Heidelberg, 797-808.

Sparrenbom, C.J., Bennike, O., Bjorck, S., Lambeck, K., (2006) Relative sea-level changes since 15000 cal. Yr BP in the Nanortalik area, southern Greenland, Journal of Quaternary Science, Vol 21, Issue 1, 29-48.

Sparrenbom, C.J., Bennike, O., Bjorck, S., Lambeck, K., (2006) Holocene relative sea-level changes in the Qaqortoq area, southern Greenland, Boreas, Vol 35, Issue 2, 171-187.

Uehara, K., Scourse, J.D., Horsburgh, K.J., Lambeck, K., Purcell, A.P., (2006) Tidal evolution of the northwest European shelf seas from the Last Glacial Maximum to the present, Journal of Geophysical Research, Vol 111, Issue C9, C09025.

Yokoyama, Y., Purcell, A., Marshall, J.F., Lambeck, K., (2006) Sea-level during the early deglaciation period in the Great Barrier Reef, Australia, Global and Planetary Change, Vol 53, Issue 1-2, 147-153.

Rawlinson, N., Reading , A. M. and Kennett, B. L. N., 2006. Lithospheric structure of Tasmania from a novel form of teleseismic tomography, J. Geophys. Res., 111, B02301, doi:10.1029/2005JB003803.

Rawlinson, N., Kennett, B. L. N. and Heintz, M. 2006. Insights into the structure of the upper mantle beneath the Murray Basin from 3-D teleseismic tomography, Aust. J. Earth Sci., 53, 595-604.

de Kool, M., Rawlinson, N. and Sambridge, M. 2006. A practical grid based method for tracking multiple refraction and reflection phases in 3D heterogeneous media, Geophys. J. Int., 167, 253-270.

Rawlinson, N., de Kool, M. and Sambridge M., 2006. Seismic wavefront tracking in 3-D heterogeneous media: applications with multiple data classes. Explor. Geophys., ***to be published in December issue.***

Hauser, J., Sambridge, M. and Rawlinson, N. 2006. Phase space methods for multi arrival wavefronts. Exploration Geophysics, ***to be published in December issue.***

Boehm, J., A. E. Niell, P. Tregoning, H. Schuh, (2006) The GMF: A new empirical mapping function based on numerical weather model data, Geophysical Research Letters, Vol 33(7), L07703, doi:10.1029/2005GL025546.

Walpersdorf, A., S. Baize, E. Calais , P. Tregoning and J.-M. Nocquet (2006) Deformation in the Jura Mountains (France): First results from GPS measurements, Earth and Planetary Science Letters ,Vol 245, 365-372.

C. Watson, P. Tregoning, R. Coleman (2006) The impact of solid Earth tide models on GPS time series analysis, Geophys. Res. Lett., 33(8), L08306, 10.1029/2005GL025538.

Boehm, J., P.J. Mendes Cerveira, H. Schuh, P. Tregoning, (2006) The impact of tropospheric mapping functions based on numerical weather models on the determination of geodetic parameters, IAG Proceedings, Vol 130, in press.

Tregoning, P. and T. A. Herring (2006) Impact of a priori zenith hydrostatic delay errors on GPS estimates of station heights and zenith total delays, Geophysical Research Letters, in press.

Dawson, J., Sarti, P., Johnston, G., Vitturi, L., (2006) Indirect Approach to Invariant Point Determination for SLR and VLBI Systems: An Assessment, Journal of Geodesy, *in press.*

Robinson, D., Dhu, T. and Schneider, J., (2006) Practical probabilistic seismic risk analysis: A demonstration of capability, Seismological Research Letters, Vol. 77(4), 453-459.

Robinson, D., Dhu, T. and Schneider, J., (2006) SUA: A computer program to compute regolith site-response and estimate uncertainty for probabilistic seismic hazard analyses, Computers and Geosciences, Vol. 32, 109-123. doi:10.1016/j.cageo.2005.02.017

Kerr, R., Griffiths, R., Cashman, K., (2006) The formation of channelized lava flows on an unconfined slope,Journal of Geophysical Research, Vol 111, B10206, doi:10.1029/2005JB004225.

Lyman, A., Kerr, R., (2006) The effect of surface solidification on the emplacement of lava flows on a slope, Journal of Geophysical Research, Vol 111, B05206, doi:10.1029/2005JB004133.

Meredith, M.P. & Hogg, A.McC., (2006), Circumpolar response of Southern Ocean eddy activity to changes in the Southern Annular Mode, Geophys. Res. Lett., 33, doi:10.1029/2006GL026499.

Mullarney, J.C., Griffiths, R.W., Hughes, G.O. (2006) The effects of geothermal heating on the ocean overturning circulation. Geophys. Res. Lett. 33, doi:10.1029/2005GL024956.

Mullarney, J.C., Griffiths, R.W., Hughes, G.O. (2006) The role of freshwater fluxes in the thermohaline circulation: insights from a laboratory analog. Deep-Sea Res. I, doi:10.1016/j.dsr.2006.10.001.

Sambridge, M. and Beghein, C. and Simons, F. and Snieder, R., (2006) How do we understand and visualize uncertainty ? *The Leading Edge* , Vol 25, 542-546.

de Kool, M., Rawlinson, N. and Sambridge, M., (2006) http://rses.anu.edu.au/%7Emalcolm/papers/pdf/dekool06.pdf A practical grid based method for tracking multiple refraction and reflection phases in 3D heterogeneous media, *Geophy. J. Int.* , Vol 167, 253-270.

Reading , A.M. 2006 (in press – details to follow). The seismicity of the Antarctic Plate. In: Intraplate seismicity, Stein, S. and Mazzotti, S. *Geological Society of America Book* .

Reading , A.M. , 2006. The seismic structure of Precambrian and early Palaeozoic terranes in the Lambert Glacier region, East Antarctica . *Earth and Planetary Science Letters* , 244, 44-57.

Reading , A.M . 2006. On seismic strain-release within the Antarctic Plate. In: Futterer, D.K. Damaske, D., Kleinschmidt, G., Miler, H., Tessensohn, F. (Eds), *Antarctica – Contributions to Global Earth Sciences* . Springer-Verlag, 351-356.

Sambridge, M., Gallagher, K, Jackson, A., and Rickwood, P., (2006) Trans-dimensional inverse problems, Model Comparision and the Evidence, *Geophy. J. Int.* , Vol 167, 528-542.

Rickwood, P. and Sambridge, M., (2006) Efficient parallel inversion using the Neighbourhood Algorithm *Geochem. Geophys. Geosyst* , Vol 7,Q11001.

Brodie, R., and Sambridge, M., (2006) A holistic approach to inversion of frequency domain airborne EM data, *Geophysics* , **71** , No. 6, pp G301-G312, 2006.

Subbey, S., Monfared, H., Christie, M., and Sambridge, M., (2006) Quantifying uncertainty in flow functions derived from SCAL data, *Transport in Porous Media* , Vol 65, No. 2, 265-286.

Stegman, D.R., J. Freeman, W.P. Schellart, L. Moresi, and D. May (2006) Influence of trench width on subduction hinge retreat rates in 3-D models of slab rollback. *Geochemistry Geophysics Geosystems* 7, Q03012, doi:10.1029/2005GC001056.

Schellart, W.P., G.S. Lister and V. G. Toy, (2006) A Late Cretaceous and Cenozoic reconstruction of the Southwest Pacific region: Tectonics controlled by subduction and slab rollback processes. *Earth-Science Reviews* 76, EARTH-01424, doi:10.1016/j.earscirev.2006.01.002 , 191-233.

Hunt, S.P., Morelli, C., Boult, P.J., Hill, T., Sinadinovski, C., (2006) Seismic hazard assessment through predictive modelling of local stress changes due to hot rock fractures (HRF) geothermal energy operations in the Cooper Basin of South Australia , AEES Conference proceedings, 203-205.

Itikari, I. , Kennett, B.L., Sinadinovski, C., (2006) Volcano-Tectonic earthquakes and magma reservoirs; their influences on volcanic eruptions in Rabaul caldera, AEES Conference proceedings, 205-211.

Sinadinovski, C., Greenhalgh , S.A. , Love, D., (2006) Historical earthquakes: a case study for the Adelaide 1954 earthquake, AEES Conference proceedings, 151-157.

Zhong, L., Hao, H., Gaull, B.A., Sinadinovski, C., (2006) Simulation of strong ground motions with a combined Green's function and stochastic approach, AEES Conference proceedings, 213-219

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Dr. M. Gagan: Indian Ocean Dipole, Australasian Drought and the Great Earthquake Cycle. $1,016,000 (2006-2010)

Dr. M. Gagan: Monsoon Extremes, Environmental Shifts and Catastrophic Volcanic Eruptions. $445,000 (2006-2008)

Prof. R. Griffiths: From the Ocean Depths to Abrupt Climate Change. $401,000 (2006-2010)

Prof. R. Grun: Microanalysis of Human Fossils – New Insight into Age, Diet and Migration. $285,000 (2006-2008)

Prof. R. Grun: Out of Africa and into Australia: Robust Chronologies for Turning Points in Modern Human Evolution and Dispersal. $316,000 (2006-2010) - Via University of Wollongong

Prof. M. Harrison: Exploring the Hadean Earth. $280,000 (2006-2008)

Dr. T. Ireland: Sources and Processes in the Early Solar System – An Isotopic Study. $230,000 (2006-2008)

Prof. B. Kennett: Seismic Constraints on the Assembly of Cratons. $535,000 (2006-2009)

Prof. H. O'Neill: Understanding Deep Mantle – Experimental Petrology at Very High Pressures. $480,000 (2006-2008)

Dr. M. Sambridge: Precise Location of Earthquakes. $337,000 (2006-2009)

Linkage Infrastructure Equipment & Facilities Grants

Dr. J. Brocks: A Highly Sensitive Mass Spectrometer for Trace Analysis of Biomarker Molecules to Study Changes in Recent and Ancient Environments. $390,700 (2006)

Prof. B. Kennett: Instrumentation for Combined Seismic and Electromagnetic Earth Sounding. $350,000 (2006)

Linkage International Grants

Dr. A. Hogg: Non-Hydrostatic Waves and Instabilities in Rotating Fluids. $16,400 (2006-2007)

Other Grants

Australian Institute of Nuclear Science and Engineering (AINSE) Grant

Dr. W. Dunlap: 40Ar/39Ar Dating for Tectonics and the Environment. $15,552 (2006)

Australian Nuclear Science & Technology Organisation (ANSTO) Grants

Dr. K. Evans: Speciation of S, Mn, Co, Ni in Silicate Melts: $6,335 (2006)

Dr. K. Evans: Speciation in Concentrated, Supercritical RbBr-H2O-CO2 Fluids: A Corundum-Hosted Synthetic Fluid Inclusion Study. $11,860 (2006)

Dr. K Evans: Complexation of S, Cl & Transition Metals in Silicate Melts. $7,830 (2006)

Major Equipment Grants

Dr. J. Brocks: A Highly Sensitive Mass Spectrometer for Trace Analysis of Biomarker Molecules to Study Changes in Recent and Ancient Environments. $50,000 (2006)

Prof. B. Kennett: Instrumentation for Combined Seismic and Electromagnetic Earth Sounding. $60,000 (2006)

A. Wilson: Replacement of Workshop Machine-Wire-cut EDM (Electro Discharge Machine). $40,200 (2006)

De Beers Group Exploration

Prof. G. Lister: Diamonds & Lithosphere Dynamics. $25,000 (2006)

Department of Innovation, Industry and Regional Development

Dr. G. Yaxley: Calibration of Iron XANES in Garnets – Application to the Search for Diamonds. $11,000 (2006-2007)

NATIONAL AND INTERNATIONAL LINKS 2006

COLLABORATION WITH AUSTRALIAN UNIVERSITIES, CSIRO & INDUSTRY
INTERNATIONAL COLLABORATION
COOPERATION WITH GOVERNMENT AND INDUSTRY

COLLABORATION WITH AUSTRALIAN UNIVERSITIES, CSIRO & INDUSTRY

Earth Chemistry

Dr J.J. BROCKS continues to collaborate with Dr S. George (Macquarie University) on the organic geochemistry and microbial history of saline Lake Tyrrell .

Dr J.J. BROCKS continues to collaborate with Dr B. Rasmussen (University of Western Australia) on the carbon isotopic evolution of organic matter in the Archaean and Palaeoproterozoic.

Dr I.H. CAMPBELL and Dr C.M. ALLEN, with Dr R. Squire, (Monash University); Dating detrital zircons from Western Australia Archaean sediments.

Dr I.H. CAMPBELL and Dr C.M. ALLEN, with Dr R. Squire, (Monash University); Dating detrital zircons from Victorian sediments.

Dr I.H. CAMPBELL and Dr C.M. ALLEN collaborated with Dr Mark Paine (CRC-LEME) on sources of heavy mineral sands, S.A.

Ms C. G REGORY collaborated with Dr I. Buick (formerly Monash University, now ANU) and Dr C. McFarlane (ANU).

Dr M. HONDA, with Dr D. Phillips, Prof Gleadow and Dr B. Kohn (University of Melbourne), Prof S. O'Reilly (Macquarie University), Prof A. Chivas, Prof R. Roberts and Prof C. Murray-Wallace (University of Wollongong), Dr D. Cooke (University of Tasmania), on "A New Generation Noble Gas Mass Spectrometer Facility for Advanced Research in the Earth, Planetary and Environmental Sciences".

Dr M. HONDA, with Dr D. Phillips (University of Melbourne) on noble gas studies of diamonds.

Dr M. HONDA collaborates with Prof A. Chivas (University of Wollongong) on cosmogenic neon exposure dating of young basalts.

Dr T.R. IRELAND continues to collaborate with Dr I. Buick (formerly Monash University, now ANU), Dr P. Vasconcelos (University of Queensland), Dr P. Carr and 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.

Mr A.P. KALLIO collaborated with Dr L. Danyushevsky (University of Tasmania) and Dr D. Kamenetsky (University of Tasmania).

Dr D. RUBATTO, with Prof I. Buick (Monash University / RSES, ANU).

Dr R. SALMERON collaborates with Associate Prof M. Wardle (Physics Department, Macquarie University), on the structure and dynamics of magnetized protostellar disks.

Dr I.S. WILLIAMS, with Australian Scientific Instruments on SHRIMP development, Dr A. Kennedy (Curtin University) on SHRIMP development, Geoscience Australia on granite geochemistry, Prof B.W. Chappell (Macquarie University) on granite geochemistry, and Dr I.S. Buick (formerly Monash University) on metamorphic geochronology.

Earth Environment

Mr M. AUBERT with Dr S. O'Connor (Research School of Pacific and Asian Studies, ANU), on dating the rock art of Lene Hara cave, East Timor.

Dr M.J. ELLWOOD with Prof W. Maher (University of Canberra), on the Ge/Si geochemistry of diatoms and siliceous marine sponges.

Dr M.J. ELLWOOD with Dr Andrew Bowie (ACE CRC & ACROSS, University of Tasmania), on the influence of trace elements on ocean productivity (GEOTRACES).

Dr S. EGGINS and Prof R. R. GRÜN with Prof C.V. Murray-Wallace (University of Wollongong), on the dating of marine molluscs and late Quaternary shoreline deposits of southern Australia .

Dr S. EGGINS and Mr J.M.G. SHELLEY with Dr J. MacDonald (Department of Sustainability and the Environment, Victoria), on the geochemistry of Australian bass otoliths.

Dr M.K. GAGAN, Dr L.K. AYLIFFE, and Mr D. QU 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 and Dr L.K. AYLIFFE 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 J. Magee (DEMS, ANU), Associate investigators on National Geographic Society Grant: Aepyornis extinction and environmental change in Madagascar: assessing human impacts through precise dating and paleoenvironmental proxies preserved in eggshells and US NSF Grant: Collaborative Research: Identifying the footprints of human colonization on Australian ecosystems and climate.

Dr M.K. GAGAN with Dr A. Moy and Dr W. Howard (University of Tasmania), Late Quaternary palaeoceanography of the Circumpolar Deep Water from the South Tasman Rise.

Dr M.K. GAGAN with Prof G. Skilbeck (University of Technology, Sydney), Reconstruction of the post-glacial history of the El Niño-Southern Oscillation using stable-isotope ratios in foraminifera and organic matter in Ocean Drilling Program cores from the Peruvian continental margin.

Dr M.K. GAGAN with Dr I. Goodwin (University of Newcastle), Measurement of stable-isotope ratios in Holocene coral microatolls from the tropical southwest Pacific.

Dr M.K. GAGAN with 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 eastern Indian Ocean.

Prof R. GRÜN and Dr M.K. GAGAN collaborate on the ARC grant Stable isotopes in marsupials: reconstruction of environmental change in Australia with Dr R. Wells (Flinders University) and Dr D. Bowman (Northern Territory University).

Prof R. 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 R. 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 R. GRÜN together with Dr E. RHODES, Prof S Webb (Bond), Dr N Stern (La Trobe University) and Dr A. Fairbairn (University of Queensland) obtained an ARC Linkage grant Environmental Evolution of the Willandra Lakes World Heritage Area. The partners in this grant are the Three Traditional Tribal Groups (3TTG) of the Willandra Lakes Area and the NSW Department of Environment and Conservation.

Prof R. 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.

Dr S.D. JUPITER together with Professor M. T. McCULLOCH are collaborating with Prof O. Hoegh-Guldberg, Prof S. Phinn, Dr N. Duke, G. Marion, M. Lawrence, M. Henderson, & J. Roff (University of Queensland), Dr J. Lough & Dr K. Fabricius (AIMS) on, historical connectivity for landuse change and water quality in the Mackay-Whitsundays region.

Prof M.T. McCULLOCH is an Associate Director of the ARC Centre of Excellence Coral Reef Studies. The new Centre, known as the ARC Centre of Excellence for Coral Reef Studies is a partnership of James Cook University (JCU), the Australian Institute of Marine Science (AIMS), The Australian National University (ANU), the Great Barrier Reef Marine Park Authority (GBRMPA) and The University of Queensland (UQ). The budget for the Centre of Excellence will be approximately A$40 million over the next 5 years. The centre is headquartered at James Cook University, in Townsville under the Directorship of Professor Terry Hughes and is now the focus for Australia's leading contribution to coral reef sciences, and acts to foster 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.T. McCULLOCH is collaborating with Dr J. Lough and Dr K. Fabricius, Australian Institute of Marine Sciences (AIMS), on a wide range of coral reef projects.

Prof M.T. McCULLOCH and Dr S. JUPITER with Prof O. Hoegh-Guldberg, (University of Queensland) and Prof R. 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.

Prof M.T. McCULLOCH and Prof M. Kingsford and Dr H. 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.T. McCULLOCH and Prof Bob Wasson from Charles Darwin University in the Northern Territory are collaborating on a project estimating recent soil losses in the Himalayas.

Prof M.T. McCULLOCH and Dr B. Gulson (CSIRO and Macquarie University) are collaborating on a medical project on the possible health hazards of zinc in humans.

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

Dr E.J. RHODES with Dr P. Fanning, on "Predicting the past – Time, Landscape and Indigenous Australian History", ARC Discovery Grant.

Dr E.J. RHODES with Dr P. Hesse (Macquarie University) and Dr T. Pietsch (CSIRO), on issues of aridity.

Dr E.J. RHODES with Dr S.W. Franks, Dr R.N. Drysdale, Dr I.D. Goodwin, Dr W.D. Erskine (University of Newcastle), Dr J.C. Hellstrom, Dr R. Maas (University of Melbourne), derivation of long term hydroclimatic sequences for water resources engineering, management and planning.

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

Earth Materials

Prof S.F. COX is collaborating with Dr D Cooke (University of Tasmania) under the auspices of the recently funded Centre of Excellence in Ore Deposits. The focus of the collaboration is "Fracture arrays in intrusive-related systems – controls on fluid flow and the generation of giant deposits".

Prof S.F. COX continued his co-supervision of CSIRO PhD student Mr W Potma at the University of Western Australia.

Dr W.J. DUNLAP with Geoscience Australia, Dr S. Golding (University of Queensland), Dr J. Menzies (University of Adelaide), Dr S. McLaren (Melbourne University), Dr M. Sandiford

(Melbourne University), Dr P. Rey (University of New South Wales), Mr D. Braxton (University of Tasmania).

Dr K.A. EVANS collaborates with Roger Powell at the University of Melbourne, Australia, on the integration of new activity-composition models for geological fluids into the THERMOCALC software.

Dr J.D. FITZ GERALD with Dr M.L. de Vries and Dr I.E. Grey (CSIRO), with Dr M.R. Phillips (University of Technology Sydney), Dr Z. Jin (University of Queensland), and Drs S. Reddy and N. Timms (Curtin University).

Prof D.H. GREEN collaborated with Dr T. J. Falloon and Dr L. D. Danushevsky (University of Tasmania) on the genesis of Mid-Ocean Ridge and Island Chain ('Hot-spot') basalts, with particular emphasis on criteria to test the relative temperatures of the mantle source regions for these different magma types

Dr J. HERMANN with Dr I. Buick (Monash University).

Prof H. O'NEILL collaborated with Dr M.I. Pownceby (CSIRO) on Mg-Fe 2+ exchange between minerals and with Prof B. J. Wood (Macquarie University) on high-pressure research.

Prof I. JACKSON participated in the NCRIS planning meeting in Sydney (April) and visited Curtin University/CSIRO Petroleum (28 July) and Melbourne University (20 October) presenting lectures on laboratory measurement of seismic wave attenuation and exploring potential for collaboration.

Dr J. KURTZ collaboration with Dr Rosenbaum (University of Queensland): Dr Rosenbaum is a user of the Pplates software being developed for ACcESS MNRF. I am currently collaborating with him on the continued development of Pplates with respect to the needs of his group at UQ. We are also developing proposals for ARC to be submitted in 2007 for purposes of including geodynamic process-oriented tectonic reconstructions.

Drs MAVROGENES and McFARLANE are collaborating with Randgold and AngloGold-Ashanti on the mineralization at the Morila Mine, Mali.

Dr S. MICKLETHWAITE is collaborating with Dr H. Sheldon (CSIRO), plus 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).

Dr T. ULRICH collaborated with researchers from James Cook University and industry (Auzex Resources Ltd), namely in fluid and melt inclusion analysis using the LA ICPMS facility at RSES. Some of the projects involved the analysis of samples for the pmd CRC project on predictive mineral discoveries.

Earth Physics

Drs. Schellart and Dr. J. Freeman collaborated with Dr. D. Stegman (Monash University, Melbourne) on three-dimensional numerical simulations of subduction.

Prof K. LAMBECK with Geoscience Australia led the successful bid by a multi-institutional group for NCRIS funding for Geospatial science.

Dr Nick RAWLINSON collaborates with Dr. Michael Roach (University of Tasmania)

Dr A.M. READING collaborates with Dr M. Keep (University of Western Australia) on the seismic structure and seismotectonics of Western Australia.

Dr P. TREGONING with Prof. R. Coleman and Dr C. Watson (The University of Tasmania), Dr M. Stewart (Curtin University) and Prof. C. Rizos (The University of New South Wales).

Dr. M. SAMBRIDGE collaborates with Dr K. Gallagher (Imperial College, London, UK) and Prof. A. Jackson (ETH, Zurich, Switzerland) on aspects of probability theory and its applications to geophysical inversion; with Dr. S. Subbey (Inst. Of Marine Research, Bergen, Norway) and Prof. M. Christie (Heriot-Watt Univ., UK) on history matching in oil reservoirs; with Prof. R. Snieder (Colorado School of Mines, USA) on seismic applications of coda wave interferometry.

David Robinson collaborates with members of the Risk Research Group at Geoscience Australia

Dr C. SINADINOVSKI with Geoscience Australia, Adelaide University, UWA and PIRSA.

Australian National Seismic Imaging Resource (ANSIR)

Prof B.L.N. KENNETT is Director of ANSIR which continues as a National Research Facility until mid-2007, as a joint venture between The Australian National University and Geoscience Australia. RSES has responsibility for the reflection equipment and vibrator sources, as well as the portable instruments that are housed at RSES.

The ANSIR equipment is available via a competitive proposal scheme. In 2006 instrumentation has been provided to:

- 20 sets of broad-band equipment to RSES for the Tasman Line experiments
- 6 sets of broad-band equipment for studies of the structure near the recent volcanics of Mt Gambier, South Australia
- 50 sets of short period equipment for detailed structural studies in SE Australia

Reflection experiments carried out in 2006:

- Transect across Victoria (450 km of profile)
- Sequence of lines in the Mt Isa Region (700 km of profiles)

And a number of smaller experiments using the mini-vibrator

PRISE

Dr R.A. ARMSTRONG with Prof M. Barley (University of Western Australia), ARC project on "Precise Global Time Scale Of The Oxidation Of Earth's Atmosphere Between 2.6 And 2.0 Billion Years Ago", Prof D. Gray (University of Melbourne) and Dr B. Goscombe (NT Geological Survey) on geochronology of the Kaoko Belt, Namibia, Dr I.T. Graham and Dr L. Sutherland (Australian Museum), on dating megacryst zircons from Cenozoic intraplate basalts along the Indo-Pacific continental margins.

Mr C.M. FANNING with Prof C. Fergusson (University of Wollongong), provenance and evolution of Neoproterozoic to Ordovician sequences in north Queensland, Dr S. Boger (University of Melbourne), Mr J. Skinner (James Cook University), Geological Survey of South Australia, on the geochronological evolution of The Gawler Craton, the Curnamona Craton and the Adelaide Fold Belt, Geological Survey of Victoria and Mr G. Teale (Teale and Associates)

Dr M.D. NORMAN with Dr David Belton, CSIRO, on trace element compositions and cooling ages of apatite, Dr Robert Hough, CSIRO, on the distribution of gold pathfinder elements in the Australian regolith, and Dr David Braxton, University of Tasmania, Hobart, on the ages of igneous intrusions associated with mineralisation.

Dr G.M. YAXLEY collaborated with Dr Vadim Kamenetsky of CODES, University of Tasmania and Dr Geoff Nichols, formerly of GEMOC, Macquarie University in a study of alkaline picrites from the Prince Charles Mountains, Antarctica.

INTERNATIONAL COLLABORATION

Earth Chemistry

Dr C.M. Allen collaborated with Dr C.G. Barnes (Texas Tech University) and Dr C. Frost (U of Wyoming) on geochronology of central western Norway.

Dr V.C. BENNETT 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.

Dr V.C. BENNETT with Prof M. Garcia (University of Hawaii) on in situ measurements of Pb isotopic compositions of olivine hosted melt inclusions in Hawaiian lavas using the multi-collector SHRIMP II.

Dr J.J. BROCKS continues to collaborate with Prof J. Banfield, Ms C. Jones (UC Berkeley) and Prof E. Roden (University of Wisconsin, Madison) on the Lake Tyrrell Environmental Genome Project.

Dr I.H. CAMPBELL and Dr C.M. ALLEN with Dr M. Palin (University of Otago); Dating zircons from the two youngest caldera-forming ignimbrites of the Yellowstone volcanic field, using the laser ablation ICP-MS.

Dr I.H. CAMPBELL and Dr C.M. ALLEN with Prof P. Reiners (Yale University); Double-dating [U/Pb and (Th + U)/He)] of detrital zircons in sedimentary provenance studies.

Dr I.H. CAMPBELL and Dr C.M. ALLEN with Dr S. Bryan (Yale University); Geochronology and geochemistry of the long-lived, large-volume silicic magmatism of the Sierra Madre Occidental, Mexico.

Dr I.H. CAMPBELL and Dr C.M. ALLEN with Prof P. Clift (University of Glasgow); Double-dating zircons from Southeast Asian Rivers.

Dr I.H. CAMPBELL and Dr C.M. ALLEN with Professor Matthias Bernet and Professor Mark Brandon (Yale University); Double-dating detrital zircons from the major rivers that drain the Alps.

Mr J. CÉLÉRIER with Dr O. Beyssac (Ecole Normale Supérieure, Paris), Mr A.A.G. Webb (UCLA, Los Angeles)

Ms C. Gregory , Dr D. Rubatto and Dr J. Hermann collaborate with Prof M. Engi, Dr A. Berger and Dr E. Janots, Institute of Geology , University of Bern on the dating of monazite and allanite in low-grade metamorphic terranes and migmatites of the Southern Steep Belt of the Central Alps . Collaboration with Prof R. Compagnoni and Mr I. Gabudianu, University of Torino on the dating of monazite and allanite from the high-pressure Gran Paradiso massif of the Western Alps.

Dr M. HONDA collaborates with Dr J. Harris, University of Glasgow, and Dr R. Mohapatra, University of Manchester, on noble gas studies of diamonds.

Dr T.R. IRELAND continues to collaborate with Dr S. Weaver, University of Canterbury, New Zealand, Prof E. Zinner, Washington University, USA, and Dr B. Fegley, Washington University, USA.

Dr C.H. LINEWEAVER collaborates with Dr P.C.W. Davies, Origins Institute, Arizona State University, 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, Dept. of Biological Sciences, Kent State University on interpretations of the phylogenetic tree of life.

Dr D. RUBATTO collaborates Prof M.T Gomez-Pugnaire, University of Granada, Spain, and Prof B. Cesare, University of Padova, Italy, on the age of Tertiary magmatism in Neogene Volcanic Province of SE Spain.

Dr D. RUBATTO collaborates with Prof D. Visoná, CNR-University of Padova, Italy, and Dr R. Carosi, University of Pisa, Italy, on the geochronology of monazite in extensional shear zones, Higher Himalayan Crystallines.

Dr D. RUBATTO collaborates with Prof O. Müntener, University of Bern, Switzerland, and Miss M.-A. Kaczmarek, University of Neuchatel, Switzerland, on the geochronology of the Lanzo Massif, Western Alps, and on deformation-induced recrystallization of zircon.

Dr D. RUBATTO collaborates 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 Prof G. Hoinkes and Mr C. Bauer, University of Gratz, Austria, on the geochronology of the UHP rocks of the Kimi Complex, Greece.

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.

Dr D. RUBATTO collaborates with Prof P. Rossetti and Miss M. Padoan, University of Turin, Italy, on the p etrography, geochemistry and geochronology on the Choco 10 Greenstone Belt: El Callao Gold Mining District, Venezuela.

Dr D. RUBATTO collaborates with Prof S. Poli and Mr S. Zanchetta, University of Milan, Italy, on the age of UHP metamorphism of the Ulfas eclogite, Italy.

Dr D. RUBATTO collaborates with Dr P.H. Leloup and Miss C. Sassier, Ecole Normale Superieure de Lyon, France, on the duration of deformation along the Ailao-Shan - Red River Shear Zone, China.

Dr R. SALMERON, with Professor A. Konigl (Department of Astronomy & Astrophysics and Enrico Fermi Institute, The University of Chicago) and Dr C. Tassis (Department of Astronomy & Astrophysics, The University of Chicago) on dust dynamics and planet formation in protostellar discs.

Dr I.S. WILLIAMS and Prof R.W.R. RUTLAND with Dr K. Korsman and Dr J. Kousa (Geological Survey of Finland) and Dr T. Schiöld (Swedish Museum of Natural History, Stockholm), on the evolution of the Svecofennian orogen.

Dr I.S. WILLIAMS with Dr J. Wisniewska and Ms E. Krzeminska (Polish Geological Institute, Warsaw), The evolution of the basement beneath the East European Platform in Poland.

Dr I.S. WILLIAMS with Prof A. Neiva (Universidade de Coimbra, Portugal), The chronology of Hercynian granites in the Gouveia area, Portugal.

Dr I.S. WILLIAMS with Prof Oh C.W. and Dr Kim S.W. (Chonbuk National University, South Korea), The timing of UHP and UHT metamorphism in South Korea and its relationship to the Dabie-Sulu UHP metamorphic belt in China.

DR I.S. WILLIAMS with Dr S. Weidong and Dr Liu Yulong (Guangzhou Institute of Geochemistry), The age of the Bayan Obo giant REE deposit, Inner Mongolia.

DR I.S. WILLIAMS with representatives of the Korea Basic Science Institute, South Korea, Performance testing of the SHRIMP II ion microprobe.

Earth Environment

Dr S. EGGINS and Mr A. SADEKOV with Prof P. De Deckker (DEMS, ANU), Prof D. Kroon and Dr S. Troelstra (Vrije University, Amsterdam), on the geochemistry of live-collected foraminifera from the Netherlands Snellius expeditions in the Indian Ocean and Red Sea.

Dr S. EGGINS with Dr S. Troelstra and students (Vrije University, Amsterdam), on the geochemistry of freshwater and marine mollusks grown under monitored natural conditions.

Dr S. EGGINS and Mr A. SADEKOV with Dr K. Kimoto (Japan Agency for Marine Science and Technology), and Prof P. De Deckker (DEMS, ANU) on the geochemistry of live-collected and cultured planktonic foraminifera.

Dr S. EGGINS with Dr C. McKee (Geophysical Observatory, Port Moresby, PNG), and Dr R. Torrence (The Australian Museum), on the geochemistry of tephras from West New Britain.

Dr S. EGGINS and Mr A. SADEKOV with Prof P. De Deckker (DEMS, ANU) and Prof A. Rathburn (University of Iowa), on the geochemistry of benthic foraminifera from Venice Lagoon, Italy.

Dr S. EGGINS and Mr J.M.G. SHELLEY with Mr E. Christensen and Mr R. Olley (University of Otago), on the geochemistry of brown trout otoliths from the South Island, New Zealand.

Dr M.J. ELLWOOD with Drs P. Boyd, M. Kelly, J. Hall and C. Law (National Institute of Water and Atmospheric Research, New Zealand), on the use of sponges for paleo-chemical reconstructions and on the influence of trace elements on ocean productivity (GEOTRACES).

Dr T.M. ESAT collaborates with Dr Y. Yokoyama (University of Tokyo), on various aspects of Quaternary climate and sea-level change; and with Dr C. Stirling (Otago University), on dating of coral reefs from Ningaloo, Western Australia.

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 and Dr L.K. AYLIFFE 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 Prof G. Miller (University of Colorado), Associate investigators on National Geographic Society Grant: Aepyornis extinction and environmental change in Madagascar: assessing human impacts through precise dating and paleoenvironmental proxies preserved in eggshells and US NSF Grant: Collaborative Research: Identifying the footprints of human colonization on Australian ecosystems and climate.

Dr M.K. GAGAN with Dr N. Abram (British Antarctic Survey), Seasonal characteristics of the Indian Ocean Dipole during the Holocene.

Dr M.K. GAGAN with Dr G. Dunbar (Victoria University at Wellington), Skeletal mass accumulation in the tissue layer of Porites and implications for paleo-environmental reconstruction.

Prof R. GRÜN was invited as Visiting Professor at the Département de Préhistoire du Musée National d'Historie Naturelle, Paris, during May/June where he collaborated with Prof C. Falgueres, Dr J.J. Bahain and other staff members on the further development of dating techniques and with Drs D. Grimaud-Hervé and M.H. Moncel on the application of new isotopic systems on Neanderthal remains. He collaborates on similar application with Dr B. Maureille, Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1, on the site of Les Predelles, where Ms T KELLY carries 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, and Prof C.B. Stringer, Natural History Museum, London), Banyoles, Spain (Prof J. Maroto, Area de Prehistoria, Universitat de Girona), Irhoud, Sale and Thomas Quarry, Marocco (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.

Prof R. GRÜN continues collaboration with Dr A. Pike (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 and dating human material from Sidron.

Dr S.D. JUPITER together with Prof M.T. MCCULLOCH collaborates with Dr M. Field & Dr C. Storlazzi (U.S. Geological Survey), and Dr M. D'Iorio (William Lettis & Associates, California, USA) on linkages between land use and water quality changes on Molokai, Hawaii.

Prof M.T. MCCULLOCH is collaborating with Prof C. Mazzoli (Dipartimento di Mineralogia e Petrologia, Università di Padova , Italy), and Dr P. Montagna and Dr S. Silenzi (Istituto Centrale di Ricerca Applicata al Mare – ICRAM, Rome, Italy) on shallow water coral reefs in the Mediterranean.

Prof M.T. MCCULLOCH is collaborating with Dr M. Taviani, and Dr A. Remia (ISMAR-CNR, Bologna, Italy) and Dr P. Montagna (Istituto Centrale di Ricerca Applicata al Mare – ICRAM, Rome, Italy), on deep sea corals in the Mediterraean.

Prof M.T. MCCULLOCH is continuing collaborating with Prof R. Dunbar and Dr B. 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 Superieure de Lyon, France), on Boron isotopic systematics in marine bio-apatites and Lu-Hf isotopes in ancient zircons.

Prof M.T. MCCULLOCH is collaborating with Dr J-P. Bernal (Septo.Geoquimica, Instituto de Geologia, Universidad Nacional Autonoma de Mexico, Mexico) on the Terrestrial impacts on Coral reef in the Carribean and speleothem deposits in Mexico.

Prof M.T. MCCULLOCH is collaborating with Prof T. Correge (Departement de Geologie et Oceanographie, Universite de Bordeaux I, France) on U-series dating of modern corals from New Caledonia.

Prof M.T. MCCULLOCH is collaborating with Dr D. 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.

Prof B.J. PILLANS with Dr J. Ogg (Purdue University, USA) on the status of the Quaternary in the International Geological Time Scale

Dr E.J. RHODES is collaborating with Prof C. Stringer (Natural History Museum, London), Prof N. Barton and Dr J.L. Schwenninger (University of Oxford), human evolution and dispersal in Iberia and North Africa.

Dr E.J. RHODES with Prof P. Gibbard (University of Cambridge), glaciation of East Anglia.

Dr E.J. RHODES with Dr C.S. Marcen (University of Zaragoza), Dr C. Lewis (Los Alamos National Laboratory, USA), Dr E. MacDonald (Desert Research Institute, Reno, USA), landscape evolution and climatic conditions in northeast Spain.

Dr E.J. RHODES with Dr G.H. Miller (INSTAAR, Boulder, USA), climatic reconstructions of central Australia.

Dr E.J. RHODES with Dr D. MacCarroll (University of Wales, Swansea, UK), glaciation of the Irish Sea.

Dr E.J. RHODES with Dr S. Doerr (University of Wales, Swansea, UK), fire history in New South Wales.

Dr P.C. Treble collaborates with Prof T.M. Harrison & Dr A.K. Schmitt (University of California Los Angeles), and Prof R.L. Edwards (University of Minnesota), on the reconstruction of rapid climate events in speleothems.

Dr P.C. Treble collaborates with Dr E. Tonui (University of California Los Angeles), on the measurement of Mg isotopes in modern speleothems.

Dr P.C. Treble collaborates with Dr E.J. Hendy (Lamont Doherty Earth Observatory), on synchrotron measurements of speleothem phosphorus, and with Prof C Spötl (University of Innsbruck), on trace elements in high altitude Austrian speleothems.

Earth Materials

Mr S. BARKER collaborated with Professor Zachary Sharp in the Department of Earth and Planetary Sciences at the University of New Mexico, conducting in situ laser ablation stable isotope analyses to examine the fine-scale history of hydrothermal fluid flow recorded in carbonate and quartz veins.

Prof S.F. COX continued a collaboration with Dr N Mancktelow (ETH-Zurich), Dr A.-M. Boullier (Univertite 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 is collaborating, via an ARC Discovery Grant, with Dr S Miller (University of Bonn) on modelling of fluid flow in fault networks.

Dr W.J. DUNLAP collaborates with Dr C. Teyssier, of the University of Minnesota, on the exhumation of the Valhalla Complex, British Columbia.

Dr W.J. DUNLAP collaborates with Dr H. Fossen, of the Bergen Museum and Bergen University (Norway), on the exhumation of the Ulven Complex in western Norway.

Dr W.J. DUNLAP collaborates with Dr H. Davies, of the University of Papua New Guinea (Port Moresby), on the determination of the age of Papuan Highlands fossils.

Dr W.J. DUNLAP collaborates with Dr J. Weber, of the Grand Valley State University, on the dating of mylonites on the coastal islands of Venezuela.

Dr W.J. DUNLAP collaborates with Dr S. Mazur, of the University of Wroclaw (Poland), on the exhumation and development of the mylonitic basement-cover contact in the Paleozoic Variscan foreland basins, Poland.

Dr W.J. DUNLAP collaborates with Dr A. Tulloch, of the Institute of Geological and Nuclear Sciences (Dunedin, NZ), on the age and significance of the Sam's Creek gold-bearing dyke in Nelson, New Zealand.

Dr W.J. DUNLAP collaborates with Dr N. Mortimer, of the Institute of Geological and Nuclear Sciences (Dunedin, NZ), on the age and significance of the Wishbone Ridge, as determined from dredge samples.

Dr K.A. EVANS collaborates with Matt Newville at the APS (American Photon Source), Chicago, USA, on the use of synchrotron radiation to determine the effects of CO2 on the molecular structure of supercritical fluids.

Dr J.D. FITZ GERALD collaborates on electron microscopy studies of minerals with Prof I. Parsons, University of Edinburgh, Prof A. Putnis, University of Münster, Dr U. Faul, Boston University, Dr J.K. Lee, Queen's University, Ontario and Dr A. Camacho, University of Manitoba.

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 Dr G. Ho, Peking University, Beijing, China, on the structure, tectonics and geochronology along major western tectonic boundary of a regional-scale core complex in NW China.

Dr M. FORSTER collaborates with Prof R. Compagnoni, Università degli Studi di Torino, Dip. di Scienze Mineralogiche e Petrologiche, Torino, Italy, on the structure, tectonics and geochronology of the Western Alps and the Blueschist Belt, Greece.

Prof D.H. GREEN collaborates with Dr K. Niida, University of Hokkaido, Japan, on the origin and history of the Horoman Peridotite, Hokkaido, and with Dr F. Chalot-Prat, CRPG-CNRS and University of Nancy, France, on experimental study of the origin of mid-ocean ridge basalts and their reaction within the upper-most mantle.

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 Prof O. Müntener (University of Berne, Switzerland) on the geological map of Valmalenco, Alps.

Dr J. HERMANN collaborates with Dr A. Hack (ETH-Zurich, Switzerland) on phase relations in solid-water systems.

Dr J. HERMANN collaborates with Prof L. Morton and 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. Satish-Kumar (Shizuoka University, Japan), on monitoring volatile and trace element contents of fluids in high-grade marbles from Antarctica.

Prof I. JACKSON collaborates in studies of the elasticity and viscoelasticity of geological materials with Prof R. C. Liebermann and colleagues (Stony Brook University), Prof G. D. Gwanmesia (Delaware State University , Dover), Prof S. J. S Morris (University of California , Berkeley), Prof J.C.H. Kung (National Cheng Kung University , Taiwan), Prof K. Itatani (Sophia University, Japan), Prof F. Béjina (Toulouse , France).

Mr I. KOVACS collaborated with Dr E. Hauri, Carnegie Institute, Washington, on analyzing experimental capsules with SIMS for H.

Mr I. KOVACS collaborates with Dr Cs. SZABO and Dr L. CSONTOS, E ötvös University, Budapest, on the Paleogene-Early Miocene geodynamic reconstruction of the Alpine-Carpathian-Pannonian-Dinaric region.

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 J. MAVROGENES is collaborating with Prof B. Ron Frost, University of Wyoming, on melting of sulfide ores during metamorphism.

Emeritus Prof I. MCDOUGALL continued his long-standing collaboration with Dr F.H. Brown of the University of Utah, Salt Lake City, on the evolution of the Omo-Turkana Basin in northern Kenya and southern Ethiopia in part of the East African Rift Zone. In addition he is working with Dr F.H. Brown and also Dr J.G. Fleagle of the University of Stony Brook, New York, on finalizing a contribution for a publication on the dating of early modern humans at Kibish, Ethiopia, and palaeoclimatic links with deep sea sediments in the Mediterranean Sea.

Dr C.R.M. McFARLANE with A. Tomkins (Monash University) studying the impact of precursor hydrothermal alteration on the development of mineral assemblages in metamorphosed Au deposits.

Prof H. O'NEILL continues to collaborate with Prof H. Palme and Dr G. Witt-Eickschen of the University of Cologne, Germany, and Prof T. Irifune, Ehime University, Japan, Dr A. J. Berry (Imperial College, London, UK) all of whom visited RSES during 2006, and with Dr A Walker (Cambridge University, UK), Dr Xi Liu (University of Western Ontario, Canada).

Dr R. RAPP collaborates with Professor T. Irifune of the Geodynamics Research Center, Ehime University, Matsuyama, Japan on the development of polycrystalline sintered diamond anvils for use in the multi-anvil apparatus, with the objective of attaining pressures in the range of 40-50 GPa.

Dr R. RAPP collaborates with Professor N. Shimizu of the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA, using the secondary ion mass spectrometer to measure trace element abundances in high pressure experimental silicate melts and minerals.

Dr R. RAPP collaborates with Professor Herve Martin and professor Didier Laporte of the Laboratoire Magmas et Volcans, Universite de Blaise Pascal de Clermont-Ferrand, Clermont-

Ferrand, France, conducting an experimental study of slab-mantle interactions in subduction zones.

Dr N. TAILBY and Dr K. EVANS collaborated with Dr M. Newville and S. Sutton, Advanced Photon Source, Argonne National Laboratories, Chicago, USA, on determining Ti-site occupancy in zircon from XANES and EXAFS spectra.

Dr T. ULRICH attended two conferences and presented results of my research this year. I gave an invited keynote presentation on LA ICPMS analysis of fluid inclusions at the Asian Current Research on Fluid Inclusions (ACROFI I) conference in Nanjing in May 2006 and I presented some results of the sulphur solubility study at the 16. Goldschmidt conference in Melbourne in September 2006.

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 monitoring problems.

Dr A.McC. HOGG and Prof R.W. GRIFFITHS continued collaboration with Prof W.K. Dewar (Florida State University, USA) and Dr P. Berloff (University of Cambridge, UK and Woods Hole Oceanographic Institution, USA) on the turbulent dynamics of ocean circulation, supported by an ARC Linkage International Grant.

Dr A.McC. HOGG continued collaboration with Dr J. Nycander (Stockholm University, Sweden) and Ms Leela Frankcombe (Utrecht University, The Netherlands) on the numerical modelling of time-dependent flow through ocean straits.

Dr A.McC. HOGG embarked on a collaboration with Dr M.M. Meredith (British Antarctic Survey, UK) and Dr. C. Wilson (Proudman Oceanographic Laboratory, UK) relating to the energetics of circulation in the Southern Ocean.

Dr R.C. KERR and Prof R.W. GRIFFITHS continued collaboration with Prof K.V. Cashman (University of Oregon, USA) on the dynamics of channelized lava flows, a project funded by an ARC Discovery grant.

Prof R.W. GRIFFITHS and Dr G.O. HUGHES, with Drs J.C. Mullarney (Dalhousie University, Canada) and W.H. Peterson on 'horizontal convection'.

Prof B.L.N. KENNETT continues to collaborate with Dr E. Debayle, University of Strasbourg, France, Dr K. Priestley, Dr S. Fishwick, University of Cambridge, UK, Dr M. Ritzwoller, University of Colorado 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.

Prof K. LAMBECK was a member of the Steering Committee for the World Climate Research Programme Workshop "Understanding Sea-level Rise and Variability".

Dr H. MCQUEEN and Prof K. LAMBECK collaborate with Prof T. Sato (National Astronomical Observatory of Japan, Mizusawa) on operation of Superconducting Gravimeter at Mt Stromlo.

Dr H. MCQUEEN collaborated with Dr Y. Rogister and Dr M. Amalvict of EOST, Université Louis Pasteur in Strasbourg on FG5 Absolute Gravimeter measurements at Mt Stromlo and analysis of observations.

Dr H. MCQUEEN collaborated with S. Bonaimé and Dr G. Roult of Progamme Geosccope at the Institut de Physique du Globe de Paris on upgrading the Canberra Geoscope Seismic Station and integration into the French and Australian Tsunami Warning Centre networks.

Dr N. RAWLINGSON collaborates with: Prof. Greg Houseman, University of Leeds, on teleseismic tomgoraphy; Dr. Sebastian Rost, University of Leeds, on seismic array analysis of core phases.

Dr A.M. READING collaborates with Prof. D. Wiens (Washington University, St Louis, USA) on the seismic structure of Antarctica.

David 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 P. TREGONING collaborates with Prof. T. Herring, Drs R. King and S. McClusky , Massachussetts Institute of Technology, Cambridge on the development of functional models in the GAMIT GPS analysis software, with Drs A. Walpersdorf (Universite Joseph Fourier, Grenoble), M. Nocquet (CNRS, Geoscience Azur, Nice), S. Baize (IRSN Seismic Hazard Division, France) and E. Calais (Purdue University, West Lafayette) on deformation in the Jura Mountains, France, with Prof. H. Schuh and Dr J. Boehm, Technical University of Vienna and Dr A. Niell (Haystack Observatory, Westford) on new empirical atmospheric propagation models and with Dr N. Penna (University of Newcastle Upon Tyne) on aliasing of sub-daily periodic signals into long-frequency periodic coordinate errors.

Dr. W. P. Schellart continued collaborating with Ms. V. G. Toy (Otago University, New Zealand), primarily working on a reconstruction of the Southwest Pacific region since the Late Cretaceous.

Dr C. SINADINOVSKI collaborates with UNESCO Institute of Earthquake Engineering and Engineering Seismology in Skopje, Macedonia, on the comparison of intraplate earthquakes.

Dr C. SINADINOVSKI collaborates with China's State Seismological Bureau in Beijing and Qingdao and Guangdong centres on regional seismicity.

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, Prof N. Beukes and Prof J.

Gutzmer, University of Johannesburg, South Africa, on the chronostratigraphy of the Palaeoproterozoic sequences of the Kaapvaal Craton with special reference to evolution of the atmosphere, Dr E. Roberts, Witwatersrand University and Prof P.K. Link, Idaho State University, on provenance and age of detrital zircons from the Rukwa Rift Basin, Tanzania, Dr R.P. Xavier, Universidade Estadual de Campinas, Brazil, on geochronology of the Alta Floresta Gold Province (western Brazil), Dr R. Mapeo, University of Botswana, on the age and regional correlation of gneisses and sediments from a borehole in NW Botswana, K.H. Hoffmann, Geological Survey of Namibia, on determining the ages of Neoproterozoic glaciations in Namibia, Dr A. Cocherie, BRGM, France, on SHRIMP characterization of a potential monazite standard, Prof E. Dantas and Prof M. Pimentel, University of Brasilia, Brazil, on U-Pb-Hf geochronology and isotope geochemistry on various sequences in Brazil, Prof A. Camacho on a study of Ar/Ar, Rb/Sr and U/Pb systematics and geochronology of carbonates and associated rocks from Ontario, Prof M.Heilbron, Rio de Janeiro State University, on SHRIMP U-Pb geochronology of the Ribeira Belt, Brazil, Dr R.S. Schmitt, Rio de Janeiro State University, on the geochronology of the Kaoko Belt and correlation with South America, Dr G. de Kock, Council for Geoscience, South Africa, on the geochronology of Ghana, Dr G. Grantham and Dr M. Roberts, Council for Geoscience, South Africa, on a regional mapping and geochronological study of the Mozambique Belt.

Mr C.M. FANNING with Prof P.K. Link, Idaho State University, continuation of collaboration on the provenance and time of deposition of Neoproterozoic sequences in Utah and Idaho, Prof F. Hervé, Universidad de Chile and Dr R.J. Pankhurst (British Geological Survey), continuation of collaboration on the geochronological and tectonic evolution of the southern Patagonian batholith, Prof C. Rapela, Universidad Nacional de La Plata, Argentina, and Dr R.J. Pankhurst (British Geological Survey), c ontinuation of collaboration on the geochronological and tectonic evolution of the north Patagonian massif and adjacent cratons/terrains of Argentina, Dr J.N. Aleinikoff, United States Geological Survey, continuation of collaboration on SHRIMP II U-Pb analyses of zircon and xenotime.

Dr M.D. NORMAN collaborates with Prof L.A. Taylor, University of Tennessee, USA, Prof G.J. Taylor, University of Hawai'i, USA, Prof R.A, Duncan, Oregon State University, USA, and Drs L.E. Nyquist and A.D. Brandon, NASA Johnson Space Center, Houston, USA on the ages and geochemistry of rocks from the Moon and Mars, Prof M.O. Garcia, University of Hawai'i, USA, on the petrology and geochemistry of basaltic lavas from Hawaiian volcanoes, and Dr L. Solari, Universidad Nacional Autónoma de México, on the distribution of detrital zircons from Central America.

Dr G.M. YAXLEY, collaborated with Prof Gerhard Brey (Frankfurt University, Germany) in an experimental study of the phase and melting relations of carbonate eclogite in the upper mantle and with Dr Andrew Berry of Imperical College London and Prof Hugh O'Neill (RSES) in development of a new synchrotron based technique for the determination of Fe 3+ /?Fe in garnet. Along with Professor David Green (RSES) and Ms Anja Rosenthal (RSES) he collaborated with Professor Alex Sobolev (Max-Planck-Insitut für Chemie, Mainz and Vernadsky Institute, Moscow) and Dr Carl Spandler (Bern University, Switzerland) in high pressure experimental investigations of the partial melting of eclogitic or pyroxenite heterogeneities and their roles in upper mantle magma genesis. He is also collaborating with Prof F. Munizaga (University of Chile) and Mr Mark Fanning (RSES) in an investigation of the geochronology and evolution of Late Paleozoic – Early Triassic magmatism on the western border of Gondwana, ie the Collahuasi District, northern Chile.

Ms A. ROSENTHAL is collaborating with Dr Carl Spandler (University of Bern) in a high pressure experimental project investigating the melting of heterogeneous mantle.

COOPERATION WITH GOVERNMENT AND INDUSTRY

Earth Chemistry

Dr J.J. BROCKS started collaboration with Dr G. Ambrose (Northern Territory Geological Survey) on the petroleum potential in the Centralian Superbasin, Australia.

Dr J.J. BROCKS continues to collaborate with Dr E. Grosjean and Dr G.A. Logan (Geoscience Australia) on petroleum seeps and signatures of Australian off-shore basins.

Mr A.J. CROSS with Mr A. Crispe (Northern Territory Geological Survey), SHRIMP U–Pb study of the depositional chronology of the Tanami region, northern Australia.

Dr J.J. Foster with Australian Scientific Instruments, on SHRIMP instrumentation development.

Dr T.R. IRELAND continues to collaborate with Australian Scientific Instruments and Geoscience Australia.

Mr P. LANC continues cooperation with Australian Scientific Instruments on SHRIMP instrumentation programming.

Ms D.L. VALENTE and Dr I.H. CAMPBELL with A. Molina (S.C.M. El Abra, Chile), The Geology, Geochemistry and Geochronology of the El Abra Mine, Chile and the adjacent Pajonal-El Abra suite of intrusions.

Ms D.L. VALENTE and Dr I. H. CAMPBELL with Phelps Dodge; the geochemistry, geochronology and evolution of the El Abra porphyry copper deposit in Northern Chile.

Dr I.S. WILLIAMS holds a 25% appointment as Applications 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 applications advice to the Geological Survey of Canada (Ottawa), Hiroshima University (Japan), The National Institute of Polar Research (Japan), The Chinese Academy of Geological Sciences (Beijing) and the All Russian Geological Research Institute (St. Petersburg).

Earth Environment

Dr S.D. JUPITER and Prof M.T. McCULLOCH with the Great Barrier Reef Marine Park Authority, the Mackay Whitsunday Natural Resource Management Group and the Mackay City Council, on long-term changes in Mackay Whitsunday water quality and connectivity between coral reefs and mangrove ecosystems.

Prof M.T. McCULLOCH and Dr S.D. JUPITER from RSES are collaborating with the Great Barrier Reef Marine Park Authority, the Mackay Whitsunday Natural Resource Management Group and the Mackay City Council, Long-term changes in Mackay Whitsunday water quality and connectivity between coral reefs and mangrove ecosystems.

Prof M.T. McCULLOCH together with Mr J. 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. Professor McCulloch is involved in a project Funds to support the conservation and sustainable use of the Great Barrier Reef and the connecting coastal regions.

Prof B.J. PILLANS with Newmont Australia, on Geochronology of landscape evolution in the Tanami region, Northern Territory

Dr P.C. Treble with Land & Water Australia, WA Department of Conservation and Land Management, Naracoorte Caves World Heritage Area, and NSW Department of Environment and Conservation (Yarrangobilly Caves)

Earth Materials

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 W.J. DUNLAP with Dr A. Wygralak (Northern Territory Geological Survey) on the age of mica bearing quartz veins, at a regional scale, Northern Territory.

Dr W.J. DUNLAP with Dr M. Dawson (New South Wales Geological Survey) on the dating of volcanic rocks in New South Wales.

Dr W.J. DUNLAP with Dr A. Wankovitch (Oolithica Geosciences, UK) on the age of volcanic rocks in petroleum producing fields in the Middle East.

Dr W.J. DUNLAP with Dr P. Lindberg (Self-employed) on the age and significance of basaltic volcanic rocks in Arizona, USA.

Dr W.J. DUNLAP and Dr M. NORMAN with Hess Oil on the age of illites extracted from quartzites in oil producing fields in northern Africa.

Dr J.MAVROGENES and Prof H. O'Neill are collaborating with UWA and AMIRA (BHP and Lion Ore) on an ARC Linkage funded study of controls on trace elements in komatiites.

Dr C.R.M. MCFARLANE with R. Skirrow (Geoscience Australia) studying in-situ Nd isotopic composition of allanite and epidote in IOCG-type Cu-Au prospects, Curnamona Province, South Australia. Cooperation with T. Poustie (Dominion Mining Ltd) led to a new model for pre-metamorphic gold deposition at the Challenger Mine, South Australia. A petrological and isotopic study of the Morila Gold Mine, Mali, began in cooperation with G. Cameron (Randgold Resources Limited).

Dr S. Micklethwaite with M. Humphreys and K. Weber (Harmony Limited), the application of Stress Transfer Modelling to exploration in the New Celebration goldfield, Western Australia. Also with S. Shakesby (Newcrest Limited) on the geometry and mechanical interactions of normal faults and dykes in Cracow epithermal gold deposit.

Earth Physics

Dr D.R. CHRISTIE with Dr D.J. Brown (Geoscience Australia) on matters related to infrasound verification of the Comprehensive Nuclear-Test-Ban Treaty.

Professor 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 Jingming Duan and Scott Savage. 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, chaired a PMSEIC Working Group on Australia's Science and Technology Priorities for Global Engagement. He was also a member of the Nuclear Expert Review Panel appointed to comment on the Report of the Uranium Mining, Processing and Nuclear Energy Review (UMPNER) Taskforce.

Dr H. MCQUEEN collaborated with G. Luton of Geoscience Australia on absolute gravity measurements and instrument calibrations at the Mt Stromlo Gravity Station in support of the Superconducting Gravimeter installation and absolute gravity determinations at other Australian sites.

Dr H. MCQUEEN collaborated with R. Tracey and N. Dando (Geoscience Australia) on intercomparison of relative gravimeters for accurate determination of ocean tide loading signals.

Dr H. MCQUEEN collaborated with Dr S Spiliopoulos (Geoscience Australia) on a major upgrade of the Canberra Geoscope Seismic Station.

Dr N RAWLINSON with Dr. Marthijn de Kool (Geoscience Australia) on seismic wavefront propagation in complex 3-D media; with Dr. Dave Robson (NSW Geological Survey) on teleseismic tomography in NSW.

Dr A.M. READING collaborates with Dr P. Cummins on the seismic structure of West Australia and East Antarctica.

Dr M. SAMBRIDGE with Dr Phil Cummins and Mr. Ryan Ruddock, Geoscience Australia, on probabilistic methods for seismic ground motion estimation, and earthquake location methods.

Dr P. TREGONING with Dr P. Cummins and Mr G. Johnston (Geoscience Australia) on modelling co-seismic displacements in Papua New Guinea and developing the geospatial component of the AuScope submission to NCRIS.

PRISE

Dr R.A. ARMSTRONG with G. Cameron (Randgold Resources Limited), Sulphur isotope profiles of mineralization of the Morila gold deposit, Mali, J. Greenfield (Geological Survey of NSW) on Sm-Nd isotope characterization of the Koonenberry Belt, Dr R.S.C. de Brito (Geological Survey of Brazil, CPRM), SHRIMP geochronology for the Mato Grosso Do Sul and Arapiraca projects, Dr Carlos da Silva (Geological Survey of Brazil, CPRM), on various aspects of Brazilian geochronology and stratigraphy, the Council for Geoscience, South Africa, on various aspects of the stratigraphy and geochronology of southern Africa.

Mr C.M. FANNING with Mr C. Georgess (Kagara Zinc Exploration)

Dr M.D. NORMAN with SonaHess Petroleum Company and Newcrest Mining Limited.

Dr G.M. YAXLEY, funded by de Beers to conduct a high pressure experimental investigation of Ni partitioning between upper mantle phases, and to investigate its use as a geothermometer with applications to diamond exploration; awarded an ARC-Linkage Grant with industry partner AMIRA International (The project will develop new techniques for the interpretation of diamond indicator minerals and apply them to samples supplied by the sponsor companies (BHP-Billiton, de Beers and Rio Tinto)). Along with Dr Andrew Berry (Imperial College, London), Dr G.M. YAXLEY was awarded, by the Australian Synchrotron Research Program, funding and several days beam-time at the Australian National Beamline facility in Tsukuba, Japan in June. XANES measurements on synthetic garnets were performed as part of development of a new technique for determination of Fe 3+ /?Fe in garnets. Dr G.M. YAXLEY was also awarded $10k funding for this project from the Victorian Department of Innovation, Industry and Regional Development and the Australian Synchrotron Project, to facilitate future visits to overseas synchrotrons.

STAFF ACTIVITIES 2006

CONFERENCES AND OUTSIDE STUDIES
EDITORIAL RESPONSIBILITIES
OUTREACH AND WORKSHOPS
TEACHING ACTIVITIES
HONOURS SUPERVISION
OTHER MATTERS

CONFERENCES AND OUTSIDE STUDIES

Earth Chemistry

Mr A. AIKMAN, 16th Goldschmidt Conference, Melbourne, 27 August – 1 September, presented a paper entitled "Himalayan evolutionary models: constraints from Eocene – Miocene granitoid bodies".

Dr C.M. Allen, 16th Goldschmidt Conference, Melbourne, 27 August – 1 September, and presented a paper entitled "Identification of first and multi-cycle zircons through U-Pb and (U+Th)/He dating of river sands".

Mrs J.N. ÁVILA, 16th Annual V.M. Goldschmidt Conference, Melbourne, Australia, 27 August - 1 September.

Mrs J.N. ÁVILA, 3rd SHRIMP Workshop, Rottnest Island, Australia, 3 - 7 September.

Dr V.C. BENNETT was a visiting scientist at the Lunar and Planetary Institute and NASA Johnson Space Center, Houston, Texas, USA from 17 April - 14 July.

Dr V.C. BENNETT, 16th Goldschmidt Conference, Melbourne, 17 August - 1 September, presented a paper entitled " Variable Earth evolution recorded in the oldest (>3.7 Ga) Archean terranes?".

Dr V.C. BENNETT, Earth Dynamics Conference, 22 - 23 November, Canberra, presented a paper entitled " In the beginning...early Earth dynamics from the old rock record".

Dr V.C. BENNETT, 6th Australian Space Science Conference, 19 - 21 July, Canberra, presented a paper on "Rapid Accretion and Formation of the Terrestrial Planets".

Dr V.C. BENNETT, Lunar and Planetary Institute Planetary Differentiation Workshop, Sonoma, California, 7 - 9 December.

Dr V.C BENNETT, American Geophysical Union Conference, San Francisco, USA, December, 10 - 15 December, presented a paper entitled "Combined ^{142}Nd- ^{143}Nd isotopic data of >3.7 Ga rock suites document incomplete mixing of the early mantle".

Dr J.J. BROCKS, Australian Organic Geochemistry Conference, Rottnest Island , WA , 12 - 15 January, oral presentation "Eukaryote and steroid evolution in the Proterozoic".

Dr J.J. BROCKS, Lake Tyrrell field trip, 4 – 10 March with Prof J. Banfield, Ms C. Jones (UC Berkeley), Dr Prof S. George, Prof M. Walter and Ms C. Oliver (Macquarie University) to study the hydrology and microbiology of saline Lake Tyrrell , Victoria .

Dr J.J. BROCKS, DEMS Planetary Sciences guest lecture, Canberra 31 May, "How to detect life on early Earth (and other planets?)".

Dr J.J. BROCKS, From Stars to Brains – A Conference in Honour of Professor Paul Davies, Canberra 20 June, invited presentation "Geochemical cycles and the late rise of complex life".

Dr J.J. BROCKS continued fieldwork in 21 August – 1 September at saline Lake Tyrrell , Victoria , with Prof J. Banfield, Ms C. Jones (UC Berkeley), Prof E. Roden (U. Wisconsin, Madison) and the Mars Robotics team of the University of Pennsylvania .

Dr J.J. BROCKS, 16 th Annual V. M. Goldschmidt Conference, Melbourne 27 August - 1 September, invited presentation "Proterozoic ocean chemistry and the evolution of complex life".

Dr I.H. CAMPBELL , 16 th Annual Goldschmidt Conference from 28 August - 1 September, presented a paper entitled "Testing the mantle plume theory".

Dr I.H. CAMPBELL , IAVCEI 2006, Guangzhou , China , 14 – 18 May, presented a paper entitled "Do mantle plume exist?"

Mr J. CÉLÉRIER, 16 th V.M Goldschmidt Conference, Melbourne, Australia, 27 August - 1 September, presented a paper entitled "Ar diffusion in muscovite".

Mr A.J. CROSS, 3 rd SHRIMP workshop in Perth , WA , from 2 - 7 September and presented a paper entitled "Some insights into the SHRIMP U–Pb analysis of xenotime".

Mr R.O.C. F onseca , 16th Annual V. M. Goldschmidt Conference, Melbourne , 27 August - 1 September, presented a paper entitled "An experimental study of the chalcophile character of Re: the effect of fO_2 , fS_2 and temperature".

Dr J.J. FOSTER, visit Ion Optical consultant regarding development of SHRIMP SI instrument, Prince Edward Island, Canada, and SHRIMP laboratory colleagues, Los Angeles, USA, 1 - 12 June.

Dr J.J. FOSTER, SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Dr J.J. FOSTER, ATF and SEAP Conference, Sydney and Canberra , 15 - 20 October.

Ms C. GREGORY conducted fieldwork in the Central and Western Alps from 2 June – 14 July.

Ms C. GREGORY, visitor of the Institute of Geology , University of Bern , 4 June, presented a seminar entitled: "Geochronology, chemistry and petrology of allanite: exploring its potential as a geochronometer of high-grade crustal processes".

Ms C. GREGORY, 16th Annual VM Goldschmidt conference, Melbourne , Australia , 27 August – 1 September, presented a paper entitled "Exploring the potential of allanite as a geochronometer of high-grade crustal processes".

Ms C. GREGORY, 3rd Annual SHRIMP workshop, Rottnest Island , WA , 3 - 7 September, presented a paper entitled "SHRIMP and LA-ICP-MS analysis of allanite in magmatic and high-grade crustal rocks".

Ms C. GREGORY, 3 rd Bringing Science Together conference, ANU, Canberra , 11 - 12 December, presented a paper entitled "Exploring the potential of allanite as a tool for dating geological processes".

Mr J. HIESS conducted fieldwork in collaboration with the Geological Survey of Denmark and Greenland , 5 July – 21 August, Kapisillit area, Greenland .

Mr J. HIESS, 16th Annual V.M. Goldschmidt Conference, Melbourne , Australia , 27 August - 1 September, presented a poster entitled "Ti zircon thermometry applied to metamorphic and igneous systems."

Mr J. HIESS, 3rd SHRIMP Workshop, Rottnest Island , Australia , 3 - 7 September, presented an oral presentation entitled "Redesign of SHRIMP mounts to minimize geometric effects on isotopic and inter-elemental fractionation."

Dr P. HOLDEN, 16th Annual V.M. Goldschmidt Conference, Melbourne, 27 August - 1 September, poster presentation entitled "Automated mining of detrital Hadean zircons from Jack Hills , Western Australia : Flash geochronology with SHRIMP II."

Dr P. HOLDEN, 3rd SHRIMP Workshop, Rottnest Island , WA , 3 - 7 September, presented talk entitled "SHRIMP quality control using NIST 610."

Dr M. HONDA, 16 th Goldschmidt Conference, Melbourne , 27 August – 1 September.

Mr R.B. ICKERT, GAC/MAC Annual Meeting, Montreal, Canada, 14 - 17 May, presented a paper entitled "Petrogenesis of adakite and high-Mg# andesite in the Eocene Princeton Group (BC): Remelting of metamorphosed Mesozoic arc basalt in the lithospheric mantle"

Mr R.B. ICKERT, SHRIMP Workshop, Perth , WA , 2 - 7 September, presented a paper entitled "Electron Induced Secondary Ion Emission (EISIE): An important consideration in the analysis of light isotopes in insulators"

Dr T.R. IRELAND , 37 th Lunar and Planetary Science Conference and Council Meeting, Houston , Texas , USA , 6 - 22 March.

Dr T.R. IRELAND , AUSCOPE Meeting, Sydney , 10 - 12 April.

Dr T.R. IRELAND , AUSCOPE Meeting, Adelaide , 27 - 28 April.

Dr T.R. IRELAND , AUSCOPE Meeting, Sydney , 31 May.

Dr T.R. IRELAND , AUSCOPE Meeting, Sydney , 6 - 7 June.

Dr T.R. IRELAND , Hayabusa Symposium II, Tokyo , Japan , 11 - 16 July.

Dr T.R. IRELAND , 69 th Annual Meeting of the Meteoritical Society, ETH Zurich , Switzerland , 3 - 13 August,

Dr T.R. IRELAND , 16 th Annual V. M. Goldschmidt Conference, Melbourne , 27 August to 1 September.

Dr T.R. IRELAND , 3 rd SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Dr T.R. IRELAND , U. Canterbury and U. Otago , New Zealand , 7 - 12 November, to discuss projects with colleagues and to talk with prospective students.

Dr T.R. IRELAND , final talks in conjunction with Australian Scientific Instruments and gave a presentation to the selection committee of the Korea Basic Science Institute, Daejeon , South Korea , 26 November - 1 December.

Mr B. JENKINS, 3 rd SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Mr B. JENKINS, ATF and SEAP Conference, Sydney and Canberra , 15 - 20 October.

Ms F. JENNER, 16 th Goldschmidt Conference, Melbourne , 27 August - 1 September.

Mr A.P. KALLIO, 6 th Australian Space Science Conference, Canberra , Australia , 19 - 21 July, and presented a paper entitled "Differentiation of terrestrial planets: insights from the volatile alkali elements rubidium and cesium".

Mr A.P. KALLIO, 69 th Annual Meeting of the Meteoritical Society, ETH Zurich, Switzerland, 6 - 11 August, and presented a paper entitled "The cosmochemical Cs-problem".

Mr A.P. KALLIO, the 16 th Annual V. M. Goldschmidt Conference, Melbourne , 27 August – 1 September, and presented a paper entitled "Silicate melt inclusions in archean komatiites as potential indicators for crustal growth".

Mr A.P. KALLIO, 3 rd SHRIMP workshop, Perth , Australia , 3 - 7 September, presented a paper entitled "Measurements of cesium from olivine-hosted silicate melt inclusions using SHRIMP".

Mr P. LANC, 16th Annual V.M. Goldschmidt Conference, Melbourne, 27 - 28 August providing assistance Australian Scientific Instruments.

Mr P. LANC, 3 rd SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Dr C.H. Lineweaver, American Astronomical Society Meeting 207, Washington DC , USA , 8 - 12 January, presented a paper entitled "Quantifying the Short-Period Brown Dwarf Deserts".

Dr C.H. LINEWEAVER, Brian Josephson Workshop on Quantum Physics and Biology, Macquarie University , 23 March.

Dr C.H. LINEWEAVER, From Stars to Brains, conference in honour of Paul Davies, Canberra , ACT, 20 - 21 June, Canberra , presented a paper entitled "Is Human-like Intelligence a Convergent Feature of Cosmic Biological Evolution?"

Dr C.H. LINEWEAVER, 6 th Australian Space Science Conference, Canberra, ACT, 19-21 July, chaired a session and presented two papers entitled "Towards a Classification System of Terrestrial Planets" and "Is the Sun a Random Star?" with PhD student Mr J. Robles.

Dr C.H. LINEWEAVER, Goldschmidt 2006 Geochemistry conference, Melbourne, 27 August - 1 September, presented a paper entitled "The Range of Geochemistries of Terrestrial Planets in the Universe: Exogeochemistries".

Dr C.H. LINEWEAVER presented a talk "Worlds without Water" to the Abi Environmental Consulting Conference at the Mitchell Library NSW Sydney , 28 September.

Dr C.H. LINEWEAVER, Earth Dynamics 2006, the annual conference of the Earth Systems Dynamics Network 22 - 24 November, ANU presented a talk entitled "The very early Earth, the heat budget, resurfacing and life".

Dr C.H. LINEWEAVER American Geophysical Union, Fall Meeting, San Francisco , CA 12-16 December and presented paper entitled "Why We Should Expect to Find Alternative Forms of Life on Earth".

Dr C.H. LINEWEAVER, Tree or Forest ? Searching for Alternative Forms of Life on Earth Conference, Arizona State University, Phoenix, USA, 17 - 20 December, presented a paper "What is life and how much don't we know about it?"

Mrs R.A. PETCH, 3 rd SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Dr D. RUBATTO conducted fieldwork in the Alps (Europe), 14 - 28 June.

Dr D. RUBATTO, 16 th Goldschmidt Conference, Melbourne , Victoria , 27 August - 1 September 2006 , presented an invited paper entitled "Geochronological constraints on fast exhumation: the example of the Central Alps ", and a paper entitled "Zircon/garnet trace element partitioning: a tool for P-T-time paths".

Dr D. RUBATTO, 3 rd SHRIMP Workshop 2006, Rottnest Island , WA , 1 - 8 September.

Dr R. SALMERON, Disks in Young Stars Conference, Centre of Astronomy Investigations (CIDA), Merida , Venezuela , 13 – 15 March, presented a talk entitled "Angular momentum transport in protostellar disks".

Dr R. SALMERON, Physical Processes in circumstellar disks around young stars, Centro de Astrofisica da Universidade do Porto, Portugal, 18 – 23 September, presented a poster entitled "Angular momentum transport in protoplanetary disks".

Dr R. SALMERON, 5 th Stromlo Symposium: Disks, Winds and Jets, from Planets to Quasars", Research School of Astronomy and Astrophysics, The Australian National University, 3 – 8

December, presented a talk entitled "Radial and vertical angular momentum transport in protostellar disks".

Ms D.L. VALENTE, 16 th Annual V.M. Goldschmidt Conference, Melbourne, 27 August – 1 September, presented a poster entitled "The Geology, Geochemistry and Geochronology of the El Abra Mine, Chile and the adjacent Pajonal-El Abra suite of intrusions: a U/Pb zircon dating and thermal perspective.

Dr I.S. WILLIAMS, conducted field work on southeastern Australian granites, 16 - 18 March, 5 - 6 April, 15 - 16 May, 6 - 7 June, and 9 November.

Dr I.S. WILLIAMS, invited lecture at the Chinese Academy of Geological Sciences, Beijing, entitled "The surprising tectonic implications of SHRIMP dating 'Proterozoic' granulites from central Australia", 4 August.

Dr I.S. WILLIAMS, invited lecture at the Guangzhou Institute of Geochemistry, Guangzhou, entitled "An introduction to the design and geological applications of the SHRIMP (Sensitive High Resolution Ion MicroProbe)", 7 August.

Dr I.S. WILLIAMS, 16 th Annual V.M. Goldschmidt Conference, Melbourne , 27 August - 1 September, represented Australian Scientific Instruments at their exhibition booth by demonstrating SHRIMP remote analysis.

Dr I.S. WILLIAMS, 3 rd SHRIMP Workshop, Rottnest Island , 3 – 7 September, presented a paper entitled "Further progress towards high precision oxygen isotopic analyses on the multicollector SHRIMP II".

Dr I.S. WILLIAMS, presentation to selection committee at the Korea Basic Science Institute, Daejeon, South Korea, entitled "An introduction to the SHRIMP II Sensitive High Resolution Ion MicroProbe", 28 November.

Earth Environment

Mr M. AUBERT , Australian Archaeometry conference, Canberra , Australia , 12-15 December, presented a poster entitled "Uranium-series dating carbonate-covered rock art in East Timor ".

Mr M. AUBERT, 150 Years of Neanderthal Discoveries, Bonn , Germany , 21-26 July, presented a poster entitled "High-resolution in situ analysis of O and Sr isotopes in fossil human teeth"

Mr M. AUBERT spent two months in France collecting reference samples of bedrock, soil and plants. The strontium isotopic composition of those samples will be compare with the skeletal Sr isotopic composition of tooth enamel in order to reconstruct Neanderthal annual and lifetime migrations.

Ms R.B. BERDIN, Australian Coral Reef 2006 Conference, Mission Beach , Queensland 18-20 August and 5 th NCCR Climate Summer School, Grindelwald , Switzerland , 27 August - 1 September, presented a paper entitled "Reconstructing Holocene climate from corals in the Philippines , northern Indo-Pacific Warm Pool" .

Dr S. EGGINS, attended the 15 th Annual Goldschmidt Conference, Melbourne , Australia , 26 th Aug-1 st September.

Dr S. EGGINS undertook field work on the Eyre Peninsula from 30 th October to 6 th November; and participated as a shipboard scientist on the 'AUSCAN 2006 and PalaeoMurrays' cruise aboard the CSIRO vessel 'Southern Surveyor' from 28 th February to 15 th March.

Dr M.J. ELLWOOD, 7th International Sponge Symposium, Búzios, Brazil 7-13 May, presented a paper entitled "Silica Banding in the Deep-Sea Lithistid Sponge Corallistes undulatus: Investigating the Influence of Diet and Environmental Conditions on Growth".

Dr T.M. ESAT attended an INQUA field meeting at Exmouth , WA , during August 2006.

Dr T.M. ESAT attended the SEALAIX'06 meeting on sea level changes: records, processes and modeling, in France during September-October and presented a paper titled "Growth Patterns of the Last Ice Age Coral Terraces at Huon Peninsula ."

Dr T.M. ESAT attended the 9 th symposium of Japanese AMS Society in Tokyo during October and presented a paper on "Radiocarbon Calibration Beyond 25,000 years before present."

Mr T. FUJIOKA, the 12th Australian and New Zealand Geomorphology Group (ANZGG) conference, Taipa Bay , New Zealand , 13-17 February 2006, presented a paper entitled "Initiation of Australian stony desert, dated by cosmogenic 21 Ne and 10 Be".

Dr M.K. GAGAN, Earth Dynamics 2006, RSES, ANU, 22-24 November, presented a talk entitled "Chemical seismometers – revealing past disasters."

Dr M.K. GAGAN led a coral drilling expedition to the Mentawai islands, Sumatra , Indonesia from 21 May to 30 June and a speleothem collecting expedition to Flores , Indonesia from 23 July to 26 August.

Prof R. GRÜN gave a presentation entitled High-resolution in situ analysis of O and Sr isotopes in fossil human teeth , co-authored by M. AUBERT, Drs S. EGGINS, I. WILLIAMS and M.H. Moncel, at the meeting: 150 years of Neanderthal discoveries. Early Europeans - continuity & discontinuity. 21-26 July 2006, Bonn , Germany (see Terra Nostra 2006/2: p. 115).

Prof R. GRÜN gave two seminars at Département de Préhistoire du Musée National d'Historie Naturelle, Paris, a seminar at the Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1, one at the Geographisches Insitut der Universität zu Köln and a three hour lecture at the Marillac Field-School of the Department of Archaeology, Princeton University.

Dr S.D. JUPITER, 13 th Ocean Sciences Meeting, Honolulu , USA , 20-24 February, presented a poster entitled, "Coral trace element records of terrestrial, agricultural and land-use change in a Great Barrier Reef catchment."

Dr S.D. JUPITER conducted field work on the central Great Barrier Reef from 6-12 March, on the far northern Great Barrier Reef from 1-11 October, and in Molokai , Hawaii , from 13-17 November.

Prof M.T. McCULLOCH, conducted field work in Hawaii , on Molokai from 13-17 November and on the Big Island from 18-26 November.

Prof M.T. McCULLOCH, 2006 Goldschmidt Conference, far north, Queensland and Melbourne, Victoria, 22-31 August, presented 3 papers entitled "Proliferation and demise of Mediterranean deep-sea corals"; "Contemporary changes in continental run-off: Evidence for increased sediment and freshwater fluxes into the Great Barrier Reef"; and "Coral record of human impacts on land-sea interactions in the inner Great Barrier Reef " and co-authored a further 6 papers presented at the conference.

Prof M.T. McCULLOCH, Coral Reef Society Conference, Mission Beach, far north Queensland, 18-20 August, presented a paper entitled "A Tale from Two Continents: Soil erosion and sediment fluxes into coral reefs from Kenya, Africa and the Grest Barrier Reef of Australia".

Prof M.T. McCULLOCH, Australian Maritime Safety Association AMSA 2006 "Catchments to Coast Conference" in Cairns, 9-13 July, presented a paper entitled "Coral record of human impacts on land-sea interaction in the inner Great Barrier Reef".

Prof M.T. McCULLOCH, presented a paper at the AGU 2006 Ocean Sciences Meeting, Honolulu , Hawaii , entitled "Coral record of landuse changes and terrestrial runoff into the Great Barrier Reef ", 19-22 February.

Prof B.J. PILLANS, 12 th Australian & New Zealand Geomorphology Group Conference, Taipa Bay, New Zealand, 13-17 February. Keynote Speaker: "Timescales in geomorphology".

Prof B.J. PILLANS, Beyond the GSSP: The Future of Chronostratigraphy. Penrose Conference, Schloss Seggau , Austria , 3-9 June 2006. Invited Speaker: "The Quaternary: Where do we go from here?'

Prof B.J. PILLANS, Geological Society of New Zealand Conference, Palmerston North, New Zealand, 4-7 December 2006. Plenary Speaker: "Defining the Quaternary"

Prof B.J. PILLANS conducted field work in the Tanami Desert, Northern Territory, from 15 th to 25 th August.

Dr E.J. RHODES, Australian New Zealand Geomorphology Group 2006 meeting, 13-17 th February, presented a joint talk titled " Ancient surfaces?
Dating archaeological surfaces in western NSW using OSL" and a poster titled "OSL and cosmogenic dating of linear dunes in the Simpson Desert , Australia ", and at the 2006 Australasian INTIMATE meeting, 29-30 th November, presented a joint talk titled "Central Australian palaeoenvironments of the last 30,000 years – evidence from dune building".

Dr P.C. TREBLE, Goldschmidt Conference, Melbourne, 27-31 August, presented an invited paper entitled "High resolution SIMS d 18 O of Hulu Cave at the time of Heinrich event 1".

Earth Materials

Mr S. BARKER, 17th American Geophysical Union Conference, San Francisco , USA , 5-9 December, presented a paper entitled "Chemical evidence for episodic growth of a fibrous antitaxial calcite vein from externally derived fluid".

Mr S. BARKER, 6 th Gordon Research Conference on Rock Deformation, Big Sky, Montana , USA , September 3-8, presented a paper entitled "Episodic fluid migration during crustal deformation – vein chemistry at all scales"

Mr M. BELTRANDO, Gordon Research Conference/workshop, Montana , USA , 3-16 September.

Prof S.F. COX presented invited lectures at the Geological Society of London Fermor Conference, London , 13-15 September, 2006, and at the meeting of the Asia-Oceania Geoscience Society, Singapore , July 10 –14, 2006. Prof S COX also participated in a workshop on "Active Fluid Flow and Deformation", Wellington , New Zealand , November 28 – 30.

Dr W.J. DUNLAP attended the Himalaya-Karakoram-Tibet Conference in Cambridge , U.K. , from March 21-29.

Dr K.A. EVANS Invited Talk. Synchrotrons in the geosciences, Synchrotron workshop, MacQuarie University , Sydney .

Dr K.A. EVANS Invited Keynote. Redox budget: an extensive variable for quantification of redox processes. Goldschmidt 2006, Melbourne Australia .

Dr K.A. EVANS and Powell, R., (2006) . Improvements in thermodynamic models of hydrothermal fluids through better configurational entropy terms. Goldschmidt 2006, Melbourne Australia .

Dr K.A. EVANS attended the 16th Annual V.M. Goldschmidt Conference, Melbourne , 27 th August to 1 st September 2006 , where she gave two talks, one of which was an invited keynote.

Dr K.A. EVANS made visits to the NSRRC (Taiwan Synchrotron) in April and November, and to the APS (American Synchrotron) in Chicago , USA , in October. She conducted research on the nature of sulphur and chlorine complexation in silicate glasses, and on the effects of CO2 on the molecular structure of supercritical fluids.

Dr J.D. FITZ GERALD, 19th Australian Conference on Microscopy and Microanalysis, Sydney , 5-9 February, presented a poster detailing defects of exsolution in alkali feldspars.

Dr M. FORSTER, 21 st Himalaya-Karakoram Tibet (HKT) Workshop, Cambridge, England, 29-31 March, presented a paper entitled "Tectonic shuffle zones: Lithosphere-scale movement zones that reverse their shear sense during orogenesis".

Dr M. FORSTER, 21 st Himalaya-Karakoram Tibet (HKT) Workshop, Cambridge , England , 29-31 March, co-authored a paper entitled "Episodes in Himalayan orogenesis".

Dr M. FORSTER, Backbone of the Americas, Patagonia to Alaska Conference, Mendoza, Argentina, 3-7 April, presented a paper entitled "Tectonic shuffle zones: Lithosphere-scale movement zones that reverse their shear sense during orogenesis".

Dr M. FORSTER, Backbone of the Americas , Patagonia to Alaska Conference, Mendoza , Argentina , 3-7 April, coo-author on a paper entitled "The plate-tectonic significance of inversion cycles during orogenesis".

Dr M. FORSTER, Australian Earth Sciences Convention, Melbourne , Australia , 3-7 April, coo-author on a paper entitled "Contrasting styles in accretionary versus collisional orogens".

Dr M. FORSTER, 16 th Annual V.M. Goldschmidt Conference, Melbourne, Australia, 27 August- 1 September, presented on a paper entitled "Seismogenic strain rates during ductile deformation: The example of South Cyclades Shear Zones, Greece".

Dr M. FORSTER, Gordon Research Conference/workshop, Montana , USA , 3-16 September.

Dr M. FORSTER conducted fieldwork in the Franciscan Blueschist Belt and Shuffle Zone , California from 8-18 April.

Dr M. FORSTER conducted fieldwork in the NW Himalaya, Ladakh India from 14-23 August.

Dr M. FORSTER conducted fieldwork in core complexes of NW China from 25-26 September.

Dr M. FORSTER conducted fieldwork on major movement zones in Broken Hill region, Australia from 26 July to 2 August.

Dr M. FORSTER conducted collaboration at New Delhi University , India from 24-30 August.

Dr M. FORSTER conducted collaboration with structure and geochronology group at Stanford University , USA . Presented a lecture titled: " Argon Geochronology: *Dating deformation in the argon partial retention zone".*

Dr M. FORSTER conducted collaboration with structure and geochronology group at Peking University , China , from 20 September – 2 October. Presented a double lecture titled: " Unravelling the timing of deformation events *".*

Mr S. GIGER, Geologia strutturale "Giampaolo Pialli", Perugia , Italy , 18-22 September, participated in a course entitled "Mechanics and physics of the earthquake process".

Mr S. GIGER, 18th American Geophysical Union Conference, San Francisco , USA , 11-15 December, presented a paper entitled "Permeability and porosity evolution of quartz fault gouges during hot pressing under hydrothermal conditions".

Prof D. H. GREEN attended the 16th Annual V.M. Goldschmidt Conference, Melbourne , 27 th August to 1 st September 2006 , where he gave two talks.

Prof I. JACKSON attended the Annual Condensed Matter and Materials Meeting in Wagga Wagga (7-10 February) presenting two poster papers; the Ahrens Symposium, California

Institute of Technology (11-12 May) and the Margins Symposium 'Interpreting Upper-Mantle Images', Woods Hole (17-19 May) presenting invited papers on the laboratory measurement of seismic wave attenuation at both and at Yale University (15 May). He also visited Stony Brook University for discussion of collaborative research on 22 May.

Dr J. HERMANN, 16 th annual V.M. Goldschmidt Conference , Melbourne, Australia, 27 August-1 September, presented a Key-note lecture "Experiments and eclogites: constraints on element recycling in subducted crust" a paper entitled "Sediment melts at sub arc depths" and was co-author on 10 other contributions.

Dr J. HERMANN conducted field work in the Central Alps from 19-28 June; in the Western Alps from 18-23 July 2005 and in New Caledonia from 22-29 November.

Mr I. KOVACS, 16 th Annual Goldschmidt Conference, Melbourne , 27 August-1 September, presented a paper entitled "Water solubility in forsterite and enstatite: implications for the secular evolution of mantle convection"

Mr I. KOVACS, Workshop on Nominally Anhydrous Minerals, Verbania , Italy , 1-4 October, gave a talk and presented a poster entitled " Water solubili ty in forsterite and enstatite as a function of temperature and silica activity" and " Quantitative IR spectroscopy with unpolarized light", respectively.

Mr I. KOVACS, 4th meeting of the Central European Tectonic Studies Group (Ceteg), Zakopane, Poland, 20-24 April, presented a poster entiled "Paleogene-Early Miocene Igneous Rocks and Geodynamics of the Alpine-Carpathian-Pannonian-Dinaric Region: an Integrated Approach" and "Geodynamic Implications of Flattened Equigranular Textured Peridotites from the Central Part of the Carpathian–Pannonian Region"

Dr J.J. KURTZ, 2006 American Geophysical Union Conference, San Francisco, USA, 11-15 December, presented a paper entitled " Improving Reconstruction With Deformable Continents: The fit of South America and Africa" (260108).

Emeritus Prof I. MCDOUGALL attended the 16 th Goldschmidt Conference held in Melbourne in August 2006 and presented a paper entitled "Earliest known modern humans from Kibish , Ethiopia ".

Dr J. MAVROGENES and Dr McFarlane conducted fieldwork in August on the Morila gold mine, Mali .

Dr J. MAVROGENES attended the 16th Annual V.M. Goldschmidt Conference, Melbourne , 27 th August to 1 st September 2006 , and presented a paper.

Dr J. MAVROGENES attended the Spring AGU Conference, in Baltimore , Maryland in May, presented a paper and chaired a special session (with B. Scaillet, CNRS, Orleans France) on sulfur in magmas.

Dr J. MAVROGENES presented a seminar on Metamorphism of Ore Deposits to the School of Earth and Geographical sciences, UWA in October.

Dr J. MAVROGENES presented a seminar on Sulfur Solubility in melts to the Geology Department, University of Witswatersrand , Johannesburg South Africa in August.

Dr C.R.M. McFARLANE attended the joint meeting of the Geological Association of Canada and the Mineralogical Association of Canada (GACMAC), Montreal, May 2006, and presented a paper entitlted "Seeing a hydrothermal Au deposit through the veil of partial melting: physical and geochemical constraints on precursor mineralization at Challenger, South Australia," Diversification of mineral exploration special session.

Dr C.R.M. McFARLANE & Prof M. McCULLOCH presented at talk entitled "In-situ 143Nd/144Nd in LREE-rich minerals via LA-MC-ICPMS," in the Thematic session on geochemical constraints on timescales and mechanisms of tectonic processes, 16th Annual Goldschmidt Conference, Melbourne, August 2006

Dr C.R.M. McFARLANE undertook one week of fieldwork at the Morila Mine, Mali , in September 2006.

Dr S. MICKLETHWAITE, 2006 American Geophysical Union Conference, San Francisco , USA , 10-15 December, presented a paper entitled "Fluid flow controlled by progressive fault triggering and aftershock distributions in Archean fault systems".

Prof H. O'NEILL attended the 16th Annual V.M. Goldschmidt Conference, Melbourne , 27 th August to 1 st September 2006 , where he gave two talks.

Ms S.N. BURGESS, 3rd International Deep-Sea Coral Symposium, Miami , Florida , USA , 28 November – 2 December, presented a paper entitled "Evaluating the use of Plesiastrea versipora as a coral archive of temperate paleoclimate."

Dr R. RAPP, Geological Society of America, Penrose Conference on "Arc Crustal Genesis", Valdez, Alaska, 9-15 July, presented a paper on "17th American Geophysical Union Conference, San Francisco, USA, 5-9 December, presented a paper entitled "Whither the source? Interactions between slab-derived adakitic melts and the mantle wedge, and the origin of high-magnesian andesites."

Dr R. RAPP, 16 th Annual Goldschmidt Conference, 27 August- 1 September, Melbourne , Australia , presented a paper entitled "Experimental insights into slab-mantle interactions in subduction zones: melting of adakite-metasomatized peridotite and the origin of the "arc signature".

Mr N. TAILBY, 16th Annual Goldschmidt Conference, Melbourne , AUSTRALIA , 27 August - 1 September, presented a talk entitled "Solubility, activity and phase relationships in silicate-H 2 O systems: insights from new hydrothermal experimental techniques".

Dr Dr Eric Tenthorey attended the Asia Oceania Geosciences Society Annual Meeting, Singapore and presented a talk entitled: "Cohesive strengthening of fault zones during the interseismic period."

T. ULRICH attended two conferences and presented results of my research this year. I gave an invited keynote presentation on LA ICPMS analysis of fluid inclusions at the Asian Current

Research on Fluid Inclusions (ACROFI I) conference in Nanjing in May 2006 and presented some results of the sulphur solubility study at the 16th Goldschmidt Conference in Melbourne in September 2006.

Earth Physics

Dr D.R. CHRISTIE, 28 th Seismic Research Review Symposium, Orlando , Florida , 19-21 September, presented a paper entitled "Detection of Atmospheric Explosions at IMS Monitoring Stations Using Infrasound Techniques".

Dr D.R. CHRISTIE, Infrasound Technology Workshop, Fairbanks , Alaska , 25-28 September, presented a paper entitled "Wind Noise Reduction at Infrasound Monitoring Stations".

Ms M.A. COMAN, Ocean Sciences meeting of the AGU, Hawaii, USA, 20-24 February 2006, presented a paper on "Horizontal convection and Sandstrom's postulate re-visited" (with R.W. GRIFFITHS and G.O. HUGHES).

Ms M.A. COMAN, 6th International Symposium for Stratified Flows, Perth, 11-14 December 2006, presented a paper entitled "Horizontal convection driven by two spatially separated regions of destabilising flux" (with R.W. GRIFFITHS and G.O. HUGHES).

Dr G.F. DAVIES presented a paper at the Penrose Conference "When Did Plate Tectonics Begin?" in Lander, Wyoming , June 2006.

Dr G.F. DAVIES presented a paper at the Goldschmidt International Geochemistry Conference in Melbourne , August 2006 entitled "Depletion, plates and a revised cooling history".

Dr G.F. DAVIES presented three papers (including one invited) at the American Geophysical Union Fall Meeting, San Francisco , USA , 11-15 December 2006.

"Dynamics of the early, hot mantle: depletion, plates and slower cooling."

"Mantle regulation of core cooling: geodynamo without core radioactivity?

"Controls on stirring in three-dimensional mantle stirring models."

entitled "Relative sea-level changes due to recent mountain deglaciation

Ms G. ESTERMANN, World Climate Research Program, Workshop on "Understanding sea level rise and variability", Paris , France , 6-9 June, presented (by invitation) a poster".

PROF R.W. GRIFFITHS, Ocean Sciences meeting of the AGU, Hawaii, USA, 20-24 February 2006, presented a paper on "Mixing in two-layer exchange flows" (with T.J. Prastowo , G.O. HUGHES and A.McC. Hogg).

PROF R.W. GRIFFITHS, Complex Dynamics of Rotating Flows Workshop, Adelaide , 13-14 July 2006.

Prof R.W. GRIFFITHS, Ocean Sciences Meeting of the American Geophysical Union, Hawaii, USA, 20-24 February 2006, presented a paper on “Mixing in two-layer exchange flows” (with G.O. HUGHES and T.PRASTOWO). He also co-authored papers presented by Dr J.C. Mullarney(Dalhousie University , Canada) Dr G.O. HUGHES and Ms M.A. COMAN.

PROF R.W. GRIFFITHS, 6th International Symposium for Stratified Flows, Perth, 11-14 December 2006, presented a paper entitled "Adjustment Processes and Timescales in Horizontal Convection" (with G.O. HUGHES).

Dr A.McC. HOGG, Turbulence and coherent structures workshop, 10-13 January 2006, presented a paper entitled “Low Frequency Ocean Variability: Feedbacks between eddies and the mean flow”.

Dr A.McC. HOGG, Australian Meteorological and Oceanographic Society 13 th Annual Conference, Newcastle , 6-8 February 2006, presented a paper entitled “Interdecadal Variability of the Southern Ocean”.

Dr A.McC. HOGG presented a seminar at Monash University , 20 April 2006 entitled “Hydraulic Control in Geophysical Flows: Viscosity, Shear and Time-dependence” (with G.O. Hughes and L.M. Frankcombe).

Dr A.McC. HOGG presented a seminar to CSIRO Marine and Atmospheric Research, 21 April 2006 entitled “Interdecadal Variability & Eddies in the Southern Ocean” (with M.P. Meredith and J.R. Blundell).

Dr A.McC. HOGG, Complex Dynamics of Rotating Flows Workshop, Adelaide , 13-14 July 2006, presented a paper entitled “The turbulent oscillator in the double gyre circulation” (with P. Berloff and W.K. Dewar).

Dr A.McC. HOGG, 17 th Australia New Zealand Climate Forum, Canberra, 5-7 September 2006, presented a paper entitled “Circumpolar response of Southern Ocean eddy activity to changes in the Southern Annular Mode” (with M.P. Meredith).

Dr A.McC. HOGG, Magic of Modelling, Southampton, UK, 28-29 September 2006, presented a paper entitled “Self-similarity and hydraulics in stratified exchange flows”.

Dr A.McC. HOGG presented a seminar to the Institute for Theoretical Geophysics, University of Cambridge , 2 October 2006 entitled “Eddies, Interdecadal Variability & Warming in the Southern Ocean” (with M.P. Meredith and J.R. Blundell).

Dr A.McC. HOGG, 6th International Symposium for Stratified Flows, Perth, 11-14 December 2006, presented a paper entitled "Viscous hydraulic control: A reduced gravity model" (with G.O. HUGHES).

Dr J.S. HUANG presented a paper at the 2006 West Pacific Geophysics Meeting, Beijing , China , 24-27 July 2006 entitled “Stirring in Three-Dimensional Mantle Convection and Implications for Geochemistry” (with G.F. Davies).

Dr J.S. HUANG presented a paper at the Australian Institute of Physics 17 th National Congress, Brisbane, 3-8 December 2006 entitled "Stirring in Three-Dimensional Mantle Convection Models: Differentiation of heavy tracers" (with G.F. Davies).

Dr G.O. HUGHES, 6th International Symposium for Stratified Flows, Perth, 11-14 December 2006, presented a paper entitled "A theoretical model for 'horizontal convection'" (with R.W. GRIFFITHS, J.C. MULLARNEY and W.H. PETERSON).

Dr G.O. HUGHES, American Geophysical Union Ocean Sciences Meeting, Hawaii, USA, 20-24 February 2006, presented a paper entitled "A simple convective model of the global overturning circulation, including effects of entrainment into sinking regions" (with R.W. GRIFFITHS).

Dr G.O. HUGHES, European Geophysical Union General Assembly, Vienna , 2-7 April 2006, presented an invited paper entitled "The sensitivity of the convective circulation in a rectangular ocean basin to entrainment into slope currents and interior vertical mixing" (with R.W. GRIFFITHS). He also presented a poster entitled "Horizontal convection and Sandstrom's postulate revisited" (with M.A. COMAN and R.W. GRIFFITHS).

Dr G.O. HUGHES gave seminars at Utrecht and Eindhoven on "Sandström's observations, horizontal convection, and the ocean overturning circulation".

Dr G.O. HUGHES, Complex Dynamics of Rotating Flows Workshop, Adelaide , 13-14 July 2006, presented a paper entitled "The role of dense geostrophic slope currents in the global overturning circulation of the oceans" (with R.W. GRIFFITHS).

Prof B.L.N. KENNETT spent most of May and June in Europe on Outside Studies Leave based at the University of Munich . In early May he went to London to receive the Murchison Medal of the Geological Society of London. He returned to Australia at the beginning of July and made two presentations at the Australian Earth Sciences Convention. In August he attended the Goldschmidt conference in Melbourne and gave an invited talk on Lithosphere structure beneath Australia . He also attended the Fall Meeting of the American Geophysical Union with two oral presentations.

Dr R. KERR, American Geophysical Union Fall Meeting, San Francisco , USA , 11-15 December 2006, presented a paper entitled " The formation of channelized lava flows on an unconfined slope ".

Prof K. LAMBECK, London Geological Society Conference on External Controls on Deepwater Depositional Systems, London, UK, 27-29 March 2006, presented a paper entitled "Sea level during glacial cycles: constraints on ice sheets and their rates of growth and decay during the past 140,000 years".

Prof K. LAMBECK, World Climate Research Programme Workshop on Understanding Sea-level Rise and Variability, Paris , France , 6-9 June 2006, presented a paper entitled "Paleo- and 20 th Century Sea-level Variations".

Prof K. LAMBECK, ACE CRC Symposium 2006, Hobart, Tasmania, 29-30 August 2006, presented a paper entitled "Quantifying ice volumes during glacial cycles".

Prof K. LAMBECK, International Symposium SEALAIX'06 "Sea level changes: Records, processes and modeling", Giens , France , 25-29 September 2006, presented a paper entitled "Sea-level change during the last glacial cycle: constraints on ice sheets and their rates of growth and decay".

Prof K. LAMBECK, 15 th International Laser Ranging Workshop, Canberra , Australia , 16-20 October, presented a paper entitled "Satellite Laser Ranging in the National (Australian) Collaborative Research Infrastructure Proposal for Geospatial R&D".

Prof K. LAMBECK, Inter Academy Panel Conference and General Assembly, Alexandria, Egypt, 1–5 December 2006, presented a paper entitled "The Shape of the Earth: From Erostothenes to the Space Age" in his role as President of the Australian Academy of Science.

As President of the Australian Academy of Science, Prof K. LAMBECK participated in several Conferences and Symposia including the Federation of Asian Scientific Academies and Societies (FASAS) Council Meeting, Singapore, 11-12 September 2006, The High Flyers Think Tank on Innovative technical solutions for water management in Australia, Adelaide, 30 October 2006, and the Australia-China Energy Symposium, Sydney, 5-7 November 2006.

M.J. O'BYRNE Australian Meteorological and Oceanographic Society 13 th Annual Conference, Newcastle, 6-8 February 2006, presented a paper entitled "Interaction of coherent eddies with headland wakes" (with R.W. GRIFFITHS).

Mr T. PRASTOWO, 6th International Symposium for Stratified Flows, Perth, 11-14 December 2006, presented a paper entitled "Mixing in exchange flows through a contraction" (with R.W. GRIFFITHS, G.O. HUGHES and A.McC. HOGG).

Dr. N. RAWLINSON, Australian Earth Sciences Convention 2006, Melbourne, 2-6 July, presented two papers: "Seismic wavefront tracking in 3-D heterogeneous media" and "Detailed teleseismic imaging of the crust and upper mantle beneath south east Australia".

Dr. N. RAWLINSON, Mastering the data explosion in the earth and environmental sciences, Canberra , 19-21 April, presented a paper entitled "Teleseismic Imaging in South East Australia using data from Multiple high density Seismic Arrays"

Dr. N. RAWLINSON conducted fieldwork in Victoria from 4-15 January; 20-31 March; 15-23 May, and in Tasmania from 1-12 October and 15-22 November

Dr A.M. READING, European Geophysical Union , Vienna , 02-07 April 2006. Presented a contribution on 'Seismic structure of Precambrian terranes in Western Australia and East Antarctica : insights into building ancient cratons and supercontinents'.

Dr A.M. READING, Scientific Committee for Antarctic Research, Open Science Meeting in Hobart , 12-14 July 2006. Presented a contribution entitled 'POLENET, the polar Earth observing network'.

Dr A.M. READING, Goldschmidt Meeting, Melbourne , 28 August – 01 September 2006 . Presented a contribution on 'Precambrian terranes in West Australia and East Antarctica : seismic structure and implications for continent formation and evolution'.

Dr A.M. READING, American Geophysical Union , San Francisco , 11-15 December 2006. Presented a contribution on 'Lithospheric Structure and Seismotectonics of Central East Antarctica'.

Dr A.M. READING conducted seismological fieldwork in West Australia from 23 January- 03 February, 13-30 June and 6-20 November 2006.

Dr A.M. READING conducted seismological fieldwork in East Australia 15-23 May 2006.

David 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, Lorentz Center workshop *The World a Jigsaw: Tessellations in the Sciences* , 6-10 March 2006, Lorentz Center , Univ. of Leiden , The Netherlands (invited speaker).

Dr M. SAMBRIDGE, 3 rd SPICE Research and Training workshop on *Computational Seismology and Inverse Problems* , 23-28 July, Kinsale , Ireland (invited speaker).

Dr M. SAMBRIDGE, Australian Earth Sciences Convention, 2-6 July 2006.

Dr. W.P. Schellart presented a seminar at The University of Queensland entitled " Incorporating Northland (New Zealand) and New Caledonia geology into Southwest Pacific tectonic reconstructions ", 25 May 2006 .

Dr. W.P. Schellart presented a seminar at The Australian National University entitled " Physical parameters that control the trench velocity and the mode of subduction" , 15 June 2006 .

Dr. W.P. Schellart presented a seminar at The University of Western Australia entitled "Late Cretaceous-Cenozoic reconstructions of the SW Pacific: Incorporating geological data from Northland (New Zealand) and New Caledonia " 13 October 2006 .

Dr. W.P. Schellart, 18 th Australian Earth Science Convention Melbourne, July 2006 presented a poster entitled "Dependence of subducting plate motion, trench motion and mantle flow patterns on the plate/mantle viscosity ratio" (with Prof. R.W. Griffiths).

Dr. W.P. Schellart , 18 th Australian Earth Science Convention Melbourne, July 2006 presented a paper entitled "Fitting Northland, New Caledonia and d'Entrecasteaux geology into the Late Cretaceous-Cenozoic Southwest Pacific tectonic framework ".

Dr. W.P. Schellart , 18 th Australian Earth Science Convention Melbourne, July 2006 co-authored a paper presented with Stegman et al entitled "New insights into upper mantle flow from 3D numerical models of subduction ".

Dr. W.P. Schellart presented a paper at the 18 th Australian Earth Science Convention in Melbourne (July 2006) with co-authors Freeman and S tegman entitled "Defining an absolute reference frame for plate motions on Earth from minimizing subduction zone trench migration".

Dr. W.P. Schellart presented a paper at the 16 th Annual Goldschmidt Conference in Melbourne (August-September 2006) with co-authors Freeman and S tegman entitled " Subduction-induced mantle convection on Earth: Poloidal versus toroidal flow".

Dr W.P. Schellart was co-author on a paper presented by S tegman et al. at the 16 th Annual Goldschmidt Conference in Melbourne (August-September 2006) entitled " Evolution and dynamics of subduction zones from 4-D geodynamic models".

Dr C.SINADINOVSKI, 8 th U.S. National Conference on Earthquake Engineering and Centenial SSA Meeting, San Francisco, USA, 18-22 April.

Dr C.SINADINOVSKI, 15 th Australian Earthquake Engineering Society (AEES)Conference, Canberra , ACT, 24-26 November.

Dr P. TREGONING spend two weeks at the Laboratoire de Meteorologie Physique, Observatoire de Physique du Globe de Clermont-Ferrand , Clermont-Ferrand , France to integrate surface atmospheric observations into GPS analysis and to discuss GPS tomography.

PRISE

Dr R.A. ARMSTRONG, South American Symposium on Isotope Geology V, Punta del Este, Uruguay, 24-27 April, presented a Keynote address entitled "The expanding world of the SHRIMP: new developments and future trends", and co-authored a number of other papers. Attended the 21 st Colloquium of African Geology, Maputo , Mozambique , 3-6 July, and co-authored a number of presentations and attended business meetings. Attended 16 th Annual V.M. Goldschmidt Conference, Melbourne , Victoria , 27 August – 1 September, and co-authored one paper.

Dr R.A. ARMSTRONG conducted field work in Namibia in July with Dr T. Becker of the Namibian Geological Survey.

Mr C.M. FANNING, V South American Symposium on Isotope Geology, Punta del Este, Uruguay, 24 – 27 April, presented a paper entitled "U-Pb and Lu-Hf isotopic constraints on the provenance of Permian detritus in metasedimentary rocks of southern Chile and Livingston Island, Antarctica" and co-authored five other papers.

Mr C.M. FANNING, Australian Earth Sciences Convention 2006, Melbourne , Australia , 2 – 6 July.

Mr C.M. FANNING, 19 th General Meeting of the International Mineralogical Association, Kobe , Japan , 23 – 28 July, convened a session and presented an invited paper entitled "An update of More SHRIMP for the Geological Feast; new developments and future trends".

Mr C.M. FANNING, 16th Annual V.M. Goldschmidt Conference 2006, Melbourne, Australia, 27 August – 1 September, presented a paper entitled "U-Pb and Lu-Hf Isotopic Constraints on the Provenance of Permian Detritus in Metasedimentary rocks of Southern Chile and Livingston Island, Antarctica " and a poster entitled "Constraints on the timing and isotopic evolution for the 150 my emplacement history of the South Patagonian batholith, southern Chile".

Mr C.M. FANNING, 2006 Geological Society of America Annual Meeting & Exposition, Philadelphia, USA, 22 – 25 October, presented two papers entitled "U-Pb and Lu-Hf isotopic constraints on the provenance of Permian detritus in turbidites from Patagonia and Livingston Island, Antarctica; implications for plate reconstructions" and "Constraints on the timing of the Sturtian glaciation from southern Australia; ie for the true Sturtian" and co-authored six other papers and two posters.

Mr C.M. FANNING conducted fieldwork in the Flinders Ranges , South Australia from 27 February – 4 March and in Chile and Argentina from 10 November – 13 December.

Dr M.D. NORMAN, 16th Annual V.M. Goldschmidt Conference 2006, Melbourne, Australia, 27 August – 1 September, presented a paper entitled "Compositions of Hawaiian Basalts Preclude Eclogite Mantle Plumes", and Lunar and Planetary Science Conference, Houston, USA, 12-17 March, presented a paper entitled "Impactor Populations and Lunar Crustal Compositions Inferred from Highly Siderophile Elements in Apollo 16 and 17 Melt Breccias".

Dr G.M. YAXLEY, 16th Annual V.M. Goldschmidt Conference 2006, Melbourne , Australia , 27 August – 1 September, presented a talk entitled "Carbonate-eclogite in the upper mantle", attended a synchrotron-related Seminar-Series held by the Australian X-ray Analytical Association (AXAA) at CSIRO in April.

Dr C. MAGEE, 16 th Annual Goldschmidt conference, Melbourne , August 28-Sept 1, presented a poster, "Alkali background reduction in routine laser ICP-MS analysis"; attended an Agilent Users group conference, August 24-25, Melbourne .

Ms A ROSENTHAL, 16th Annual V.M. Goldschmidt Conference 2006, Melbourne, Australia, 27 August – 1 September, presented a paper entitled "Ugandan kamafugites: re-melting of a variable enriched veined subcontinental lithospheric mantle".

EDITORIAL RESPONSIBILITIES

Earth Chemistry

Dr C.M. Allen , Associate Editor, Australian Journal of Earth Sciences.

Dr V.C. BENNETT, Co-editor of "Earth's Oldest Rocks", Elsevier Press.

Dr J.J. BROCKS is a newly appointed Associate Editor of Palaios, a Journal of the Society of Sedimentary Geology.

Dr I.H. Campbell, Co-editor Chemical Geology Special Issue on Mantle Plumes.

Dr C.H. LINEWEAVER, co-editor, Proceedings of the 5 th Stromlo Symposium Disks, Winds and Jets: from Planets to Quasars, Conference held at Mt Stromlo, Dec 4-8.

Dr D. RUBATTO, Associated Editor, Lithos.

Dr D. RUBATTO, Editorial Review Board, Journal of Metamorphic Geology.

Dr R. SALMERON, Reviewer, Origins of Solar Systems/Terrestrial Planets Finder Programs, NASA.

Earth Environment

Dr S.M. EGGINS, Editorial Board, Journal of Geostandards and Geoanalysis.

Dr S.M. EGGINS, Editorial Board, Quaternary Geochronology.

Prof R. GRÜN is Editor of Quaternary Geochronology.

Prof R. GRÜN is a member of the Editorial Boards of Quaternary Science Reviews and Radiation Measurements.

Prof R. GRÜN is a Member of reviewers' panel of Ancient TL.

Prof R. GRÜN is member of the Organising Committee of the Congress of the International Quaternary Association, which will be held in Cairns in July 2007.

Prof R. GRÜN is a standing member of the scientific committee.

Prof R. GRÜN is a editor of the proceedings of the International Conferences on Luminescence and Electron Spin Resonance Dating, the next conference will be held in Beijing 2008.

Prof M.T. McCULLOCH is on the Editorial Board of Earth and Planetary Science Letters.

Prof B.J. PILLANS, Editorial Board, Quaternary Science Reviews.

Prof B.J. PILLANS, Editorial Board, Catena

Prof B.J. PILLANS, Section Editor, Elsevier Encyclopedia of Quaternary Science

Dr E.J. RHODES, Editorial Board, Quaternary Geochronology.

Earth Materials

Prof S.F. COX continued as a member of the Editorial Advisory Boards of Journal of Structural Geology and Geofluids.

Dr W.J. DUNLAP, Associate Editor, Australian Journal of Earth Sciences.

Dr J.D. FITZ GERALD, Editorial Board, Physics and Chemistry of Minerals.

Dr J. HERMANN, Associate Editor, LITHOS.

Prof I. JACKSON, Editorial Boards, Physics and Chemistry of Minerals, 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, Elements; and Associate Editor, e-Earth.

Earth Physics

Prof R.W. GRIFFITHS served as a member of the Editorial Committee of the Annual Reviews of Fluid Dynamics (this journal has the highest impact factor of 120 journals in the area of mechanics).

Prof B.L.N. KENNETT, Editor-in-Chief of Physics of the Earth and Planetary Interiors (until June 2006) and an Associate Editor for Earth and Planetary Science Letters.

D. ROBINSON, Book Review Editor, Preview Magazine

Dr. P. TREGONING, Associate Editor, Journal of Geophysical Research-Solid Earth.

Dr. P. TREGONING, Dynamic Planet: Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, IAG Symposium, Cairns , Australia , 22-26 August, 2005, Vol 130, edited by P. Tregoning and C. Rizos.

r. W.P. Schellart served as an Associate Editor of Journal of Geophysical Research-Solid Earth.

PRISE

Dr R.A. ARMSTRONG, Editorial Board, Journal of African Earth Sciences.

Dr G.M. YAXLEY and Prof Gerhard Brey (University of Frankfurt) are currently co-ordinating a special issue of the Journal of Petrology to honour the career of Prof David Green.

OUTREACH AND WORKSHOPS

Earth Chemistry

Dr V.C. BENNETT participated in the “Workshop on Surface ages and Histories: Issues in Planetary Chronology”, Lunar and Planetary Institute, Houston , Texas , 21-23 May.

Dr V.C. BENNETT gave an invited talk entitled “Deep Time, Deep Earth: The Accretion, early History and Large Scale Geochemical Evolution of the Earth” at the “Stars to Brains Conference” Australian Academy of Science, Canberra , 20-21 June.

Dr V.C. BENNETT gave a presentation at the ANU Planetary Science Institute workshop held in conjunction with the visit of the Jaeger-Hales lecturer, Professor David Stevenson.

Dr J.J. BROCKS was interviewed for the newspage Biogeosciences.org on 4 April (http://www.biogeosciences.org/interviews/interviews/brocks.htm).

Dr J.J. BROCKS was interviewed by the ANU magazine ‘Science Wise'.

Dr T.R. IRELAND , with Prof M. McCulloch and Dr M. Gagan , hosted a o ne-day visit by Dr Yusuke Yokoyama, with 16 staff and students from the University of Tokyo, Japan, to visit the RSES SHRIMP laboratories and other facilities.

Dr C.H. LINEWEAVER was interviewed by Sarah Clarke for the " A sk an Expert" segment of ABC Science online, July 13,

http://www.abc.net.au/science/expert/realexpert/space/01.htm

Dr C.H. LINEWEAVER was interviewed by ABC radio about the demotion of Pluto from planet status, 16 August,

http://www.abc.gov.au/science/news/space/SpaceRepublish_1427030.htm

Dr C.H. LINEWEAVER was interviewed by Jonathan Green of The Age about the status of Pluto.

Dr C.H. LINEWEAVER was interviewed by Andrew Carswell of the Daily Telegraph about the status of Pluto.

Dr C.H. LINEWEAVER was interviewed on ABC National television about the demotion of Pluto from planet status, August 17, a 3-minute interview organised by Sarah Clarke of ABC, broadcast 17 August.

Dr C.H. LINEWEAVER was interviewed by Sarah Clarke for ABC National News about the new IAU draft resolution on the definition of a planet, broadcast 7pm , 23 August.

Dr C.H. LINEWEAVER was interviewed by Sarah Clarke for ABC National News about the IAU decision to demote Pluto to "dwarf planet'', broadcast midday and 7pm , 25 August.

Dr C.H. LINEWEAVER was interviewed by Juanita Phillips for Radio Adelaide, 101.5 FM, 5-minute interview on demoting Pluto to "dwarf planet'' status, broadcast at 5 pm Adelaide time.

Dr C.H. LINEWEAVER was interviewed by Triple 6 Radio, Canberra , 666 AM, a 5-minute interview on hitting golf balls from the Moon, with David Kilby, July 12.

Dr C.H. LINEWEAVER participated in a debate about physics, cosmology and exoplanets organised by Abbie Thomas for ABC for Science Week. The debate was titled Café Scientific and took place at the Glasshouse Bar, UTS, Sydney , 20 August.

Dr C.H. LINEWEAVER was interviewed by Will Ockenden on the status of Pluto for the Melbourne youth radio station, SYN FM. 90.7.

Dr C.H. LINEWEAVER moderated a discussion/debate on the topic "Proposals, promotion and patent applications: does communication get in the way of good science?" at the CSIRO Discovery Centre, Black Mountain Laboratories, Clunies Ross St, Acton, 25 September .

Dr C.H. LINEWEAVER gave a talk at Melrose High School entitled "Cosmology and Are We Alone?" to Year 10 science class of Geoff McNamara, 7 November.

Dr C.H. LINEWEAVER gave a talk at the Planetary Science Institute Research Workshop in honour of David Stevenson held at RSES 24 October. The talk was entitled "Estimating the Compositions of Extrasolar Terrestrial Planets".

Dr C.H. LINEWEAVER, at the Thiess Environmental Workshop, gave a presentation entitled "Worlds without Water", Nov 15.

Dr C.H. LINEWEAVER was interviewed by Phil Clarke on 2GB radio (873 AM) about NASA's plans to set up a Moon base (7-minute live interview), Nov.

Dr C.H. LINEWEAVER was interviewed by "Big George" on BBC London 94.9 FM about Mars Global Surveyor's discovery of recent water on Mars (20-minute live interview), which was also broadcast on the Internet at www.bbc.co.uk .

Dr D. RUBATTO was interviewed on SBS-Italian Radio for National Science Week (approximately 5 minutes interview).

Dr R. SALMERON, Colloquium speaker, Research School of Astronomy and Astrophysics, "Jets and outflows in protostellar disks".

Dr R. SALMERON, S peaker, Planetary Sciences Institute Workshop, "Magnetic fields in protostellar disks".

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students from Radford College , 4 April.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students attending the Siemens Summer School, 6 October.

Earth Environment

Dr S. EGGINS was invited to a workshop on laser ablation ICPMS, Vrije University , Amsterdam , by the Netherlands Research School for Sedimentary Geology, where he presented seminars on 'Fundamentals of Laser Ablation ICPMS' and 'Applications of LA-ICPMS to environmental and climate research'

Dr M.K. GAGAN was interviewed for the ABC television science show, Catalyst, about coral records of submarine groundwater discharge to the Great Barrier Reef . Approximately 5 minute interview with Mark Horstman, broadcast at 8:00 pm 18 May.

Dr M.K. GAGAN contributed information on his coral research for a feature article in the spring edition of the ANU Reporter (Coral seer, ANU Reporter, 37(3): 10-13), written by Simon Couper with the aim of communicating ANU research to the wider public.

Dr M.K. GAGAN jointly hosted with Prof M.T. McCULLOCH and Dr T. Ireland a RSES laboratory information and workshop to visiting academics and students from University of Tokyo , 15 September.

Dr S.D. JUPITER was interviewed on Channel 7 news, Mackay, following fieldwork on the Mackay section of the Great Barrier Reef , 13 March.

Dr S.D. JUPITER presented to Stanford University study abroad students during a workshop in Mackay, QLD, on regional environmental issues, 3 November.

Dr S.D. JUPITER delivered a presentation entitled "History of environmental change in the Mackay Whitsunday region: a case study from the Pioneer catchment" at the ARC Centre of Excellence for Coral Reef Studies 2006 Public Forum, 19-20 October, Townsville, QLD.

Prof M.T. McCULLOCH was interviewed on ABC radio Brisbane regarding Ocean acidification, July.

Prof M.T. McCULLOCH pr esented a talk to visiting academics from Stanford University , Herron Island Queensland , entitled "Coral Reefs: Silent Sentinels of Global Change", 5 February.

Prof M.T. McCULLOCH was interviewed and quoted in an article in the Western Australian entitled "Reef exposes evidence of 4m ocean rise", 10 November.

Prof M.T. McCULLOCH was interviewed by ABC radio Adelaide regarding the fossil coral reef findings, November.

Prof M.T. McCULLOCH was interviewed and quoted in an article in The Sydney Morning Herald entitled "Reef insight on global meltdown on the rocks", 10 November.

Prof M.T. McCULLOCH was interviewed and quoted in an article in The Canberra Times entitled "Oceans can't soak up greenhouse gas emissions indefinitely: geochemist", 7 July.

Prof M.T. McCULLOCH received editorial citation in The Canberra Times, regarding the impact on the oceans' food chain as the marine environment reaches its limit of ability to absorb carbon dioxide, 8 July.

Prof M.T. McCULLOCH presented a paper at the History of the Great Barrier Reef Workshop, Townsville , Queensland , entitled "Coral Reefs and the History of the Great Barrier Reef ", 2 February.

Prof M.T. McCULLOCH attended the Marine and Tropical Sciences Research Facility Workshop in Townsville , Queensland , 16 March.

Prof M.T. McCULLOCH presented a talk entitled "Environmental changes in coral reefs: Back to the future" at the ARC Centre of Excellence Coral Reef Studies Public Symposium, Townsville , Queensland , 19-20 October.

Prof M.T. McCULLOCH jointly hosted with Dr M. GAGAN and Dr T. Ireland a RSES laboratory information and workshop to visiting academics and students from University of Tokyo , 15 September.

Dr P.C. TREBLE was interviewed for the Western Wildlife Newsletter issued by the Department of Conservation and Land Management (January issue) and The Naracoorte Herald (27 July). Her research also featured in the Australian Caves & Karst Management Journal (July issue). Dr Treble attended the British Council INYS workshop on Abrupt Climate Change (ANU) 22-24 February.

Earth Materials

Prof S.F. COX presented a structural geology workshop to geoscientists of Gold Fields Australia Ltd at Kambalda, May 17-18, 2006 . He also presented a lecture course on coupling between fluid flow and deformation to graduate students and staff from various Swiss universities at the University of Geneva , 19-20 September, 2006.

Dr K.A. EVANS was invited to present on 'Synchrotron Applications in the Geosciences' at the synchrotron workshop recently held at MacQuarie University .

Dr M. FORSTER, set up, co-ordinate and chair the 'Australian Noble Gas and Argon User Group' includes University of Queensland , The University of Melbourne, Geoscience Australia and The Research School of Earth Sciences.

Dr M. FORSTER, 1 st Australian Noble Gas and Argon User Group workshop, at RSES. Presented a paper entitled "The Structure and Tectonic Team and Argon Geochronology at RSES".

Dr M. FORSTER, representing 1 st Australian Noble Gas and Argon User Group in a workshop with ANSTO Lucas Heights, Sydney. Presenting RSES needs for future use of OPAL reactor.

Dr J. HERMANN was interviewed on radio SBS (in Italian) about the activities in science week and his personal research.

Dr J. HERMANN supervised two high-school students for a week for the 2006 CSIRO Student Research Scheme.

Dr J.J. KURTZ, 2006 Earth Dynamics conference, 22-24 November, RSES, Australian National University , chaired Auscope Pplates Workshop.

Dr S. MICKLETHWAITE organised the visit of 15 high-school students to RSES, as part of the Siemens Science Experience 2006. This involved a half-hour introduction to Earth Science and laboratory visits to GFD, Experimental Petrology and SHRIMP.

Dr S. MICKLETHWAITE arranged and presented in conjunction with Dr S. RICHARDS a geological workshop for the climbing guides of the Sydney Harbour Bridge Company. This ran for approximately 90 minutes.

Earth Physics

Drs A.McC. HOGG, G.O. HUGHES, Ms M.J. O'BYRNE and Mr Tjipto 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 and Mr Tjipto PRASTOWO introduced a group of undergraduate students from Tokyo University to the research undertaken in the Geophysical Fluid Dynamics Laboratory.

Prof B.L.N. KENNETT gave a number of radio interviews about the tsunami that hit the south coast of Java in July including the ABC (Canberra and Northern Territory), and the Foreign Service of Radio Beijing.

Drs R.C. KERR, G.O. HUGHES, Ms M.A. COMAN and Mr T.J. PRASTOWO introduced participants in the Siemens Science Experience, held in Canberra , to the research undertaken in the Geophysical Fluid Dynamics Laboratory.

Prof K. LAMBECK, as President of the Academy of Science , has provided a number of interviews on television, radio and print during 2006.

Prof K. LAMBECK presented a televised address at the National Press Club on 23 August 2006 entitled "Sea level in a changing climate environment".

Dr A.M. READING appeared on ABC television in connection with air support of deep field science in Australian Antarctic Territory . Dr A.M. Reading wrote the website for POLENET, an international consortium of observational geophysics in the polar regions , approved for the International Polar Year 2007-08.

Dr M. SAMBRIDGE was the lead organizer of the Australian Academy of Sciences , Elizabeth and Frederick White conference on `Mastering the data explosion' 19-21 April 2006, an interdisciplinary meeting attended by national and international scientists from academia, government and industry.

Dr P. TREGONING was the rapporteur for the session "Geodetic observation and the precise reference system for global an regional sea-level measurements" at the World Climate Research Programme Workshop on Understanding Sea-level Rise and Variability in Paris , June 6-9, 2006 .

Dr. W.P. Schellart was interviewed for an article that appeared in *News in Science* from the ABC " *Mountains grow in wind and rain* ", 24 April 2006 .

Dr. W.P. Schellart published a letter in TAG (The Australian Geologist) " *Plate tectonics is not a myth* ", volume 140, pages 40-41, September 2006.

PRISE

Dr G.M. YAXLEY's diamond indicator research was featured in an article in Materials Monthly, a publication of ANU's Centre for the Science and Engineering of Materials.

Dr G.M. YAXLEY was Co-chair of the Scientific Program Committee for Goldschmidt 2006, held in Melbourne in August-September. He also co-convened several symposia and sessions during the conference.

Dr G.M. YAXLEY organised a workshop in the electron microprobe-based Flank Method for measuring Fe^{3+} contents of garnet at RSES. The workshop was conducted by Dr Heidi Höfer from the Institut für Mineralogie and the University of Frankfurt, Germany, and was attended by members of the Earth Materials group at RSES and DEMS.

TEACHING ACTIVITIES

Earth Chemistry

Dr J.J. BROCKS taught Principles of Organic Geochemistry and the History of the Atmosphere and Oceans in the Precambrian (second semester).

Dr T.R. IRELAND taught the Planetary Science Honours course at the Research School of Astronomy and Astrophysics with Dr C. Lineweaver and Dr Paul Francis (Department of Physics).

Dr T.R. IRELAND co-taught Geology 3022 with Professor R. Arculus at the Department of Earth and Marine Sciences.

Dr T.R. IRELAND gave three lectures for the Department of Earth and Marine Sciences first year course 1005.

Dr C.H. LINEWEAVER taught part of the ANU DEMS Planetary Geology Course convened by Dr R. Arculus, 7, 8 and 10 March.

Dr C.H. LINEWEAVER taught three lectures of the Introduction to Astronomy, ASTR1001, convened by Paul Francis, 1 – 3 August.

Dr C.H. LINEWEAVER taught the RSAA Honours course in Planetary Science 7 - 11 August.

Dr C.H. LINEWEAVER presented a lecture "Are We Alone?" at the Macquarie University , Foundation for Astronomy, School of Astronomy 12 - 13 August.

Dr C.H. LINEWEAVER presented a lecture "Are We Alone?" to Year 9 students as part of the National Youth Science Forum, 4 October.

Dr C.H. LINEWEAVER presented a lecture "Our Place in the Universe" for Malcolm Walter's Astrobiology Course, Macquarie University , 6 October.

Dr C.H. LINEWEAVER organised a one-day Planetary Science Institute Research Workshop in honour of David Stevenson, the Jaeger-Hales 2006 lecturer, 24 October.

Dr C.H. LINEWEAVER, convener of the RSAA Summer Scholarship Program 20 Nov 2006 – 3 Feb, 2007 .

Dr D. RUBATTO supervised two Year 12 students within the Students Research Scheme ACT 2006.

Earth Environment

Dr S. EGGINS taught units on seawater chemistry and the properties of seawater in the 1 st year course 'Marine Science for a Sustainable Future' (GEOL 1004), College of Science (first semester); and delivered a lecture on the carbonate chemistry of seawater in the 2 nd year course 'Chemistry of the Earth and Oceans' (GEOL2015).

Dr M.J. ELLWOOD contributed lectures and practicals to the Department of Earth and Marine Sciences 2 nd year course course 'Chemistry of the Earth and Oceans' (GEOL2015).

Dr M.K. GAGAN began a term as official 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.

Dr P.C. TREBLE taught 'Marine Science for a Sustainable Future' practicals (GEOL1004), College of Science (first semester).

Earth Materials

Mr S. BARKER assisted with teaching of the Department of Earth and Marine Sciences 2 nd year Field Mapping course.

Prof S.F. COX taught GEOL2012 Introduction to Structural and Field Geology, GEOL 3005 Exploration Geophysics, GEOL 3002 Structural Geology and Tectonics, and portions of GEOL 1004 and GEOL 1005 in the Department of Earth & Marine Sciences as part of his joint appointment at the Deparrtment of Earth & Maine Sciences and RSES.

Dr K.A. EVANS has co-superivised Pat Harvey and Rikki Bailey (DEMS) on projects .

Dr M. FORSTER supervises an RSES internship student, Jesse Robertson, from Otago University , Dunedin NZ. Student is undertaking project involving microstructural analysis and PT analysis of Blueschist facies rocks from Greece .

Dr M. FORSTER supervised a Leeds University structure and tectonics student, Peter Holland, for joint project at Leeds University and RSES. Research area Broken Hill region, Australia , from 7-11 July.

Dr M. FORSTER supervises a DEMS undergraduate student, Ms Jia Urnn Lee two afternoons a week for work experience. Ms Lee is a prospective summer student, she has been working on GIS maps from Sifnos Greece during 2006. Her summer project for 2006 and 2007 will involve Argon Geochronology of UHP rocks from the Western Alps .

Dr M. FORSTER advise PhD candidates Daniel Viete and Marco Beltrando on argon geochronology for their PhD research.

Dr J. HERMANN taught one hour for first year and four hours of third year metamorphic petrology at DEMS.

Dr J. MAVROGENES coordinated and taught the bulk of the GEOL1005 Earth Science and the Environment course.

Dr C.R.M. McFARLANE helped teach introductory metamorphic geology to the DEMS1003 Spring class.

Mr N. TAILBY – tutored the undergraduate Earth Science course: GEOL1005 – Earth Science and the Environment, Faculty of Science (second semester).

Earth Physics

Dr G.F. DAVIES taught the Physics of the Earth Honours course Plate Tectonics and Mantle Dynamics (PEAT 8001).

Prof R.W.GRIFFITHS, Dr G.O. HUGHES and Dr A.McC. HOGG taught the physics of the Earth Honours course on Ocean Circulation Dynamics (PEAT 8004).

Dr A.McC. HOGG taught a part of GEOL 1004 (Marine Science for a Sustainable Future).

Dr G.O. HUGHES, Dr A.McC HOGG and Pro R.W. GRIFFITHS taught Physics 3034 (Physics of Fluid Flows) and Dr R.C. KERR organized the laboratory component of that course.

Prof B.L.N. KENNETT – Online Course: Imaging the Earth's Interior. Delivered to Master of Contemporary Science, Faculty of Science (first semester).

Dr. N. RAWLINSON taught the Physics of the Earth Honours course Seismology and Seismic Imaging with Dr. Anya Reading, Dr. Maggy Heintz, and Dr. S. Fishwick.

Dr A.M. READING taught the Physics of the Earth Honours course in Seismology (PEAT 8002).

Dr M. SAMBRIDGE taught in the Physics of the Earth Honours course Seismology and seismic imaging (PEAT 8006).

r P. TREGONING was the Honours Convener for the Physics of The Earth honours programme at RSES during 2006.

PRISE

Dr R.A. ARMSTRONG acting as the external supervisor and advisor for two PhD students from Brazil and two PhD students from South Africa .

Dr M.D. NORMAN supervised undergraduate special topics courses for Mr Scott Williams (DEMS, ANU), and supervised postgraduate intern Ms. Nicola Fry.

Dr G.M. YAXLEY has supervised a new PhD student in PRISE, Ms Anja Rosenthal, who is investigating the melting of heterogeneous upper mantle.

HONOURS SUPERVISION

Earth Chemistry

Dr C.M. Allen, with Dr J. Mavrogenes, supervised Mr P. Collett's Honours thesis in DEMS, on the Petrogenesis of the Rössing Uranium Deposit, Namibia .

Dr C.H. LINEWEAVER supervised PhD student Mr D. Grether (UNSW) on statistical properties of exoplanets.

Dr C.H. LINEWEAVER supervised PhD student Mr J. Robles (RSAA) on the classification of the chemical compositions of terrestrial planets.

Dr C.H. LINEWEAVER supervised PhD student Mr C. Egan (UNSW) on various topics in theoretical cosmology.

Dr C.H. LINEWEAVER co-supervised the PhD of Mr G. Kennedy (RSAA) with Dr S. Kenyon (Harvard) and Dr P. Francis (RSAA) on numerical simulations of proto-planetary disks around low mass stars.

Dr C.H. LINEWEAVER supervised Honours student Mr S. Williams, with Prof R. Arculus (DEMS), on the formation of the Earth from Enstatite Chondrites.

Dr C.H. LINEWEAVER co-supervised the MSc of Mr M. Sundaram (RSPhyseSE) with Dr F. Mills (RSPhysSE) on the atmosphere of Venus.

Dr C.H. LINEWEAVER supervised 3 rd year physics research topic by Mr J. Smith on "The Evolution of the cosmic abundances of Elements", February - December.

Dr C.H. LINEWEAVER supervised Summer Research Scholar Ms S. Long (University of Tasmania) on the Circumstellar Habitable Zone.

Dr C.H. LINEWEAVER supervised Summer Research Scholar Ms A. Chopra (University of Western Australia) on the topic "What was the Chemical Composition of the Last Universal Common Ancestor?"

Dr C.H. LINEWEAVER supervised a PhB 3-month project by Honours student, Ms E. Jones on using the phase diagram of water to locate life in the Solar System, December 2006 – February 2007.

Earth Environment

Dr E.J. RHODES supervised the honours project of Ms C. Bolton on the 'Chronology and Palaeoenvironments of the Willandra Lakes , NSW.'

Earth Materials

Mr S. Barker was awarded an Outstanding Student Paper award at the 17 th Fall AGU meeting, San Francisco , USA , December 5-9, 2005 for a paper entitled “Chemical evidence for episodic growth of a fibrous antitaxial calcite vein from externally derived fluid”.

Prof S.F. COX supervised the Honours project of Ms Alexandra Hickey on the internal structure, petrology and geochemistry of the Condenser Dolerite, Kambalda , WA .

Dr J. MAVROGENES supervised the honours project of Pete Collet on the Rossing Uranium Mine in Namibia .

Dr J. MAVROGENES supervised the honours project of Mr N. Tailby on the Spitskopf carbonatite and of Mr M. Stevens on the Plattreef, South Africa .

Earth Physics

Dr G.F. DAVIES supervised Ms. Andreea Papuc's Honours project on the internal activity and thermal evolution of Earthlike planets of different masses.

OTHER MATTERS

Earth Chemistry

Dr V.C. BENNETT was appointed as member of the Earth Sciences review panel for the U.S. National Science Foundation.

Dr V.C. BENNETT, Program Committee, 16 th Goldschmidt Conference, Melbourne, 27 August- 1 September, where she was also co-convenor of a special session on “Earth Evolution 4.5 to 3.5 Ga: Deciphering the Earliest Global Systems”.

Dr I.H. CAMPBELL, Secretary General of the Commission for the Evolution of the Solid Earth, a sub-commission of the International Union of Geological Sciences; councilor of the International Mineralogical Association; 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.

Dr C.H. LINEWEAVER's PhD student, Ms T. Davis, was awarded the UNSW Faculty of Science prize for the best thesis, March 30.

Dr C.H. LINEWEAVER presented a talk “Are We Alone?” to the ANU School of Physics, March 30.

Dr C.H. LINEWEAVER presented a talk “WMAP Third Year Results” at the Feast of Facts, RSAA, March 31

Dr C.H. LINEWEAVER presented a talk “ Astrobiology, Viruses and the Origin of Life" in the Finkel Lecture Theatre to the Curtin School of Medicine, 26 July.

Dr C.H. LINEWEAVER gave a lecture "Cosmoplanetology" to the RSAA Summer Scholars November 28

Dr C.H. LINEWEAVER, Member, Organising Committee for 2006 Goldschmidt Conference held in Melbourne 27 August – 1 September. Co-convenor and Session Chair with Jochen Brocks and Mark Harrison of the Symposium Session: "Cosmochemistry of Habitable Planets".

Dr C.H. LINEWEAVER, Member of the Local Organising Committee of the 5 th Stromlo Symposium Disks, Winds and Jets: from Planets to Quasars, Conference, RSAA, Mt Stromlo, ACT, 4 - 8 December.

Dr C.H. LINEWEAVER organised with P. Davies the conference: Tree or Forest ? Searching for Alternative Forms of Life on Earth, Arizona State University , USA , 17 - 20 December.

Dr C.H. LINEWEAVER chaired the RSAA Colloquia Committee and organised various Planetary Science Institute Lectures.

Dr C.H. LINEWEAVER helped organise the fortnightly Planetary Science Institute Planet Informal Seminars held at RSAA.

Dr D. RUBATTO, Secretary, Association for Research between Italy and Australasia .

Dr D. RUBATTO, Convener, Session on Accessory Phases and Trace Elements, 2006 Goldschmidt Conference, Melbourne, Victoria.

Dr R. SALMERON, Member, Local and Scientific Organizing Committees for the 5 th Stromlo Symposium "Disks, Winds and Jets: From Planets to Quasars", held in the Research School of Astronomy and Astrophysics, ANU.

Dr R. SALMERON, Visiting Fellow, Macquarie University .

Earth Environment

Dr T.M. ESAT is a member of the MUSES-C Task Force of the Australian Academy of Science.

Prof M.T. McCULLOCH, is a counsel member of the Australian Coral Reef Society, and attended meetings on 18 August 2006 .

Prof M.T. McCULLOCH is a member of the governing counsel of the Geochemical Society.

Prof M.T. McCULLOCH, participated Centre of Excellence, Scientific Management Meeting, Townsville, 17 February.

Prof M.T. McCULLOCH, organised the 2006 Goldschmidt Conference fieldtrip on the Great Barrier Reef , far north Queensland , 23 - 28 August.

Dr E.J. RHODES served as the secretary to the ACT branch of the Geological Society of Australia.

Prof B.J. PILLANS, President, Stratigraphy & Chronology Commission, International Union for Quaternary Research.

Prof B.J. PILLANS, Member, Cooperative Research Centre for Landscape Environments & Mineral Exploration.

Prof B.J. PILLANS, President, ACT Branch, Geological Society of Australia .

Prof B.J. PILLANS, Chair, Working Group on Lower/Middle Pleistocene Boundary, International Commission on Stratigraphy.

Earth Materials

Dr M. FORSTER, member of the OHS Committee for RSES.

Dr M. FORSTER, maintains microscope laboratory. Supervise students undertaking micro-structural analysis, preparation of single crystal analysis for micro-drilling and argon geochronology analysis in the Microscope Laboratory and Argon Laboratory for the Structure Tectonic Team at RSES.

Dr J. HERMANN, Organizer of a research theme and convener of session for 2006 Goldschmidt Conference held in Melbourne , Victoria .

Prof I. JACKSON served as a member of the Executive Committee of IASPEI and of the Bid Committee seeking to host the 2011 IUGG General Assembly in Melbourne , and Chair of the Organising Committee for the Annual Condensed Matter and Materials Meeting in Wagga Wagga in February 2007.

Mr I KOVACS received the E. Szadeczky-Kardoss Award from the Hungarian Academy of Sciences for his outstanding publications

Mr I KOVACS received the Mervin and Katalin Paterson Fellowship from the RSES, ANU to carry out H analysis at the Carnegie Institute, Washington , USA .

Dr J. MAVROGENES was the chairman of the Geoscience Curriculum committee of the College of Science .

Prof H. O'NEILL was the Scientific Program Convenor, 16th Annual V.M. Goldschmidt Conference, Melbourne 2006

Earth Physics

Prof R.W. GRIFFITHS served as a member of the Sectional Committee 4 for Earth, Ocean and Atmospheric Sciences, Australian Academy of Science.

Dr A. McC. HOGG was a Member of the Organizing Committee for 17 th Australia New Zealand Climate Forum, 2006, held in Canberra .

Prof B.L.N. KENNETT served as a member of Sectional Committee 4 for Earth, Ocean and Atmospheric Sciences, Australian Academy of Science.

Prof B.L.N. KENNETT, Chair, Geological Society of Australia Specialist Group in Solid Earth Geophysics.

Prof B.L.N. KENNETT, Past-President of the International Association for Seismology and the Physics of the Earth's Interior (IASPEI) and a member of the Finance Committee of the International Union of Geodesy and Geophysics.

Prof B.L.N. KENNETT, Chair of the Australian Academy of Science Committee for the Frederick White Conference Series

Dr A.M. READING is a member of the Scientific Committee for Antarctic Research group of experts on Antarctic Neotectonics.

Dr A.M. READING co-convened a Workshop on Polar Seismology, San Francisco , 12 December 2006 .

D. ROBINSON is a committee member for the ACT Branch of the Australian Society of Exploration Geophysicists

Dr M. SAMBRIDGE, was a member of the AuScope working group on Vision and Integration, formed in response to section 5.13 of the Government's NCRIS strategic roadmap.

Dr P. TREGONING, Australian representative for the International Association of Geodesy (IAG) and member of the Bid Committee for the IUGG to be held in Melbourne in 2011.

Mr J. Dawson, Session Chair, Advances in the realization of global and regional reference frames, IAG/IAPSO/IABO Joint Assembly 2005.

Dr P. TREGONING, Vice President and Science Program Chair, IAG/IAPSO/IABO Joint Assembly 2005 Local Organising Committee.

PRISE

Dr M.D. NORMAN, Chair, Geological Society of Australia Specialist Group in Planetary Geoscience, Chair, Planetary Geochemistry Task Group and Member, Organizing Committee for 2006 Goldschmidt Conference held in Melbourne, Victoria, Chair, Planetary Sciences Working Group and Member, Steering Committee for Australian National Committee for Space Sciences Decadal Plan.