Research School of Earth Sciences Annual Report 2009

Exploding stars, colliding comets, DNA based life on Earth – they all connect in the search for extra-terrestrial life.
Image - Courtesy NASA/JPL-Caltech

THE AUSTRALIAN NATIONAL UNIVERSITY

TABLE OF CONTENTS

Director's Introduction 2009

This is the second year of the augmented Research School of Earth Sciences including the Earth and Marine Sciences Educational Program. A regular traffic proceeds between the Jaeger Building (#61) and the D.A. Brown Building (#47) about ten minutes walk away and it is gratifying to see so many staff engaged with teaching at undergraduate, honours and masters levels. We hope that we can provide the "research-led teaching" that will provide a satisfying and effective experience for our students. The amalgamation of research and teaching functions, for which RSES was a pioneer, has now been accomplished across the whole Science area and the former Faculty has been dissolved. Each of the entities in the College of Physical and Mathematical now has embedded teaching functions.

The fiftieth anniversary of the establishment of Geology at ANU was celebrated in April and we were fortunate that the Foundation Professor D.A. Brown was able to come to join the enjoyable proceedings and make a pointed speech. Unfortunately Prof. Brown passed away in early November, but his name continues attached to the main teaching complex for the Earth Sciences.

The early part of the year was taken up with preparations for an external Review of Geochemistry, Mineralogy and Petrology (interpreted very broadly). We are grateful to the review team of Prof R. Rudnick (University of Maryland), Prof. J. Blundy (University of Bristol), Prof. B. Bourdon (ETH, Zurich), Prof. K. Kyser (Queens University, Canada) and Prof. L: Carter (Victoria University, Wellington, NZ) who spent nearly a week in the School at the end of March having read voluminous material before their arrival. The presentations to the Review were grouped in five major themes that transcended the administrative Research Area boundaries: Cosmochemistry, Isotope Geochemistry, Experimental Petrology, Biogeochemistry and Environmental Geochemistry. The mixed nature of the groups saw some interesting dialogues emerging across the School. The Review Committee was impressed with the quality of work in the School, but provided a number of important suggestions for the future including the importance of maintaining the technical prowess in the School. Many examples of the fine research seen by the Review Committee will be found in the research highlights in this Annual Report.

The Natural Hazards Initiative that received seed funding from the Vice-Chancellor to encourage cooperation with the College of Asia and the Pacific is beginning to develop. The Masters in Natural Hazards will start next year, with both science and social science components, coordinated from the RSES side by Dr S. Pozgay. A centre for Natural Hazards has been established to form a focus for activities within the College of Physical Sciences, and across the University, and this is being steered by Dr P. Tregoning. We have also been fortunate to secure agreement from Geoscience Australia for a joint appointment for Prof. P. Cummins from January 2010, who will bring expertise in tsunamis.

This will be my last report as Director of the Research School of Earth Sciences. My successor, Prof. A. Roberts from the University of Southampton, will take over the position from February 1. The last three years have seen major changes in the School including major reviews in geophysics and geochemistry and the merger with the Department of Earth and Marine Sciences as a result of their review. The changes have coincided with the development of the College structure within the University and the environment in which the School operates has changed considerably. I hope that it can continue to thrive despite budgetary pressures.

B.L.N. Kennett
Director, RSES

Honours & Awards

Professor I.H. Campbell was elected Fellow of the American Geophysical Union.

Mr A. CHOPRA was awarded a $2700 travel grant from the organising committee to present a poster at the 2009 NASA Astrobiology Graduate Conference in Washington, USA.

Mr A. CHOPRA was awarded a $3000 travel grant from RSES and a $800 grant from local organising committee to participate in the 2009 International Summer School of Astrobiology in Santander, Spain.

Ms T.A. EWING was awarded the Geostandards and Geoanalytical Research prize for Session 18f at Goldschmidt 2009.

Mr R. FARLA has received the Paterson Fellowship award 2009.

Prof R. GRÜN was promoted to Level E2.

Ms Ms E. KISEEVA received an ANU travel grant to attend the Goldschmidt 2009 conference in Davos, Switzerland.

Ms J. MAZERAT received the ANU VC's travel grant to support fieldtrip.

Ms J. MAZERAT was awarded a Travel/Conference support by ARCNESS to attend the 8th

NCCR International Climate Summer School.

Mr J. McDONALD received the Best Student Poster – Hydrogeology Category award at the 10th Australasian Environmental Isotope and 3rd Australasian Hydrogeology Conference, Curtin University, Perth.

Emeritus Professor I. McDOUGALL was conferred with an Honorary Degree of Doctor of Science for his significant contributions to the earth sciences over many years at the University of Glasgow's Commemoration Day ceremony, 17 June 2009.

Dr M.L. RODERICK was awarded the 2009 Australasian Science Prize for research on climate change and water availability.

Ms. A. ROSENTHAL received the 2009 Directors award for Scientific Communication, RSES, ANU, September 2009.

Prof. M. SAMBRIDGE delivered the 2009 Lansdowne Lecture at the Univ. of Victoria, BC, Canada.

Prof. M. SAMBRIDGE was awarded the 2009 Price medal of the Royal Astronomical Society, UK.

Mr R. SCHINTEIE received the Vice Chancellor's Higher Degree Research Student Travel Grant (contribution to attend international conference).

Dr S. SOSDIAN received a Distinguished Scholars Fulbright Scholarship for a 1 year appointment at Cardiff University.

Dr G.M. YAXLEY was awarded an Australian Research Council Future Fellowship at RSES from 2010.

Visiting Fellows

Richard Barwick An Antarctic photograph "Hand Chablone" entered on behalf of the Palaegroup RSES in the Gobal warming competition was awarded First Prize in 'ANU Academics section' of the ANU Climate Change 'Capture' Photographic Competition 2009. Prof K. LAMBECK was elected as a Foreign Associate to the United States National Academy of Sciences.

Prof K. LAMBECK was awarded an Officer of the Order of Australia in the Queen's Birthday Honours List.

Prof K. LAMBECK was invited to present the 2009 Clarke Memorial Lecture, Royal Society of New South Wales.

Prof S. R. Taylor was admitted as Companion of the Order of Australia (AC) in a ceremony at Government House, May 4.

Academic Staff

Director and Professor

B.L.N Kennett, MA PhD ScD Cambridge, FAA, FRS

Distinguished Professors:

B.L.N Kennett, MA PhD ScD Cambridge, FAA, FRS

Professors

R.J. Arculus BSC PhD Durham, FAIMM

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

S.F. Cox, BSc Tasmania, PhD Monash

P. DeDekker BA (Geology) MSc (Hons) Macquarie, PhD DSc Adelaide

D.J. Ellis MSc Melbourne, PhD Tasmania

N. Exon, BSc (Hons) NSW, PhD Kiel

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

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

T.R. Ireland, BSc Otago, PhD ANU

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 (to 1 July 2009)

H.St.C. O'Neill, BA Oxf, PhD Manchester, FAA

B.J. Pillans, BSc PhD ANU, HonFRSNZ

M.S. Sambridge, BSc Loughborough, PhD ANU, FRAS

Senior Fellows

V.C. Bennett, BSc PhD UCLA

G.F. Davies, MSc Monash, PhD CalTech

S. Eggins, BSc UNSW, PhD Tasmania

C.M. Fanning, BSc Adelaide

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

M. Honda, MSc PhD Tokyo

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

C. Lineweaver, BSc Munich, PhD Berkeley

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

D.C. McPhail, *BSc. (Hons) MSc British Columbia, PhD. Princeton*

M. Norman, BS Colorado , PhD Harvard

I.S. Williams, BSc PhD ANU

G.C. Young BSc (Hons) ANU, PhD London

Fellows

C. Alibert MS Paris VII, first thesis ENS Paris, State thesis, CRPG, Nancy (from 17 August 2009)

Y. Amelin, MSc, PhD Leningrad State University

R. Armstrong, BSc MSc Natal, PhD Witwatersrand

J.J. Brocks, Dip Freiburg, PhD Sydney

J. Hermann, Dip PhD ETH Zürich

A.M. Hogg, BSc ANU, PhD UWA

G. Hughes, BE ME Auckland, PhD Cambridge

B.N. Opdyke, *AB Columbia, MS PhD Michigan*

N. Rawlinson, BSc PhD Monash

M.L. Roderick BAppSc QUT, PGDipGIS Qld, Phd Curtin

D. Rubatto, BSc MSc Turin, PhD ETH

H. Tkalcic, Dip Engineering in Physics, Zagreb, PhD California

P. Tregoning, BSurv PhD UNSW

G. Yaxley, BSc PhD Tasmania

Research Fellows

L. Ayliffe, BSc (Hons) Flinders, Graduate Dipolma (Oenology) Adelaide, PhD ANU

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

M. Ellwood, BSc (Hons) Otago, PhD Otago

S. Fallon, BA MS San Diego, PhD ANU

M. Forster, BSc MSc PhD Monash

O. Nebel, Diplom Geololge Dr. rer. nat. Munster, (from 2 March 2009)

J. Trotter, BSc MSc Macquarie, PhD ANU (to 1 July 2009)

Postdoctoral Fellows:

P. Arroucau, PhD Nantes University (to 4 September 2009)

M. Aubert, PhD, Université du Québec, Institut National de la Recherche Scientifique

M.A Bonnardot, MSc De Savoie, PhD Nice-Sophia Antipolis (to 24 June 2009)

K. Fitzsimmons, Bsc (Hons), Dip Modern Languages Melbourne, PhD ANU

A. Halfpenny, M.E.Sc PhD Liverpool,

F. Jenner, BSc (Hons) Oxf Brookes, PhD ANU (to 1 April 2009)

J. Mallela BSc (Hons) Leeds, MSc Heriot-Watt, PhD Manchester Metropolitan (from 3 February 2009)

L Martin BSc (Hon) MSc Paris XI, PhD Henri Poincare University (from 16 March 2009)

S. Pozgay, BA Boston A.M PhD Washington

M. Salmon, BSc (Hons) PhD, Victoria University of Wellington

E. Saygin BEng-Istanbul Technical University, PhD ANU (from 1 July 2009)

E. Vanacore BS Geological Sciences Virginia Tech , PhD Rice (from 3 August 2009)

M. Ward, BSc (Hons) Florida, C.A.S Cambridge, PhD Florida State

B. Walther, B.A B.S Texas, PhD Woods Hole Oceanographic Institution (to 27 June 2009)

M.H. Wille, Dimp Geosciences, Muenster, PhD Bern

J Zhang (to 1 August 2009)

Senior Visitors

K.S.W. Campbell, MSc PhD Queensland, FAA *

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

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

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

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

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

R. Rutland, BSc, PhD London, FTSE*

S.R. Taylor, *BSc (Hons) MSc New Zealand, PhD Indiana, MA DSc Oxford, HonAC*

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

* Emeritus Professor

Research Officers

A.G. Christy, BA (Hon) MA PhD Cambridge

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

S. Hart BSc (Hons) Melbourne (from 1 June 2009)

P. Holden, BSc Lancaster, PhD St. Andrews

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

G. Luton, Bachelor of Surveyor UNSW

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

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

J. Shelley, BSc, MSc (Geology), University of Canterbury NZ

S. Sosdian, B.Sc. Monmouth, Ph.D. (2008) Rutgers (from 1 September 2009)

Research Assistants

A. Arcidiaco, BAppSc GradDip SAInst

B.J. Armstrong, BSc UNISA

R.W.L Martin, BSc ANU (to 4 July 2009)

C. Tarlowski, MSc Moscow, PhD Warsaw (to 1 August 2009)

Post-Graduate Students

PhD Candidates

A. Arad, BSc (Hons) ANU

C. Augenstein, BSc MSc ETH-Zurich

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

F. Beavis, BA/BSc (Hons), ANU

G. Bell

R. Berdin, BSc MSc Philippines

T. Bodin, MSc Louis Pasteur University

K. Boston, BSc (Hons) ANU

R. Brodie, BSc QLD

J. Brownlow, BSc (App Geology), UNSW

B. Choo, BSc Murdoch Univ

A. Chopra, BSc Univeristy of WA, BSc (Hons) ANU

A. Clement, BSc (Hons) Melbourne University

M. Coman, BSc (Hons) ANU

M. Crawford, BSc (Hons) UQ

A. Cross, BAppSc GDipAppSc MAppSc Canberra

N. Darrenougue, BSc MSc University of Bordeaux

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

A. De Leon, BSc (Hons) University of Melbourne

J.P. D'olivo Cordero, MSc UABC Mexico

G. Estermann, MSc Vienna

T. Ewing, BSc (Hons), MSc University of Canterbury

R. Farla, Doctoraal Degree Utrecht University

B. Frasl, BSc MSc Univeristy of Leoben

C. Gouramanis, BSc (Hons) La Trobe University, BSc ANU

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

A. Higgins, BSc (Hons) ANU

J. Hoffmann, BA BSc (Hons) Monash University

K. Horner, BSc (Hons) University of British Columbia, MSc Vrije Universteit Netherlands

S. Hui, BSc Australian National University

R. Ickert, MSc (Hons) Simon Fraser University

J. Jasonsmith BSc. (Ecology) - University of Otago; B.App.Sc. (Hons, Environmental Chemistry) - University of Canberra

H. Jeon, MSc Seoul National University

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

J. Jones, Dip Gemmology GAGTL, London, BSc (Hons) Auckland University

J. Kang, BSc MSc Korea University

T. Kelly, BSc University of Tasmania, BSc (Hons) Australian National University

E. Kiseeva, BSc and MSc St Petersburg State Mine Institute

J. Lee, BSc (Hons) ANU

S. Lewis, BSc (Hons) Monash University

H. Li, BSc MSc Peking University

J. Mazerat, BSc MSc Bordeaux University

S. McAlpine, BSc (Hons) ANU

I. McCulloch, BSc UNSW, GradDip ANU

J. McDonald, BSc ANU

S. McKibbin, BSc University of Newcastle

N. Mikkelson, BSc (Hons), ANU BArts, ANU

P. Millsteed, Dip 1 cert in Gemmology ACT Institute of Technology, BSc UC

I. Moffat, BA BSc (Hons) University of Queensland

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

T. O'Kane, BSc (Hons) ANU

A. Papuc, BSc (Hons) Australian National University

J. Park, BSc MSc Korea University

C. Pirard, BSc, MSc University de Liege

L. Richardson, BSc (Hons) ANU, MSc Queens University Canada

J. Roberts, BSc (Hons) ANU

J. Robertson, DipABRSM (Piano Perf) Royal Schools of Music, BSc (Hons) University of Otago

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

J. Rogers, B.Sc. (Maths) UK, B.A. (anthropology) ANU, B.Sc (Hons) (geology) ANU

A. Rosenthal, MSc University in Freiberg, Germany

R. Schinteie, Cert Arts MSc BSc GripDip University of Auckland

G. Shirtliff BA BSc (Hons) ANU

N. Sinclair, BA/BSc Deakin University, BSc (Hons) ANU

M. Smith, BAppSc, Grad Dipl, MAppSc, Ballarat University

P. Smythe, BSc University of Wollongong, Hons (Physics) ANU

I. Stenhouse, BSc (Hons) ANU

P. Stenhouse, BSc (Hons) University of Otago NZ

A. Stepanov, BSc MSc Novosibirsk State University

K. Stewart, BSc ANU

J. Sutton, MSc B.Tech University of British Columbia, BSc University of Northern British Columbia

N. Tailby, BSc (Hons) ANU

J. Thorne, BSc (Hons) ANU

S. Tynan, BA/BSc (Hons) ANU

D. Viete, BSc BE (Hons) Monash

L. Wallace, BSc (Hons) Univ Tasmania

L. White, BSc (Hons) University of New South Wales

D. Wilkins, BA/BSc (Hons) ANU

J. Wykes, BSc (Hons) MPhil ANU

S. Yuguru, B. Env Sci (HIIA Honours Monash University, MSc University of Papua New Guinea

MPhil Candidates

L. Bean, BSc Dip. Ed. Sydney Uni, Grad Dipl. ANU

G Bell, BA (Hons), BSc ANU

A. Deonath, MSc Indian School of Mines

K. Dowell, BSc (Hons), ANU

I. Itikarai, BSc UPNG Papua New Guinea

A. Maulanai, BSc (Hons) Hasanuddin Univ, Indonesia

M. Nash, B.Comm UC, BSc ANU

R. Shi, BSc China University of Geosciences

M. Umar, BSc Syiah Kuala University, MSc ITB, Indonesia

Honours Students

Geology Honours (PT – part time, MY – mid year start)

Katherine Adena

Kiralee Beavis

Katarina Boljkovac

Mitchell Bouma (MY)

Anna Bradney (MY)

Anthony David (PT)

Nicholas Dyriw

Brendan Hanger

Kent Inverarity

Kelly James

Jonathon Knight (MY)

Aimee Komugabe

Carina Lee

Rhiannon Mann (PT)

Rebecca Norman (MY)

Ailsa Robertson (MY)

Dominique Tanner

Claire Thompson (MY)

Graduate Diploma Student

Tessa Hatlelid

Masters Students

R. Costelloe

Jingming Duan

A. Fleming

A. Hanna

J. Hill

R. Jack

D. Jaksa

L. Jones

H. Josef

M. Knafl

A. Lewis

M. Maldoni

R. Morris

A. Owen

E. Saygin

S Tatham

G. Torr

L. Wang

PhD Theses Submitted

Rose Berdin - Coral Records of El Niño and Tropical Western Pacific Climate Through the Holocene Epoch. Supervisor: Dr Michael Gagan. Advisors: Prof Malcolm McCulloch, Dr John Chappell, F.P. Siringan, Atsushi Suzuki.

Andrew Cross - SHRIMP U-Pb Xenotime Geochronology and its Application to Dating Mineralisation, Sediment Deposition and Metamorphism. Supervisor: Dr Ian Williams. Advisors: Prof Brad Pillans, Dr Daniela Rubatto, Tim Harrison, David Huston.

Christos Gouramanis - High Resolution Holocene Palaeoenvironmental and Palaeoclimatic Changes Recorded in Southern Australian Lakes Based on Ostracods and their Chemical Composition. Supervisor: Patrick De Deckker, Advisors: Dr Peter Jones, John Dodson, Stuart Halse.

John Rogers - Late Quaternary Radiolarians as Proxies for Past Environmental Conditions in the Eastern and Southern Sectors of the Indian Ocean. Supervisor: Prof. Patrick De Deckker, Advisors: Dr George Chaproniere, Dr Michael Ellwood, Dr Stephen Eggins.

Anja Rosenthal - Exploring the melting behaviour of the Earth's heterogeneous upper mantle. Supervisors: Dr. Gregory M. Yaxley, Prof. David H. Green, Advisers: Dr. Joerg Hermann, Dr. Carl Spandler

Michael Shane Smith - The Geochemistry of Alkaline Salt-Affected Soils. Supervisor: Dr DC "Bear" McPhail, Advisors: Dr Dirk Kirste, Dr Barry Croke, Dr John Field, Dr John Chappell, Dr Mirko Stauffacher.

Nicholas Tailby - New Experimental Techniques for Studying: (1) Trace Element Substitution in Minerals, and (ii) Determining S-L-V Relationships in Silicate-H2O Systems at High Pressure. Supervisor: Dr John Mavrogenes. Advisors: Dr Joerg Hermann, Prof Hugh O'Neill, Prof Richard Arculus.

Daniel Viete - The Nature and Origin of Regional Metamorphism: Observations from the Barrovian Metamorphic Series of Scotland. Supervisor: Prof Gordon Lister. Advisors: Dr Joerg Hermann, William Dunlap, Justin Freeman, Dr Margaret Forster, Grahame Oliver, Louis Moresi, Simon Richards, Geoffrey Davies.

Daniel Wilkins - Comparative Optically Stimulated Lumnescence (OSL) and AMS Radiocarbon Dating of Holocene Lacustrine and Marine Deposits in Southeast and Southwest Australia. Supervisor: Prof. Patrick De Deckker, Advisors: John Dodson, Leslie Fifield, Jon Olley.

Masters Sub-Theses Submitted

Adi Maulana - Petrology, Geochemistry and Metamorphic Evolution of the South Sulawesi Basement Complexes, Indonesia. Supervisors: Andrew Christy, David Ellis, Advisors: Prof. Richard Arculus, Dr. Ulrike Troitzsch.

Students awards

A.L. Hales Honours Year Scholarship: Kelly James
Mervyn and Katalin Paterson Travel Fellowship: Sarlae McAlpine
D.A. Brown Travel Scholarship: Kyle Horner
Robert Hill Memorial Prize: Not awarded
A.E. Ringwood Scholarship: Clemens Augenstein
John Conrad Jaeger Scholarship: Jeremy Wykes

Summer Research Scholarships

Mr A. Boskovic (Australian National University, Canberra) under the supervision of Paul Tregoning
Mr J. Hutchinson (Australian National University, Canberra) under the supervision of Rainer Grun
Mr J. Howe (University of Otago, New Zealand) under the supervision of Michael Ellwood
Ms R. Kamitakahara (Flinders University, South Australia) under the supervision of Graham Hughes
Ms N. Maher (Australian National University, Canberra) under the supervision of Andrew Hogg
Ms K. Vincent (University of Waikato, New Zealand) under the supervision of John Mavrogenes

Student Internships

Ms A. Adair of Australian National University; Supervisor Prof Rainer Grun
Mr O. Koudashev of Australian National University; Supervisor Dr Bradley Opdyke
Ms M. Olin of Australian National University; Supervisor Prof Gordon Lister

General Staff

School Manager
Michael Avent, Grad Cert Mgmnt, Grad Dip Admin, University of Canberra

Executive Assistant to the Director
Marilee Farrer

Building and Facilities Officer
Eric Ward, Cert V Frontline Management, Quest/ANU

Assistant Building and Facilities Officer
Nigel Craddy

Finance Manager
Teresa Heyne, BComm, Deakin University

Finance Officers
Natalie Fearon (Acting)

Human Resources Officer
Nathalie Garrido, Cert III Tourism & Events Management, CIT

Student Officer
Maree Coldrick

School Administrative Assistant and Student Officer
Rebecca Kelly, Cert II Business (Office Administration), QUEST Solutions

Information Technology Manager
Paul Davidson, BSc, MSc, Auckland, PhD, ANU

Information Technology Officer
Duncan Bolt, BSc Sydney
Brian Harrold, BSc ANU
Hashantha Mendis, BInfTech, Deakin University (from 19 October 2009)

Graphics Support Officer
Brad Ferguson, BDesign(Phot) CIT (to 10 January 2009)

Receptionist & Finance Assistant
Josephine Margo

Area Administrators
Earth Chemistry – Robyn Petch
Earth Environment – Susanne Hutchinson, BA, La Trobe University
Earth Materials & Processes – Kay Provins
Earth Physics – Sheryl Kluver, Assoc Diploma in Graphic Communications, Australian Army
Danica Fouarce (Prof Kurt Lambeck), BEnv.Des, BA Hons, University of WA

IODP Administrator
Alena Almassy (to 1 February 2009)
Sarah Howgego (from2 March 2009)

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

Technical Officers
Charlotte Allen, AB Princeton MSc Oregon , PhD VirginiaTech
Anthony Beasley, AssocDip CIT
Nick Best
Brent Butler, Cert III Mechanical Engineering Sydney Institute
Joseph Cali, BAppSc QIT
David Cassar, Adv. Dip of Engineering (Electronics), CIT
David Clark, Cert III Metal Fabrication, CIT, Adv. Dip Engineering (Mechanical) CIT
Aron Coffey
Derek Corrigan
Joan Cowley, BSc ANU
Daniel Cummins, Adv.Dip of Engineering (Electronics), CIT
John D. Fitz Gerald, BSc James Cook, PhD Monash
John Foster, BSc Sydney, MSc PhD ANU
Daniel J Hunt, Adv Diploma Mechanical Engineering (Trainee) to 21 February 2009)
Ben Jenkins, BSc UTS, PhD ANU
Leslie Kinsley, BSc GradDipSc ANU
Harri Kokkonen, Certificate in Lapidary, ACT TAFE, BAppSc (Geology) Canberra College of Advanced Educations
Richard Krege, MSc Australian Defence Force Academy, BSc Charles Stuart University, BE University of Canberra
Andrew Latimore, Bachelor of Engineering (Electronics) and Communications Engineering, University of Canberra
Qi Li
Linda McMorrow, AssocDip Science NTU
Graham Mortimer, BSc PhD Adelaide
Hayden Miller, Advanced Diploma in Mechanical Engineering, CIT
Samuel Mertens, BA (Hons)
Shane Paxton
Anthony Percival
Sisounthon (Tony) Phimphisane
Tristan Redman – Trainee
Eva Reynolds BSc (Hon) ANU (from 5 January 2009)
Hideo Sasaki - Trainee
Scott Savage
Norman Schram, Dip EIE SAIT
Dean Scott, Associate Diploma in Mechanical Engineering, CIT
Heather Scott-Gagan, BSc Sydney
David Thomson
Ulrike Troitzsch Diplom (Technische Universität Darmstadt), PhD ANU
Carlyle Were
Andrew Wilson
Geoffrey Woodward
Igor Yatsevich, BEng Tashkent Polytec Inst, PhD Russian Academy of Sciences
Xiaodong Zhang, PhD LaTrobe

Fitting and Machining Apprentice
Ben Tranter, Cert II in Automotive Radiator Services John Batman Institute of TAFE, Automotive Climate Control / Air conditioning Casey Institute of TAFE

Research Activities 2009

Exploding stars, colliding comets, DNA based life on Earth – they all connect in the search for extra-terrestrial life.
Image - Courtesy NASA/JPL-Caltech

THE AUSTRALIAN NATIONAL UNIVERSITY

Earth Chemistry

Introduction

The chemistry and isotope chemistry of natural materials is highly indicative of provenance and process throughout geological history. Our studies range in time from the earliest solar system through to processes that are actively taking place today, and in scope from planetary systems to individual molecules. Active areas of research centre on planetary studies, metamorphic and igneous geochemistry and geochronology, geochemistry of life processes, and chronology of all processes encompassed.
Most of our analytical work involves detailed analysis on the microscale, or concentrating trace elements from larger samples for high precision analysis. Isotopic systems can reveal both the nature of the processes involved (stable isotopes) as well as the timing of events (radiogenic isotopes), while chemical and molecular abundances can reflect protolith contributions and processes affecting various systems including biologic systems. As revealed in this year's research contributions, analytical work can be applied to topics in tectonics, ore genesis, metamorphic petrology, paleoclimate, paleoecology and regolith dating.

Highlights

Following on from the establishment of the SHRIMP and Chemistry laboratory facilities in J5, the J3 laboratory where SHRIMP II was formerly located, was renovated as a Thermal Ionization Mass Spectrometry laboratory. The Thermo-Finnigan Matt 261 mass spectrometer has been installed and is now operational. The award of a LIEF grant to fund a new Triton mass spectrometer will provide the latest technology for high-precision isotopic analysis of Earth and Planetary materials. Earth Chemistry personnel participated in the Geochemistry, Mineralogy, and Petrology review and enjoyed the opportunity of presenting their research agendas to the committee. Members of Earth Chemistry participated at numerous conferences, in particular Goldschmidt 2009 in Davos, Switzerland, Australian Space Science Conference in Sydney, and the American Geophysical Union Conference in San Francisco, USA.

Personnel

Dr Vickie Bennett was promoted to Associate Professor.

Dr Daniela Rubatto was awarded the Dorothy Hill Prize of the Australian Academy of Science for 2009.

PhD studies were completed by Ryan Ickert.

Postgraduate studies were commenced by Ms Jane Thorne and Ms Barbara Frasl (supervised by Professor Trevor Ireland), Ms Katherine Boston (supervised by Dr Daniela Rubatto), Ms Jia-Urnn Lee (supervised by Dr Marnie Forster), and Mr Aditya Chopra (supervised by Dr Charley Lineweaver).

Dr Tsuyoshi Iizuka, a long-term visitor from the University of Tokyo, was awarded an ARC post-doctoral fellowship to continue his studies in early Earth and planetary systems.

SHRIMP 'keyhole' geochronology: evidence for an extension of the Svecofennian orogenic province into north-eastern Poland

Ian S. Williams[1], Ewa Krzemińska[2] and Janina Wiszniewska[2]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Polish Geological Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland*

The basement rocks of Poland are buried beneath an extensive cover of much younger sedimentary rocks. The thickness of the cover ranges from about 500 m in the east to over 5 km in the west. The broad geological structure of the basement has previously been mapped using magnetic and gravity surveys, supplemented by deep seismic investigations. The only samples of the basement rocks that can be studied directly, however, are drill cores recovered from a limited number of boreholes, mostly drilled to investigate deep geophysical anomalies. As part of a joint research project between RSES and PGI, we are piecing together the geological evolution of the Polish basement using the limited view provided by these irregularly-spaced 'keyholes' into the buried terrane.

Our work initially focused on studies of rocks collected from holes drilled in areas that showed the most pronounced geophysical anomalies, especially magnetic or gravity highs. For example, the rocks beneath Lomza, about 150 km NE of Warsaw, were shown to be part of a late Paleoproterozoic mafic igneous suite; the 'Archean' crystalline basement of the Mazowsze granitoid massif in far NE Poland was shown to be actually of late Paleoproterozoic age; and a belt of rocks from the Warmia area about 50 km SE of Gdańsk, once considered to be high grade metasediments, was shown to be of igneous origin and coeval (possibly cogenetic) with the Mesoproterozoic Mazury Complex to the east.

Over the last two years we have turned our attention to the basement rocks cored away from the geophysical anomalies in areas that are geophysically bland. Such areas are extensive, but the density of coring is relatively low. Drill holes at Jastrzebna and Monki in far NE Poland, for example, intersected a monotonous sequence of metasedimentary rocks possibly representative of the host rocks to the igneous complexes throughout NE Poland.

Superficially the Polish metasediments resemble the Paleoproterozoic metasediments of the Svecofennian Domain exposed to the north in Finland and to the northwest in Sweden. Chemical analyses of the metasediments and SHRIMP U-Pb dating of zircon and monazite have shown that the resemblance is more than superficial—the rocks from Poland are so closely related to those in Finland and Sweden in composition, provenance and metamorphic history that they are probably part of the same orogenic province (Williams *et al*., 2009; Krzemińska *et al*., 2009).

The most compelling evidence that the Polish metasediments are part of the Svecofennian Domain comes from the ages of the detrital zircon cores. The age distribution is distinctive; a main, bimodal zircon population with ages in the range 2.05–1.85 Ga, and a secondary population with ages in the range 3.0–2.6 Ga. The same pattern of ages is seen in the detrital zircon cores from Svecofennian metasediments in Finland and Sweden (Fig. 1).

It is highly likely that the Polish basement metasediments were derived from the same source region as the 'classical' Svecofennian metasediments, and were deposited in the same basin or basin system. The ages of the detrital zircon cores do not match the ages of any known igneous rocks currently exposed within the Baltic Shield, but do match the ages of rocks to the east, indicating their possible derivation from source areas in Sarmatia and adjacent regions.

The next step will be to explore further afield to find out how far the Sevecofennian basement extends.

Williams, I.S., Krzemińska, E., Wiszniewska, J. (2009) An extension of the Svecofennian orogenic province into NE Poland: Evidence from geochemistry and detrital zircon from Paleoproterozoic paragneisses. *Precambrian Research* **172**: 234–254.

Krzemińska, E., Wiszniewska, J., Skridlaite, G., Williams, I.S. (2009) Late Svecofennian sedimentary basins in the crystalline basement of NE Poland and adjacent area of Lithuania: ages, major sources of detritus, and correlations. *Geological Quarterly* **53**: 255–272.

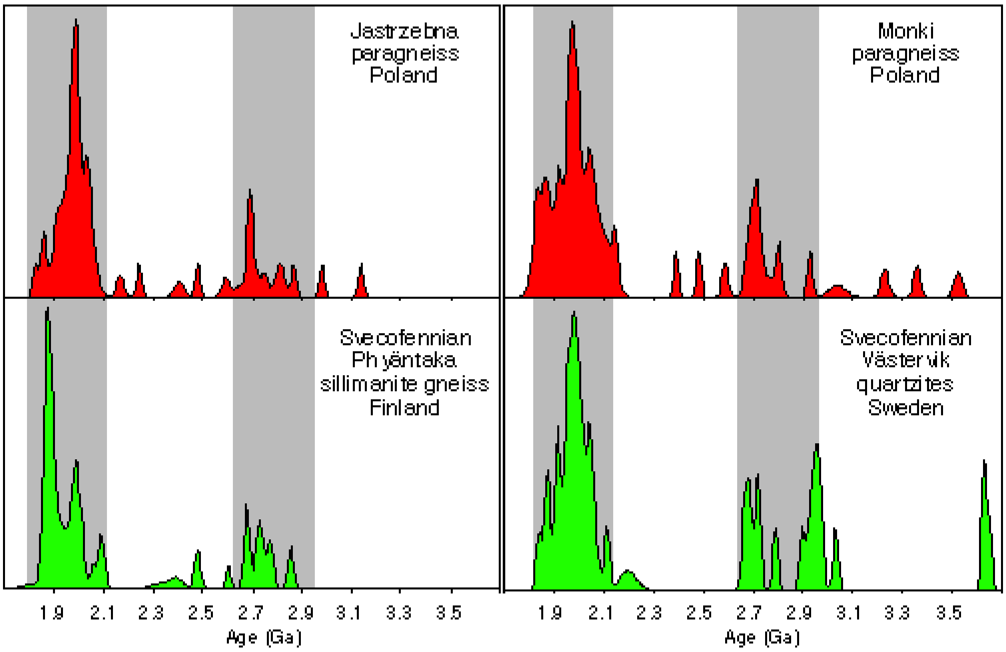


Figure 1. Relative probability plots of the $^{207}Pb/^{206}Pb$ ages of zircon cores from metasediments from NE Poland, and representative Svecofennian metasediments from Finland and Sweden, showing the close similarities between them.

Experimental study of monazite/melt trace element partitioning

Aleksander Stepanov, Daniela Rubatto and Joerg Hermann

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

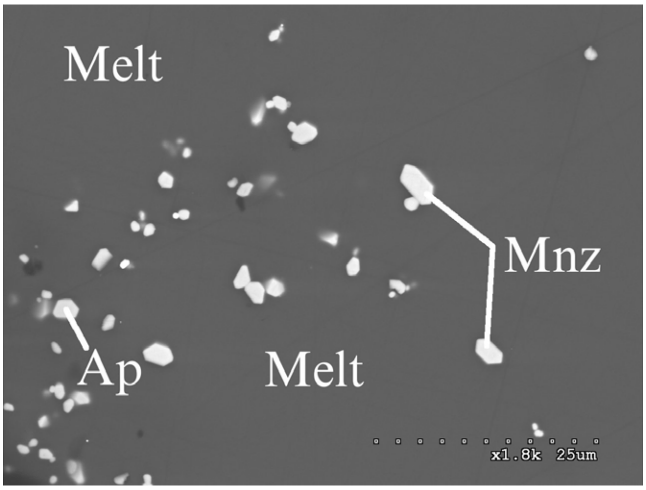


Figure 1. Texture in experimental run at 1000 ^{o}C, 40 kbar.

Monazite is a common accessory mineral (LREE,Th)PO4. In Earth Science monazite is relevant for Th, U-Pb geochronology and as host of REE, Th and U during metamorphism and melting.

Monazite is an ideal mineral for Th,U-Pb dating because of its high closure temperature and low common lead content. However, the interpretation of monazite ages may be hampered by limited knowledge of its behavior during metamorphic and igneous processes. One powerful method for the interpreting the relationship between age data and petrological events is linking accessory mineral ages with garnet growth zones through the equilibrium partitioning of trace elements. Partitioning of trace elements between monazite/garnet and monazite/melt have so far been estimated only in natural samples.

During melting the presence of monazite as a residual phase could produce enrichment in the restite of elements that are strongly incompatible in other circumstances (Rapp et al, 1987). Monazite also plays a critical role in the fractionation of REE relative to one another and could be responsible for granites with unusual REE patterns. Recently monazite has been identified as an important player in the melting of sediments withing subduction zones and magma generation at subarc depths (Hermann and Rubatto, 2009).

Experimental determination of monazite-melt partitioning was performed at conditions revalent for melting within the crust and in subduction zones. The starting composition was granite with about 8 % H2O and doped with trace elements. Experiments in piston-cylinder press were performed at 10 kbar over the temperature range from 750 and 800 to 1300°C with steps of 100°C. Additionally, a pressure series form 10 to 50 kbar with steps of 10 kbar was conducted at 1000°C. In order to reach conditions relevant to subduction zone environments, additional temperature series is planned at 30 kbar.

Experiments at temperature >800°C and pressure <30 kbar produced melt with monazite. At lower temperature additional quartz and plagioclase appeared in the experimental charges. At higher pressures, kyanite, coesite, jadeite, apatite, zircon and allanite start to crystallize. Monazite was produced in all experiments but with very small grain size (<5µm), making it impossible to determine the trace element composition of monazite alone. As alternative, LA-ICP-MS analyses of monazite-melt mixes were performed and the monazite composition was calculated using regression analysis.

Preliminary results show that monazite solubility decreases of a factor of two at pressures above 20 kbar. However, because high pressure experiments produced different melt composition and higher water content, changes in monazite solubility are likely a combination of pressure and melt composition. Study of monazite composition have shown that only REE, Th, U, Y and As strongly partitioning into monazite, whereas other trace elements (Li, Be, B, Sc, Ti, V, Mn, Sr, Zr, Nb, Ba, Hf, Ta, Pb) have a partitioning coefficients lower than 10. Monazite has the highest preference for LREE, with a decrease in partitioning coefficients for Sm, MREE and HREE. Partitioning for Th is much higher than for U.

We are made of star dust

Aditya Chopra and Charles H. Lineweaver

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

One way of answering the question 'What is life?' is to look at the ingredients of life on Earth. In terms of chemical elements, oxygen, carbon, hydrogen and nitrogen, make up 96.8 ± 0.1% of the mass of life (based on humans and bacteria). Phosphorus and sulfur together make up 1.0 ± 0.3%. The remaining 2.2 ± 0.2% is dominated by potassium, sodium, calcium, magnesium and chlorine, while 0.03 ± 0.01% is attributed to trace elements such as iron, copper and zinc.

All atoms that are or have been part of living matter on Earth have either been produced during big bang nucleosynthesis or in different processes of the stellar nucleosynthetic pathways that take place in stars. Around ~4.5 billion years ago our Sun was formed out of a collapsing molecular cloud that was polluted by earlier stellar processes and a proto-planetary disk that was made of the remaining dust gave rise to terrestrial planets like the Earth.

While the elemental composition of planets reflects to a large extent the composition of the Sun, relative to the Sun, the Earth is depleted in the most volatile elements hydrogen, helium and the noble gases. These elements were swept away by the solar wind from the region of the solar nebula where rocky planets like Earth formed. However, later input of volatile elements from chondritic material, comets and other objects from the outer solar system led to a surface crust on the Earth which exhibits elemental abundances more like the Sun depleted in volatile elements than the bulk Earth.

Life does not reside in the mantle or the core of the Earth and so its elemental abundances are more reflective of abundances in the crust (specifically the biosphere) than abundances in the bulk Earth.

Figure 1. Exploding stars, colliding comets, DNA based life on Earth - they all connect in the search for extra-terrestrial life.

Since, the abundance of most elements in life forms and their environments on Earth follow cosmic abundances (as represented by the Sun), perhaps extraterrestrial life on Mars or moons of Jupiter and Saturn or perhaps extra-solar planetary systems, will also exhibit elemental abundances similar to those found in life on Earth.

Aditya Chopra and Charles H. Lineweaver (2009), The major elemental abundance differences between Life, the Oceans and the Sun, in Australian Space Science Conference Series: 8th Conference Proceedings. Full Refereed Proceedings DVD, National Space Society of Australia Ltd, ISBN 13:978-0-9775740-2-5
www.tinyurl.com/ACCL08

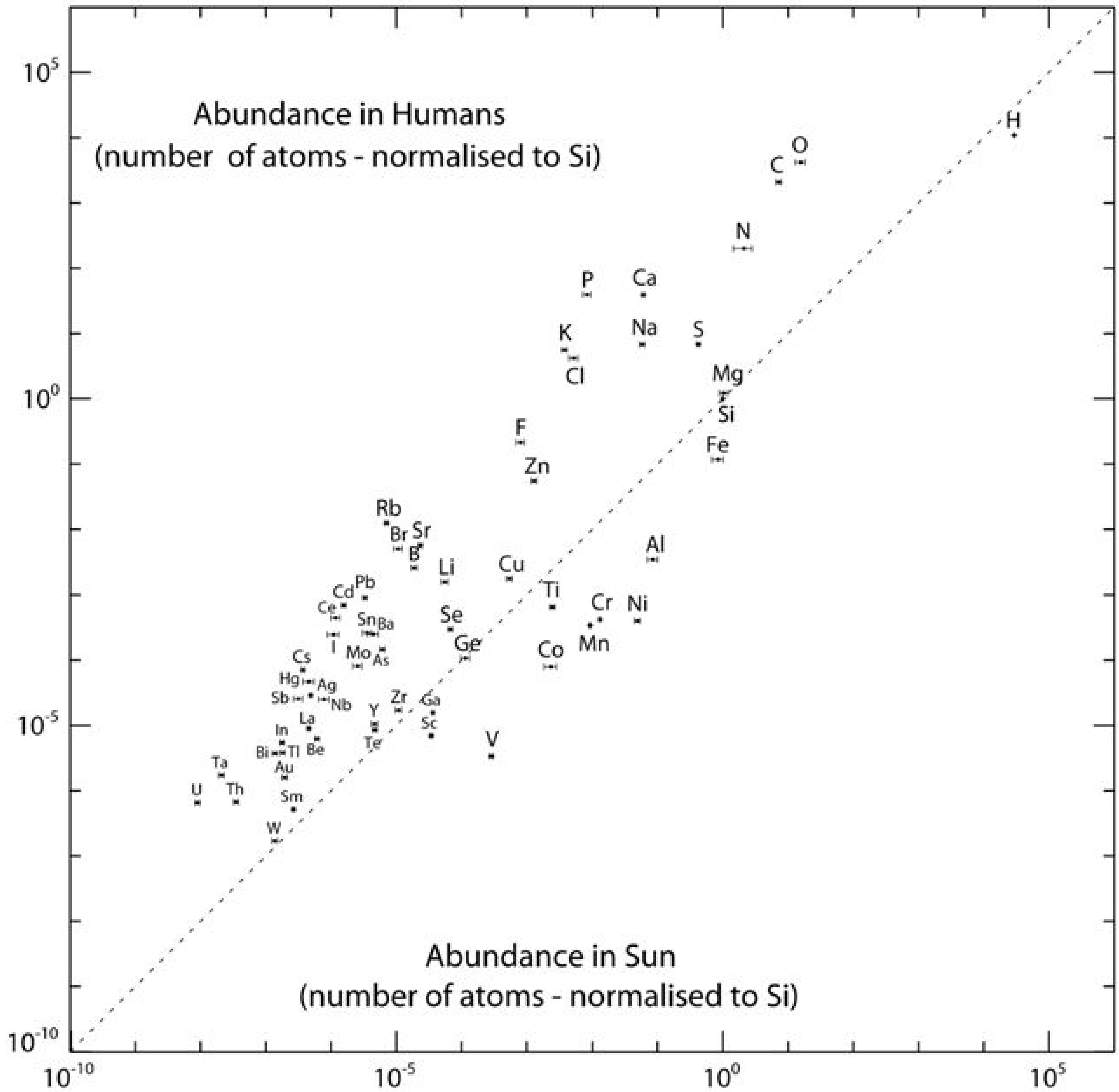


Figure 2. The positive correlation between elemental abundances (by number of atoms) in life (as represented by humans) and the Sun.

Sugar, spice and everything nice... The search for elemental ingredients of life

Aditya Chopra, Charles H. Lineweaver, Jochen J. Brocks and Trevor R. Ireland

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

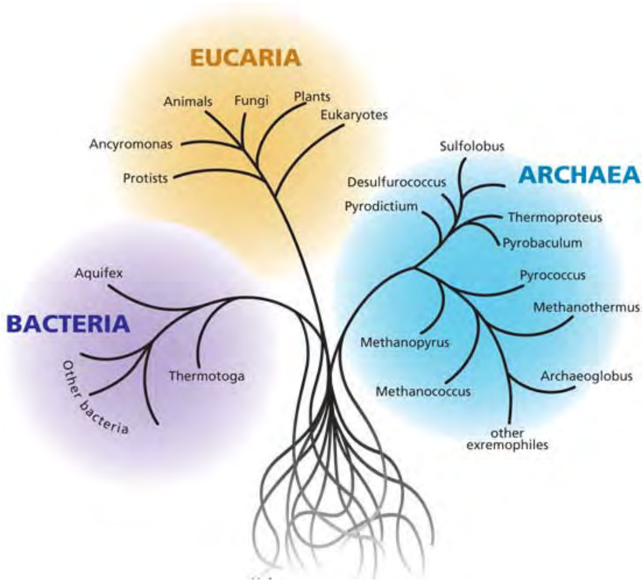


Figure 1. The Tree of Life diverged early in Earth's history into three domains. Humans, animals, plants, fungi are all kingdoms within Eucaria.

We are finding out if the most primitive organisms on Earth started out with basic ingredients of life and became more complex as they evolved. The findings from the research, could give hints on where and how life got started on Earth.

Over the next few years, we will collect samples of bacteria and archaea (a very ancient form of bacteria). The samples will include including extremophiles, the life forms that thrive in punishingly hot or acidic environments. We then use atomic emission spectrometry, mass spectrometry and elemental analysers to know precisely what these life forms are made of. We will measure the abundances of about half of the 80 most abundant stable elements in nature including major elements such as carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus and trace elements such as sodium, potassium, calcium, iron and copper.

With this information we will find out if the most ancient life forms are made of fewer elements than the life forms that appeared on Earth more recently. Just as a novice chef starts baking a cake with simple ingredients like flour, eggs and sugar, life may have started with the most abundant (or bio-available) elements. These could be elements like carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus and ions like calcium or boron to stabilise its structures, and catalytic metals like iron.

Later, life began to accessorise with more elements like bromine and selenium – like an experienced chef who has learnt to use vanilla, cinnamon and the rest of the spice rack. This increase may be in response to changes in the bioavailability of elements in environments such as the oceans – particularly during the great oxidation event ~2.4 billion years ago.

Aditya Chopra, Charles H. Lineweaver, Jochen J. Brocks and Trevor R. Ireland, Palaeoecophylostoichiometrics: Searching for the Elemental Composition of the Last Universal Common Ancestor, in Australian Space Science Conference Series: 9th Conference Proceedings (*submitted*)

Website
http://www.mso.anu.edu.au/~aditya/publications.html

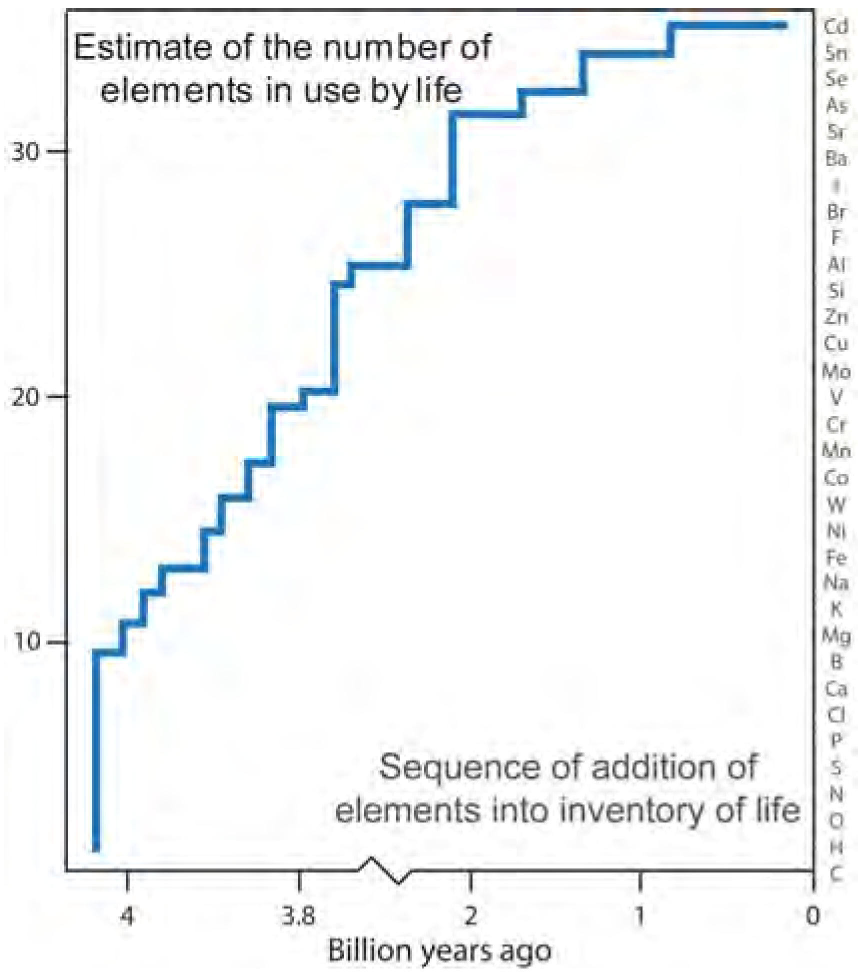


Figure 2. A possible sequence of increasing diversity of elements used by life.

Testing the significance of hafnium isotopes in rutile across a crust-mantle transition

Tanya Ewing, Daniela Rubatto and Jörg Hermann

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

The study of metamorphic rocks that have been brought to the Earth's surface gives us an insight into processes that are occurring today in parts of the Earth we cannot observe – such as deep in the Earth's crust, under mountain belts, and in subduction zones. Metamorphic histories are often complex, with multiple phases of deformation and/or heating. A powerful tool for unravelling the story of metamorphism is the study of isotope systems, such as hafnium (Hf).

Hf isotopes can be accurately measured in-situ for the metamorphic mineral rutile using our laser ablation multi-collector inductively coupled mass spectrometer (LA-MC-ICPMS). Hf isotope information is combined with U-Pb ages obtained by SHRIMP, and trace element information measured by LA-ICPMS. The formation temperature of rutile is calculated according to the Zr-in-rutile thermometer of Watson et al. (2006). Each of these techniques can be applied in sequence to a single rutile grain, providing linked age, temperature, chemical and isotopic information.

We aim to assess the significance of Hf isotopes in rutile, and how their behaviour in response to pressure, temperature and fluids compares to that of Hf isotopes in zircon. A study of the Ivrea-Verbano Zone in northern Italy will provide a "natural laboratory" to investigate these questions.

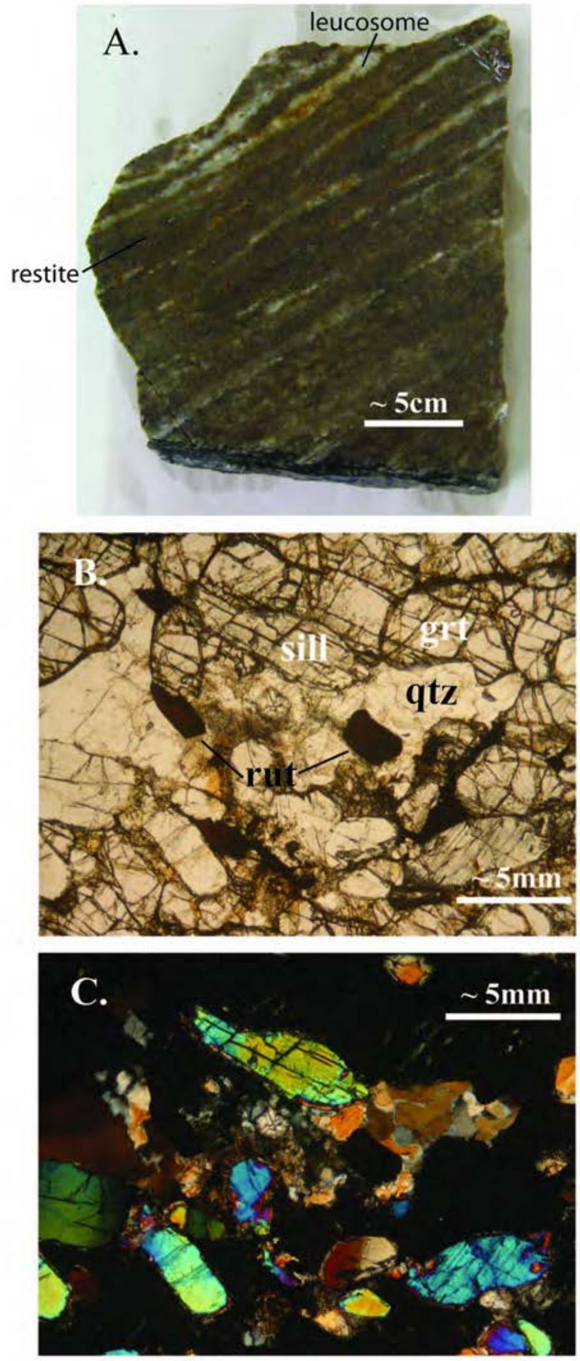


Figure 1. Rutile-bearing metapelite (A) in hand specimen; note light layers of leucosome (melt) and dark layers of restite (the rock left after melt extraction). (B) Under microscope in plane-polarised light, showing rutile. (C) Under microscope in cross-polarised light.

The Ivrea-Verbano Zone (IVZ) preserves a spectacular section through the lower crust and mantle that exposes interlayered metapelites (metamorphosed sedimentary rocks) and metabasites (metamorphosed basic igneous rocks) which have undergone metamorphism at high temperatures and pressures. The higher grade end of the section underwent significant partial melting, forming rutile in metapelites. Partially-digested slivers of metapelitic material are found within the underlying Mafic Complex. In the field, a wide range of degrees of mixing between the mafic igneous and metapelitic end-members can be observed.

Rutile-bearing samples collected from the IVZ record varying degrees of mixing between metapelite and gabbro; a range of pressures and temperatures; and variable amounts of overprinting by a later, lower-temperature metamorphic event. The presence of metamorphic zircon rims in some samples allows comparison of the behaviour of Hf isotopes in the two minerals – but their absence in other samples emphasises the relevance of a thorough understanding of Hf isotopes in rutile.

Preliminary data indicate that the Hf isotope signature of rutile may be very robust, even in an area that has seen high temperatures, mixing of different lithologies to varying degrees, and significant fluid influx.

Watson EB, Wark DA, Thomas JB (2006) Crystallization thermometers for zircon and rutile. *Contributions to Mineralogy and Petrology*, 151: 413-433.

Genesis of granites: U-Pb geochronology and O-Hf isotopic analyses

Carboniferous-Permian granites across the boundary between the Lachlan and New England fold belts

Heejin Jeon, Ian Williams and Vickie Bennett

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

Since significant fractionation of ^{18}O from ^{16}O occurs at low temperature, the $\delta^{18}O$ value of granite (7-12 ‰ in general) could be used to determine whether the source material of magma experienced low-temperature geologic processes at surface. However, the bulk $\delta^{18}O$ value could be easily affected by subsequent geologic events, and magma differentiation (even in a closed system) as the proportion of quartz and feldspar which tend to concentrate ^{18}O in more felsic magma is changed, whereas the $\delta^{18}O$ value of zircon retains constant (Valley, 2003). That is, igneous zircons potentially preserve the oxygen isotopic compositions equilibrated with the magma from the time of their crystallization. Therefore, the $\delta^{18}O$ of zircon can be used to trace relative contribution of new, mantle-derived crust ($\delta^{18}O_{zircon}$ value of 5.5 ‰) and crust that has chemically evolved and been reworked ($\delta^{18}O_{zrc}$ value of 12 to 14 ‰; Valley, 2003). In addition, development of in-situ analyses technique using SHRIMP II (Ickert et al., 2008) enables us to identify the timing of each stage of $\delta^{18}O$.

Based on the ^{176}Lu-^{176}Hf isotopic system having slightly more incompatible daughter than parent, crust which derived from partial melts of mantle contains lower Lu/Hf ratio than residual mantle, and then $^{176}Hf/^{177}Hf$ ratio in crust increases slower than in mantle where ^{177}Hf accumulates faster. The $^{176}Hf/^{177}Hf$ ratios of crust (lower) and mantle (higher) which diverge are generally represented as negative and positive εHf values, respectively. The notation of εHf expresses the difference between the initial $^{176}Hf/^{177}Hf$ ratio of rocks and the CHUR (CHondritic Uniform Reservoir) which probably coincide with a bulk earth. Therefore Hf isotopic study of granite could be used to determine crustal and/or mantle sources of magma based on their distinct εHf values, and crustal residency and continental growth based on the Hf model age for the formation of the granite or its precursor from the CHUR. Considerable amount of HfO_2 (mostly <3 wt.%) and hardly involved parent Lu in zircon (significantly low Lu/Hf) enables this mineral to well preserve the initial Hf isotopic composition. In-situ Hf analyses of each growth domain for magmatic zircons have been carried out using LA-MC-ICP-MS (Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometry). The results could be combined with SHRIMP based U-Pb ages and O isotopic composition on the same analyzed grains to determine nature of the source magma and crustal residence ages which might not correspond to the emplacement ages (Hawkesworth and Kemp, 2006; Kemp et al., 2007).

To provide a fresh approach in granite genesis, a new micro-analytical technique - *in-situ combined isotopic analyses of U-Pb, O and Hf for zircons* from granites which reserve the information about the nature of protolith, it is possible to determine most reliable emplacement ages of each plutonic body, relative contribution of recycled and/or pre-existed crustal material and juvenile/mantle derived component to magma which give rise to the granites, and crustal residency of source rocks where each zircon domain grew. Particularly, my project focuses on the granites across the boundary between the Lachlan (Carboniferous) and New England (Permian) fold belts in the southeastern Australia. So far, the preliminary results of U-Pb and O isotopic data of zircons reveal that: (1) ages (340-325 Ma) and $\delta^{18}O$ (6.5-7.8 ‰) show slight negative correlation and inherited zircons imply possible crustal assimilation consistent with O isotopic inter-granite heterogeneity in the Lachlan Fold Belt; (2) there is no inherited zircons in the late Permian I-type granites in the New England Fold Belt (same range in $\delta^{18}O$ with the Lachlan Carboniferous granites); and (3) even S-type granites (early Permian and > 11 ‰ in $\delta^{18}O$) contain only late Paleozoic inherited zircons probably from the volcanogenic sediments of the same fold belt.

- Ickert, R.B., Hiess, J., Williams, I.S., Holden, P., Ireland, T.R., Lanc, P., Schram, N., Foster, J.J., and Clement, S.W., 2008, Determining high precision, in situ, oxygen isotope ratios with a SHRIMP II: Analyses of MPI-DING silicate-glass reference materials and zircon from contrasting granites: Chemical Geology, v. 257, p. 114-128.
- Hawkesworth, C.J., and Kemp, A.I.S., 2006, Using hafnium and oxygen isotopes in zircons to unravel the record of crustal evolution: Chemical Geology, v. 226, p. 144-162.
- Kemp, A.I.S., Hawkesworth, C.J., Foster, G.L., Paterson, B.A., Woodhead, J.D., Hergt, J.M., Gray,

C.M., and Whitehouse, M.J., 2007, Magmatic and crustal differentiation history of granitic rocks from Hf-O isotopes in zircon: Science, v. 315, p. 980-983.

- Valley, J.W., 2003, Oxygen Isotopes in Zircon, in Hanchar, J.M., and Hoskin, P.W.O., eds., Zircon, Volume 53: Reviews in Mineralogy and Geochemistry, p. 343-380.

The Succession of Oxygen Producers in Early Oceans

A study of the world's oldest molecular fossils

JOCHEN J. BROCKS, AMBER JARRETT, RICHARD SCHNINTEIE and JANET HOPE

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

Figure 1. PhD Student Richard Schinteie sprays 800 million year old, carbon-rich carbonates with diesel oil: "This is the only way to find steranes in these ancient rocks", he justifies his action

Figure 2. PhD students Ben Kotrc and Jessica 'JC' Creveling (Knoll Lab, Harvard University) and Richard Schinteie (ANU) enjoying field work in Alice Springs. The rocks in the background are the Neoproterozoic to Cambrian McDonald Ranges spanning almost the entire time range of our biomarker study.

The dead biomass of organisms in the oceans is almost completely remineralised back to CO_2, water and nutrients. Only a small fraction of dead organic carbon becomes permanently buried in sediments. However, this small fraction determines the redox state of the surface of our planet: for every mole of CO_2 buried as organic C, one mole of O_2 is released into the atmosphere. A major factor contributing to carbon burial and, thus, atmospheric oxygen levels, is the type of organic matter produced by the dominant photosynthetic organisms in the world oceans and on land. For instance, the emergence of land plants led to the formation of enormous coal deposits and increasing atmospheric O_2 levels in the Carboniferous.

In the Proterozoic, the time between 2,500 and 542 million years (Ma) ago, land plants had not yet evolved, and atmospheric oxygen was controlled by single-celled primary producers such cyanobacteria and various groups of algae. Shifting regimes of these organisms in the oceans must have had dramatic effects on the atmosphere and carbon cycle, possibly triggering the late Proterozoic Snowball Earth events and an increase of oxygen that may have permitted the evolution of animals some 600 Ma ago. The most dramatic regime change in the oceans was probably the shift from cyanobacteria to algae. Most cyanobacteria produce high proportions of digestible carbohydrates, whereas algae often contain resistant cell wall material with a high chance of burial [1].

To determine when Earth's early oceans were dominated by cyanobacteria, and when and why these organisms were displaced by successive groups of algae, we studied molecular fossils (biomarkers) extracted from sedimentary rocks 2,800 to 500 million years in age. Biomarkers are the hydrocarbon fossils of biological molecules such as lipids. For instance, algae produce a wide variety of steroids, and the fossils of these steroids, the steranes, can be preserved as hydrocarbon skeletons in sedimentary rocks for hundreds of millions of years old.

In contrast to previous studies, and to our great surprise, we found that biomarkers of eukaryotic algae are rarely detected in rocks older than 635 Ma [2, 3], the time before the first animals appear in the geological record. Also, when present in ancient rocks, the steranes were very distinct from later periods in Earth's history. The record of sedimentary sequences with demonstrably indigenous biomarkers is still exceedingly patchy. However, it appears that complex algae may have displaced cyanobacteria as the rulers of the carbon cycle roughly at the time when increasing oxygen levels permitted first animals to evolve.

A new project that was generously funded by the Australian Research Council for 2010 to 2014 will now have a very close look at the exciting history of these biomarkers in the Precambrian, and how the evolution of early organisms controlled the carbon cycle and influenced the tumultuous climate of the Neoproterozoic (1000 – 542 ma ago).

For more information, go to the home page of the Brocks group.
http://shrimp.anu.edu.au/people/jjb/jjb.html

Figure 3. The famous Ellery Creek outcrop covers the time period from about 800 to 500 million years ago. On the right is the mid-Neoproterozoic Heavitree Quartzite, and the ridge in the distance is a Cambrian sandstone. The almost vertical-standing layers in between encompass glacial deposits of the Snowball Earth events, a rise in atmospheric oxygen and the first appearance of animals followed by their explosive radiation at the Precambrian/Cambrian boundary.

Molecular characterization of a Neoproterozoic hypersaline ecosystem

Richard Schinteie and Jochen J. Brocks

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

Figure 1. Example of an evaporitic sample from which lipid biomarkers were extracted. The sample is composed of grey-brown dolomitic laminae and gray-white crystaline anhydrite. Sample is 7 cm wide.

Numerous microorganisms survive and flourish in environments that are often considered “extreme” from an anthropogenic view point. Such environments include hydrothermal vents, hydrocarbon seeps, and acid hot springs. Hypersaline environments are another type of setting where microorganisms live under salinity regimes exceeding those of seawater. In order to understand the evolution of ecosystems from such settings, Neoproterozoic halite-bearing evaporites were investigated for their lipid biomarker content. While previous work identified potential halophiles in the Cambrian and Precambrian, we aim to present a more detailed investigation of a microbial ecosystem under "extreme" conditions.

Thus far, we extracted biomarkers from evaporitic sediments composed of dolomite, anhydrite and/or halite. The samples are derived from evaporitic sediments of the Neoproterozoic Bitter Springs Formation, Amadeus Basin, central Australia. Due to the broad shallow nature of the Amadeus Basin and a tenuous connection with the ocean, the water was characterized by elevated salinity levels during that time. As a result, very thick (100 m to >2000 m) evaporite units were deposited.

The Neoproterozoic evaporites are often composed of numerous microbial mat-like formations that exhibit roll-up structures and tearing. Full scans (gas chromatography - mass spectroscopy, GCMS) of the saturate fraction revealed high ratios of mono- and dimethyl alkanes relative to *n*-alkanes. Such patterns are typical of Precambrian and Cambrian samples and observed in a number of facies settings. An outstanding characteristic are several pseudohomologous series of both regular (to C_{25}) and irregular (to C_{40}) acyclic isoprenoids. These isoprenoids are present in high concentrations and have never before been reported in the Precambrian. The presence and relative concentrations of these compounds vary with regards to the sedimentology of the host rock. Hopanes and steranes are often present in low concentrations or are absent.

Based on these results, we present an ancient and extreme, saline environment dominated by prokaryotes – with potentially the oldest evidence of haloarchaea in the geologic record. The presence of exceptionally well preserved biomarkers in anhydrite, despite the fact that sulfate and biomarkers are thermodynamically not stable together, raises the prospect of finding biomarkers in sulfate deposits on Mars.

Rate of growth of the preserved North American continental crust

Evidence from Hf and O isotopes in Mississippi detrital zircons

I.H. Campbell, C. Y. Wang, C. M. Allen, I. S. Williams and S. M. Eggins

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

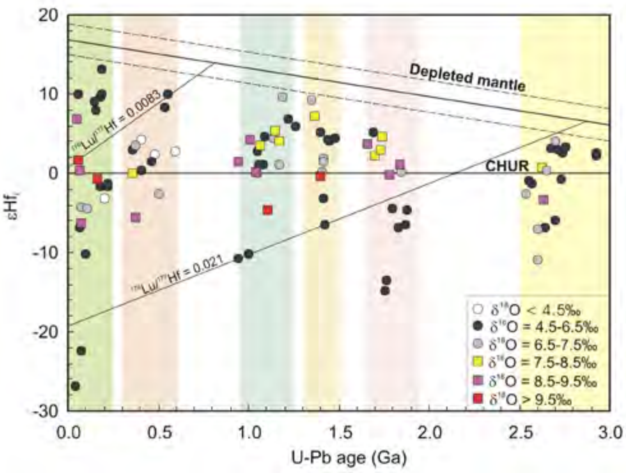


Figure 1. Plot of εHf_i versus U/Pb ages.

Detrital zircons from the Mississippi River have been analyzed for U-Th-Pb, Lu-Hf and O isotopes to constrain the rate of growth of the preserved North American continental crust. U/Pb dates on zircons mounted in epoxy resolved six major periods of zircon crystallization: 0-0.25 Ga, 0.3-0.6 Ga, 0.95-1.25 Ga, 1.3-1.5 Ga, 1.65-1.95 Ga and 2.5-3.0 Ga. These age ranges match the ages of the recognized tectonic units of the North American continent in the hinterland of the Mississippi River. Ninety-six zircons mounted on tape, which show no age zonation, were selected to represent the six U/Pb age time intervals and analyzed for Lu-Hf and O isotope by laser ablation MC-ICP-MS and SHRIMP II, respectively. Zircons derived from juvenile crust, which we define as having mantle $d^{18}O$ (4.5 - 6.5 ‰) and lying within error of the Hf depleted mantle growth curve, are rare or absent in the Mississippi basin (Fig. 1). The overwhelming majority of zircons crystallized from melted pre-existing continental crust, or mantle derived magmas that were contaminated by continental crust. The average time difference between primitive crust formation and remelting for each of the recognized lithotectonic time intervals, which is defined as crustal incubation time in this study, is 890 ± 460 Myr.

If the zircons are weighted by the area of North America covered by the six recognized periods of zircon crystallization the average Hf model age is 2.35 Ga, which compares favorably with a weighted by area Nd model age of 2.36 Ga. Our preferred approach is to use the measured O isotope values to constrain variations in the $^{176}Lu/^{177}Hf$ ratio of the granitic source region from which the zircons crystallized, making the assumption that zircons with mantle like O isotopic ratios have higher $^{176}Lu/^{177}Hf$ than zircons with higher O isotope values. This method gives an average Hf model age of 2.53 Ga, which is 180 Myr older than the constant $^{176}Lu/^{177}Hf$ calculation. The area weighted zircon Hf model ages show two distinct periods of crust formation for the North American continent, 1.6 to 2.2 and 2.9 to 3.4 Ga. At least 50% of the preserved North American continental crust was extracted from the mantle by 2.9 Ga and 90% by 1.6 Ga. Two similar periods of crustal growth are also recognized in Gondwana (Hawkesworth and Kemp, 2006), suggesting that these may be periods of global continental crustal growth.

Link to paper
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V66-4V166D3-1&_user=554534&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000028338&_version=1&_urlVersion=0&_userid=554534&md5=b8b4068dfc9d121f2e1212ddbd4f051a

Early crustal evolution deduced from monazite geochronology and geochemistry

Tsuyoshi Iizuka[1] and Malcolm T. McCulloch[1, 2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Now at School of Earth and Environment, University of Western Australia, Perth, WA 6009, Australia

Knowledge of early crustal evolution is central to deciphering the evolution of the young Earth. Mt. Narryer and Jack Hills metasediments in the Narryer Gneiss Complex of Western Australia are of particular importance for the study of early crustal evolution because they yield Hadean (>4.03 Ga) detrital zircons; no crustal rocks have been found from the first 500 Myr of Earth's history. To better understand the tectonothermal history and provenance of these ancient metasediments, we have undertaken in-situ LA-ICPMS geochronology and geochemistry of monazites from the metasediments.

Our data reveal multiple periods of metamorphic monazite growth in the Mt. Narryer metasediments during tectonothermal events, including metamorphism at ~3.3–3.2 and 2.7–2.6 Ga and a hydrothermal alteration at 3.2–3.1 Ga. These results set a new minimum age of 3.2 Ga for deposition of the Mt. Narryer sediments, previously constrained between 3.28 and ~2.7 Ga. Despite the significant metamorphic monazite growth, detrital monazites survive with a relatively high proportion in a Fe- and Mn-rich sample. This could be primarily due to its Fe- and Mn-rich bulk composition leading to the efficient shielding of old monazite by garnet. By contrast, the metamorphic monazite growth in the Jack Hills metasediments was insignificant, suggesting the lack of high-grade metamorphism in the region.

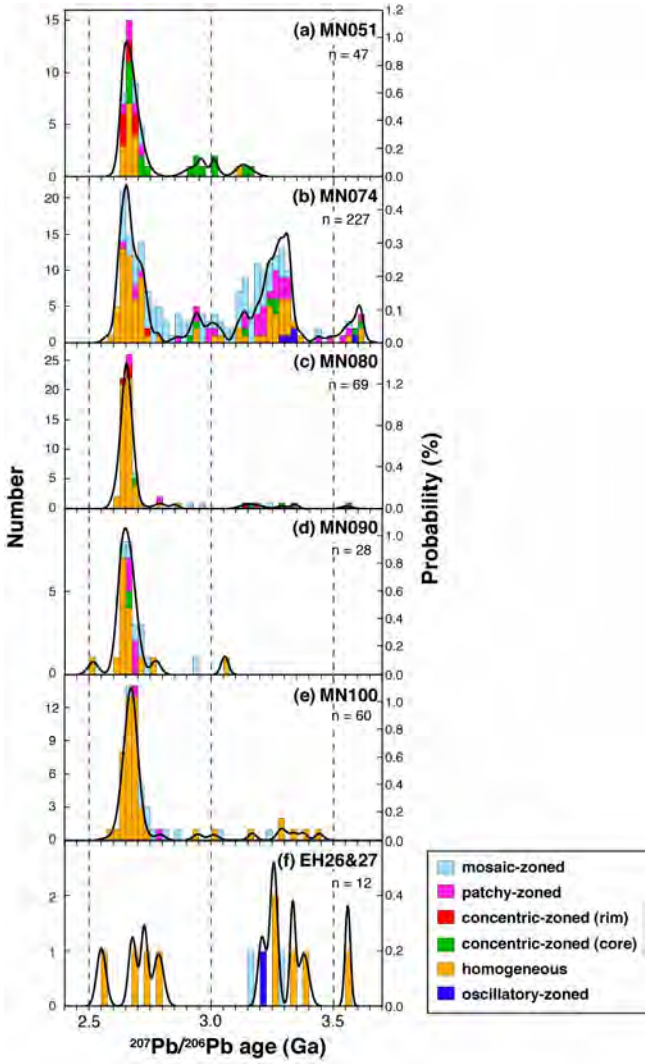


Figure 1. ^{207}Pb/^{206}Pb age histograms of concordant and <5% discordant monazites for Mt. Narryer metasediments (a) MN051, (b) MN074, (c) MN080, (d) MN090, and (e) MN100 and Jack Hills metasediments (f) EH26 and EH27. Columns are coded according to internal structure under backscattered scanning electron imagery.

The detrital monazites provide evidence for the derivation of Mt. Narryer and Jack Hills sediments from 3.6 and 3.3 Ga granites, likely corresponding to Meeberrie and Dugel granitic gneisses in the Narryer Gneiss Complex. Importantly, no monazites older than 3.65 Ga have been identified. This can be interpreted as indicating that the source rocks of the >3.65 Ga detrital zircons contained little monazite, thereby providing no evidence for the presence of granites (sensu stricto) on Hadean Earth. An alternative interpretation is that although the source rocks may have contained monazite, this phase completely dissolved/recrystallized during <3.65 Ga metamorphism or was eliminated during prolonged sedimentary recycling.

He, Ne and Ar in peridotitic and *eclogitic* paragenesis diamonds from the Jwaneng kimberlite, Botswana – constraints on diamond formation

M. Honda[1], D. Phillips[2], J. W. Harris[3] and T. Matsumoto4[4]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] School of Earth Sciences, The University of Melbourne, Melbourne, Australia
[3] Division of Earth Sciences, University of Glasgow, Glasgow, UK
[4] Institute for Study of the Earth's Interior, Okayama University,

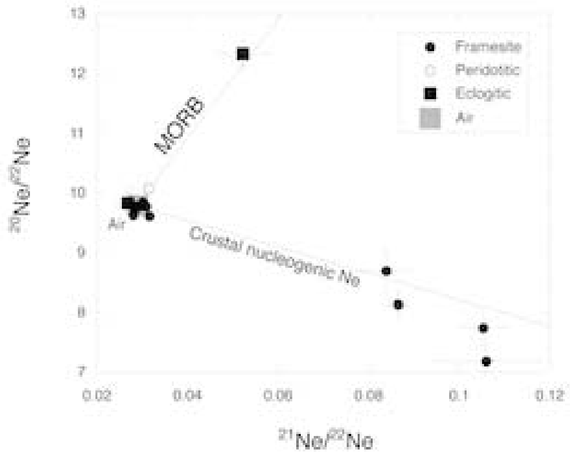


Figure 1. Neon isotope diagram, showing the results from Jwaneng polycrystalline diamonds (this study) and framesites. The MORB correlation line and a mixing line between atmospheric and crustal nucleogenic neon are also plotted.

Research goals in noble gas geochemistry include understanding the structure of the Earth's mantle and the creation of a coherent model of its evolution. In this regard, noble gas compositions in mid-ocean-ridge basalts (MORBs) and ocean island basalts (OIBs) have provided very useful information on the mantle. However, virtually all these data are from samples that are effectively of zero-age and, therefore, only give information about the present composition of mantle noble gases. If noble gas measurements are made on mantle-derived samples of different ages, these can allow further refinement of models concerning mass transport in the mantle.

Diamonds have unique characteristics which make them potentially very useful as sources of noble gases from the mantle: (1) most diamonds appear to be derived from 150 km to 200 km depth in the Earth, (2) diamonds cover a wide range of crystallization ages of between 1.0 and 3.5 billion years, and (3) diamonds have suffered little interaction with crust or atmosphere. Thus, diamonds provide a direct window into the ancient mantle.

We have undertaken helium, neon and argon analyses of eleven polycrystalline diamonds from the Jwaneng kimberlite pipe, Botswana, with known diamond paragenesis. In contrast to the findings of crustal noble gases in framesites from the same kimberlite pipe (Honda et al., 2004), the Jwaneng polycrystalline diamonds appear to have similar noble gas, particularly neon, isotope compositions as observed in MORBs, regardless of their parageneses (Fig. 1). This implies that the Jwaneng polycrystalline diamonds may have formed in recent times, and are possibly as young as kimberlite emplacement (~ 235Ma). In contrast, Jwaneng framesites could be as old as sulphide inclusions in diamonds, which have model Re-Os ages of ~2.9 Ga. Furthermore, as shown in Figure 1, neon isotope compositions in the mantle where Jwaneng diamonds formed, appear to have changed over this time period from crustal Ne (as observed in the framesites) to MORB-like Ne (as observed in the polycrystalline diamonds).

The apparent difference of neon isotope compositions and formation ages between the Jwaneng polycrystalline diamonds and framesites may imply that primordial noble gases in the upper part of the mantle were outgassed at an early stage of the Earth's formation, and that crustal noble gases could have been introduced into the diamond stability field of the sub-continental mantle by subduction-related processes. Subsequently primordial noble gases were continuously supplied from the lower to upper part of the mantle in order to form MORB-like Ne compositions in the upper mantle.

Noble gases and halogens in metamorphic, magmatic and hydrothermal systems

M. Kendrick[1], M. Honda[2], D. Phillips[1], M. Scambelluri[3], D. Kamenentsky[4], J. Herman[2], B. Rusk [5] and N. Oliver[5]

[1] *School of Earth Sciences, The University of Melbourne, Melbourne*

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

[3] *Genoa University, Genoa, Italy*

[4] *School of Earth Sciences, University of Tasmania*

[5] *Earth and Environmental Sciences, James Cook University, Townsville, Qld 4811, Australia*

Fluid inclusions enable crustal fluids to be sampled from deeper and hotter environments than can be sampled by direct means and have been trapped throughout Earth's History. Therefore fluid inclusions enable us to investigate the noble gas systematics of magmatic and metamorphic systems that have never been investigated previously. Analysis of unirradiated samples maximises information from He, Ne, Ar, Kr and Xe isotopes while complementary analysis of irradiated samples enables halogen determination (Ar-Ar methodology) meaning the fluid inclusions Ar concentration can be determined from its salinity and the measured Ar/Cl value. Combining these approaches has proven powerful because it enables the noble gases to be studied in tandem with other volatiles including the halogens, H_2O, CO_2 and CH_4.

Current projects applying these tools to important ore systems in the Mt Isa Inlier and Yilgarn Terrane of Australia have demonstrated it is a powerful tool for testing exploration models. In addition the work has lead to new insights on how noble gases are transported through the crust. We now understand noble gases are partially coupled to the major volatiles and unravelling mixing systematics can provide information on both fluid source and water-rock interactions. Measuring noble gas concentrations in the actual fluid is essential to a complete understanding and we are now developing methods to determine fluid inclusion salinity and Ar content independently. New research projects apply these techniques to subduction related metamorphic rocks and promise to transform our understanding of the noble gas volatile cycle.

Solar-wind exposure effects on lunar grains:

oxygen diffusion in iron metal

Barbara Frasl, Trevor Ireland, Masahiko Honda, Hugh O'Neill and Marc Norman

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

Most of the mass in our Solar System, more than 99,8% [1], is cumulated in our Sun, which is believed to reflect the original composition of the solar nebula, and yet little is known about its isotopic composition. Analysing the surface of lunar soil grains is an attempt to identify the isotopic oxygen signature of the solar wind and the Sun. The oxygen isotopic composition - oxygen having three stable isotopes: ^{16}O, ^{17}O and ^{18}O - is commonly plotted in a three-isotope oxygen plot. Previous analyses on solar wind implantation in lunar grains show very different results, from ^{16}O-enriched [2, 3] to ^{16}O-depleted [3, 4] compositions.

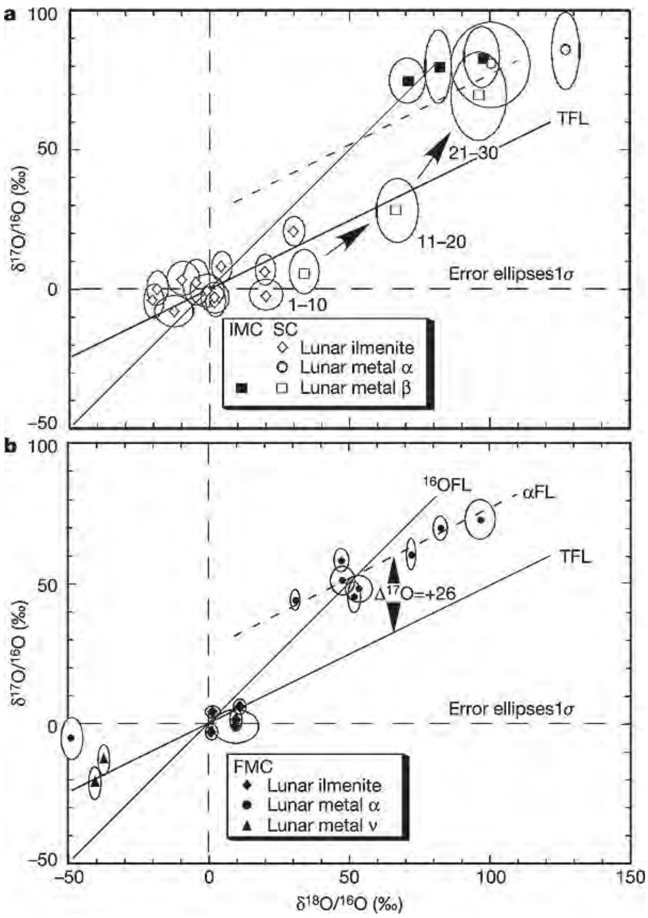


Figure 1. Figure 1: Three-isotope plots of oxygen isotopic composition in lunar metal grains and lunar ilmenites (regolith soil 10084). High-precision measurements carried out by SHRIMP II using a single collector (a) and multiple collection (b). Analyses on individual grains showed an offset from the TFL by $\Delta^{17}O$ = +25.6±3.2‰ ($\delta^{17}O = \delta^{18}O$ = +50 ‰) [3].

This research focuses on the stable isotope signature of implanted ions in the surface of lunar grains, predominantly metal spherules in the soils with a main focus on oxygen isotopes. The main goal is to understand solar wind exposure effect on lunar soils and the implications for oxygen isotopic fractionation.

A new generation of SHRIMP, optimized for stable light isotopes (SHRIMP SI), will be used to characterize the isotopic composition of oxygen, nitrogen and carbon implanted on the surfaces of individual grains and analyses on the Noble Gas Mass Spectrometer at RSES will provide noble gas isotopic and abundances, helium and neon, on single grains for correlation of measured abundances and isotopes to characterise the composition of the solar wind.

In order to gain further knowledge on the issue of oxygen diffusion in iron an experimental approach is in progress to address this matter. This aims to provide a depth profile of oxygen in various iron metals after heated to different temperatures, simulating conditions on the Moon's surface and to gain a reliable timescale for oxygen diffusion for lunar metal grains.

[1] WIENS, R., BURNETT, D., HOHENBERG, C., MESHIK, A., HEBER, V., GRIMBERG, A., WIELER, R. & REISENFELD, D. (2007) Solar and Solar-Wind Composition Results from the Genesis Mission. Space Science Reviews, 130, 161-171.
[2] HASHIZUME, K. & CHAUSSIDON, M. (2005) A non-terrestrial 16O-rich isotopic composition for the protosolar nebula. Nature, 434, 619-622.
[3] IRELAND, T. R., HOLDEN, P., NORMAN, M. D. & CLARKE, J. (2006) Isotopic enhancements of 17O and 18O from solar wind particles in the lunar regolith. Nature, 440, 776-778.
[4] HASHIZUME, K. & CHAUSSIDON, M. (2009) Two oxygen isotopic components with extra-selenial origins observed among lunar metallic grains - In search for the solar wind component. Geochimica et Cosmochimica Acta, 73, 3038-3054.

Successes and limitations of extinct nuclide initial abundances in meteorites by in-situ analysis

^{53}Mn in Angrites and Pallasites

Seann J. McKibbin, Trevor R. Ireland, Yuri Amelin and Hugh St. C. O'Neill

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

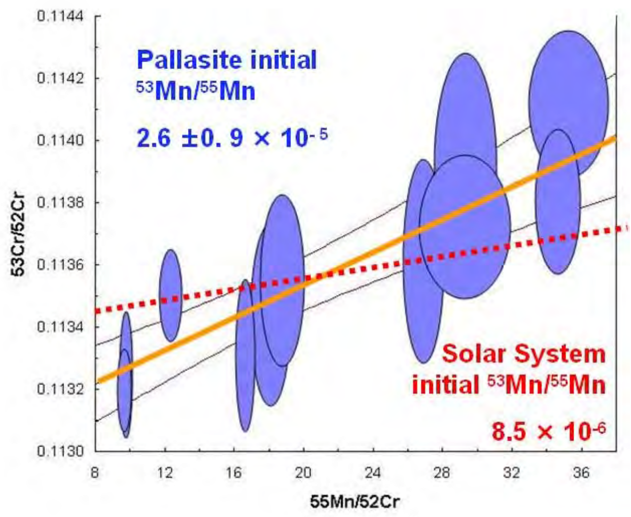


Figure 1. Initial 53Mn/55Mn for the Brenham Pallasite. The correlation between Cr-isotopes and the inter-element ratio is considerably steeper than the Solar System initial, and likely represents complex diffusion processes rather than accumulation of 53Cr from radioactive decay in a closed-system.

The abundances of extinct radioactive nuclides in the early Solar System provide constraints on the stellar environment of formation and are used for obtaining relative ages of meteorites. For some isotope systems these initial abundances serve as accurate and precise meteorite chronometers, but even reliable isotope systems sometimes turn up uncooperative samples. We have developed a technique to measure Cr isotopes by ion-probe in meteoritic olivine. Correlations between Cr isotopic composition (^{53}Cr/^{52}Cr) and the inter-element ratio (^{55}Mn/^{52}Cr) indicate the abundance of the extinct isotope ^{53}Mn (which decays to ^{53}Cr, $t_{1/2}$ 3.7 My). This is reported as the initial ^{53}Mn/^{55}Mn. We have applied this method to meteorites from two different environments: angrites, which are crustal rocks crystallised from magma near the surface of a small body, and a pallasite, which is a mixture of planetary mantle olivine and core metal.

For volcanic angrites, initial ^{53}Mn/^{55}Mn is at the level of ~3-4 × 10^{-6}. Plutonic (slowly cooled) angrites have a lower abundance, ~1 × 10^{-6}. In a pallasite, we find apparent initial ^{53}Mn/^{55}Mn of 2.6±0.9 × 10^{-5}, in agreement with previously reported ion-probe results from a different laboratory (Hsu 2005). Mn-Cr systematics in angrites are well understood in terms of chronology; angrite magma is sequentially isolated from a parent reservoir (e.g. the bulk asteroid/planet) while ^{53}Mn decays over a period of several My, resulting in differences in initial ^{53}Mn/^{55}Mn.

However, pallasite results pose a problem for Mn-Cr dating, because initial ^{53}Mn/^{55}Mn at the level of 10^{-5} translates into an unrealistic age based on intercalibration between Mn-Cr and absolute ages for angrites. Such high concentrations of ^{53}Mn are only expected in the molecular cloud or interstellar medium (initial ^{53}Mn/^{55}Mn for the Solar System is ~8.5 ± 1.5 × 10^{-6}; Scott and Sanders 2009). Pallasite absolute ages are not well known but are probably about the same as angrites and in any case they are not presolar. We conclude that microscale Mn-Cr systematics of some pallasites do not reflect initial ^{53}Mn/^{55}Mn and are the product of a complex history.

Hsu, W. 2005. Mn-Cr systematics of pallasites. *Geochemical Journal,* **39**, 311.

Scott, E. & Sanders, I. 2009. Implications of the carbonaceous chondrite Mn-Cr isochron for the formation of early refractory planetesimals and chondrules. *Geochimica et Cosmochimica Acta,* **73**, 5137.

Tectonic sequence diagrams used to characterise the evolution of the ductile movement zones in NW Himalaya

Jia-Urnn Lee[1], Marnie Forster[1], Talat Ahmad[2] and Gordon Lister[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Geology, University of Delhi, Delhi - 110007, India

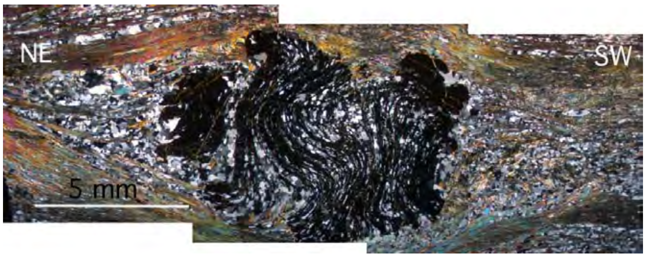


Figure 1. Garnet millipede structure where an initial garnet growth overprints crenulations. The concave rims suggest a later garnet growth over a simultaneously deflecting schistosity (XPL, x1.6 objective). This later phase is correlated with 'F3' in the TSD below.

The Himalaya is characterised by a sequence of large thrusts, each of which can be poorly extrapolated from place to place because of the rugged nature of the terrain, and the lack of continuous exposure. Previous work has extrapolated the Main Central Thrust over vast distances, but there is often little data to support the detail of the correlation. Work conducted during the 2006-2009 field seasons suggests that the areal extent, and the location, of individual thrusts (and thrust-related shear zones) is not as well defined as might be expected.

Although the Main Central Thrust in principle should juxtapose the Greater Himalayan crystalline rocks against the Lesser Himalaya, complexities and misunderstanding are increased within the Lesser Himalaya due to the existence of many smaller (?) but still laterally extensive thrust faults. One region where this is of importance is in the NW region of the Himalaya near the town of Shimla, where one of the anastomosing faults has been mislabelled as the Main Central Thrust. The Jutogh Thrust carries the Shimla klippe, allowing us to reassess the nature and timing of movement in one of the most intensely deformed movement zones along this tectonic boundary.

Tectonic Sequence Diagrams were used to establish the complex deformational and metamorphic history of this movement zone, ensuring that all field and thin-section data is included of this information, recording the timing relationships between folding, metamorphic mineral growth events and the different ductile shear zones that could be identified. Previous studies on this particular area have placed an emphasis on folding. There is a general consensus that there were three episodes or styles of folding. However results from this study suggest that these were not all distinct, separate events. A sequence diagram from a garnet-rich zone where both folding and shear zone movement has occurred shows that shear zones affected the second and possibly third folding event, and that these later fold events may be linked. Garnet-grade Barrovian metamorphism overprinted earlier formed crenulations, and ongoing shear zone operation transposed these structures and developed spectacular pressure shadows. The initial garnet porphyroblasts acted as nucleation sites for subsequent episodic garnet growth . Mineral growth alternated with shear zone activity. NE-directed shear bands may be conjugate to SE-directed ones, and conjugate crenulations may have formed as well. ^{40}Ar/^{39}Ar geochronology is being undertaken to constrain the timing of individual events within the sequence diagram.

'F' and 'M' events from published literature	**F1** **S2**	**M1**	**F2** **S3** **M2**	**F3**	**S4**	
TSD from this study	F_{ISOC}>S_{AXP} Cren>S_{CREN}	ΔGrt	SZ_{SW}>>>>>>>>>>> ΔGrt S-C'$_{SW}$ S-C'$_{NE}$ F>S_{AXP}//SZ ΔBiot	ΔGrt F_{CNJG}>S_{DIFF}		ΔGrt

Figure 2. The tectonic sequence diagram described in the text, correlated with prior deformation schemes, with folding (F1, F2, F3) and metamorphic (M1, M2) history as shown. A crenulation cleavage formed in the axial plane of isoclinal folds, followed by an upper greenschist metamorphism defined by garnet growth. Garnet growth continue during the with the operation of an overall SW-directed shear zone with both SW- and NE-directed S-C' fabrics, and recumbent folding with axial planes parallel to the shear zone. Biotite grew in the low stress zones around rotating porphyroblasts where microdilational sites opened during shearing. With continued deformation conjugate crenulations started to form, and were overprinted by yet another garnet growth episode (see millipede structure in Figure 1). The conjugate crenulations develop a weak differentiated fabric. Late near-static garnet growth may have occurred without any significant associated deformation.

Importance of uranium isotope variations for chronology of the Solar System's first solids

Yuri Amelin[1], Angela Kaltenbach[2], Tsuyoshi Iizuka[1], Claudine Stirling[2], Trevor Ireland[1], Michail Petaev[3] and Stein B. Jacobsen[3]

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

[2] Centre for Trace Element Analysis and Department of Chemistry, University of Otago, PO Box 56, Union Place, Dunedin, New Zealand

[3] Department of Earth & Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138, USA

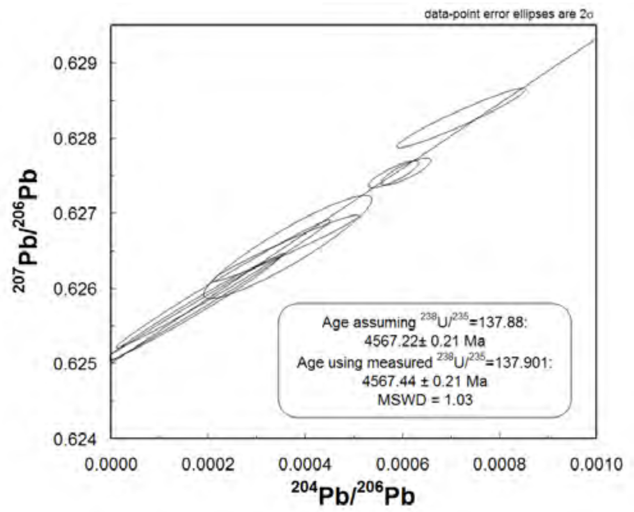


Figure 1. Pb-isotopic data for acid-washed fractions from Allende CAI SJ101, plotted in a $^{207}Pb/^{206}Pb$ vs. $^{204}Pb/^{206}Pb$ isochron diagram.

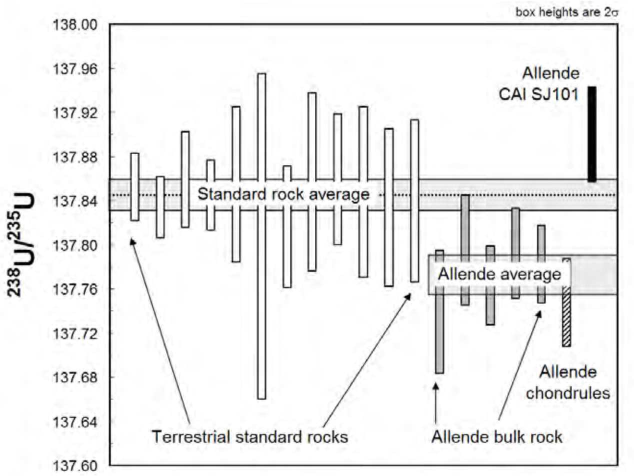


Figure 2. Uranium isotopic compositions of USGS standard rocks, fragments of the Allende meteorite, an aliquot of an assorted Allende chondrule population, and Allende CAI SJ101.

The $^{238}U/^{235}U$ ratio must be known for accurate determination of ^{207}Pb-^{206}Pb ages. This ratio was thought to be invariant until recent discoveries of uranium isotope variations in terrestrial rocks and in Ca-Al-rich refractory inclusions (CAIs) in carbonaceous chondrites. CAIs are considered the oldest Solar System objects and their ^{207}Pb-^{206}Pb age has been used as our best absolute age for the beginning of our Solar System's formation, but their Pb isotopic ages don't fit well in the emerging consistent pattern of the early Solar System chronology. It is possible that some of the differences in formation time intervals between various early Solar System objects, obtained from extinct nuclide chronologies and from ^{207}Pb-^{206}Pb dates, are caused by variations of the $^{238}U/^{235}U$ ratios. We report the first combined high precision $^{238}U/^{235}U$ and ^{207}Pb-^{206}Pb data for a large CAI from the Allende meteorite, and U isotopic data for chondrules and representative whole rock samples of the same meteorite. The difference of 0.129±0.046 in the $^{238}U/^{235}U$ ratio between the CAI and chondrules and bulk Allende meteorite increases the ^{207}Pb-^{206}Pb age difference by ~1.4 million years, yielding an accurate CAI-chondrule time interval, which is also more consistent with the extinct nuclide data. The U isotopic variations are not caused by the presence of ^{247}Cm, but may be related to isotope fractionation or nucleosynthetic anomalies. Our data support the growing evidence that small $^{238}U/^{235}U$ variations in planetary materials are pervasive, and can make significant changes in ^{207}Pb-^{206}Pb ages at the current precision of dating. It is clear that any geo- and cosmochronological study using the $^{238,235}U$-$^{206,207}Pb$ isotopic system must include precise determination of the $^{238}U/^{235}U$ ratio when the ultimate precision and accuracy of the age is needed.

Argon geochronology and microstructural analysis: a unique and reliable duo

Marnie Forster and Gordon Lister

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

$^{40}Ar/^{39}Ar$ geochronology is the only geochronometer that allows structural geologists and tectonists to directly date the complexity of deformation in a single sample, as well as acting as a geospeedometer that allows calculation of rates and the duration of events and processes. This of course cannot be done unless a number of criteria are met. In particular the sample must be taken from an ancient "argon partial retention zone" in which case there is a strong correlation between microstructure and the age spectrum that will be obtained.

To analyse such material, the sequence of events that affected the rock must be determined by microstructural analysis: these may include mineral growth, and recyrstallisation of minerals associated with distinct deformational events and the overprinting effects. The pressures, temperatures and duration of the individual events will have a major influence on the resultant apparent age spectra that is produced during incremental heating of the sample during diffusion experiments. It is often not a simple matter to correlate between the different parts of the apparent age spectrum and the observed microstructural elements. Laser *in situ* analysis is not useful because argon diffusion is clearly multiscale, and spot analyses eliminate almost all useful information.

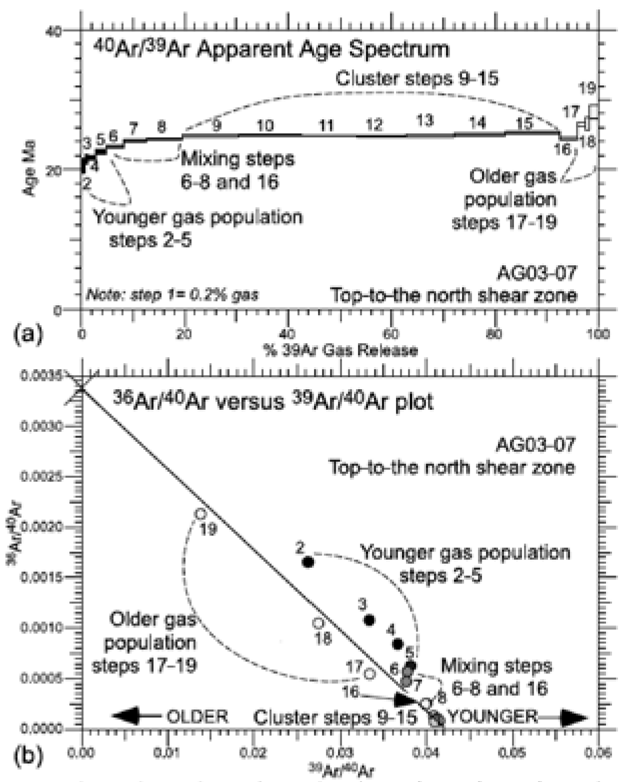


Figure 1. *Argon apparent age spectra (a) produced from furnace step-heating methods of argon geochronology, where traditionally a 'perfect' apparent age spectra with only one age or plateau would be concluded actually holds significantly more information. This particular spectra has one dominant gas population at ~25 Ma, but is overprinted by a younger event at ~20 Ma, all other steps are mixing ages; (b) Inverse Isochron Plots' can be used to understand results, in particular the different gas populations that are recorded in the apparent age spectra and the steps that are mixing or meaningless. (Forster and Lister 2009).*

The science of "cooling ages" has in the past dominated the science of $^{40}Ar/^{39}Ar$ geochronology. In reality, few terranes get so hot that "cooling ages" have much relevance, and most argon analyses are not at all amenable to this classic method of interpretation. The much sought after "plateau" in the apparent age spectrum may not exist. Nor has the concept of "closure temperature" any particular theoretical relevance. And in many cases, a "plateau", if it exists, means something quite different than classical theory would allow (see figure). In fact, unless a sample is from very hot rock and/or subject to a simple history, it can be expected that the argon system will retain multiple gas populations and information on multiple events during the history of the grain/s.

In traditional argon analysis these 'disturbed spectra' are often cast aside, but in fact much information can be obtained from samples where older gas population are at least in part preserved and only partially reset during the on-going evolution. Now, with increasingly routine application of the method of tectonic sequence diagrams to conduct fabric and microstructural analysis, and with routine application of the method of asymptotes and limits to analyse apparent age spectra obtained from carefully designed sequences of step-heating experiments, the VG1200 argon facility at ANU is producing reliable, precise and accurate age determinations of a variety of complex scenarios.

In terms of the science of the argon partial retention zone, argon geochronology and microstructural analysis offer a unique and reliable duo.

How efficiently does the crust melt?

A geochronological investigation of melting in migmatites

Daniela Rubatto [1], Joerg Hermann[1], Alfons Berger [2,3] and Martin Engi [3]

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

[2] Institute for Geography and Geology, Øster Voldgade 10, Copenhagen, 1350 Denmark

[3] Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3 Bern, 3012 Switzerland

The Earth's crust is constantly melting in regions where high thermal conditions are reached, as for example the deep roots of mountain buildings, i.e migmatites. This process is an important component of the secular chemical evolution of the crust and ultimately the planet. Migmatites (rocks that recorded melting) now exposed on the crust surface offer the opportunity to investigate the dynamic of the melting process through geological times. The timing of melting has been investigated in a well-exposed migmatitic terrane in the Alps, through U-Pb dating of the accessory minerals zircon. Over a series of samples, individual melt-related zircon domains yielded ages ranging over 10 million years (32 to 22 Ma ago). Multiple melt episodes could be analyses within a single grain indicating that the same rock reached melting temperatures more than once over that period. The chemistry of the zircon domains allows discriminating between melts formed at different conditions (temperature and chemical environment). The distribution of ages also indicates that melting occurred at different times in samples a few meters apart because of the local rock composition and localized influx of fluids; and that repeated melting was localized in particular levels with a favourable composition (leucosomes), whereas vast areas were unaffected.

Figure 1. *Field photograph of migmatite from the Central Alps.*

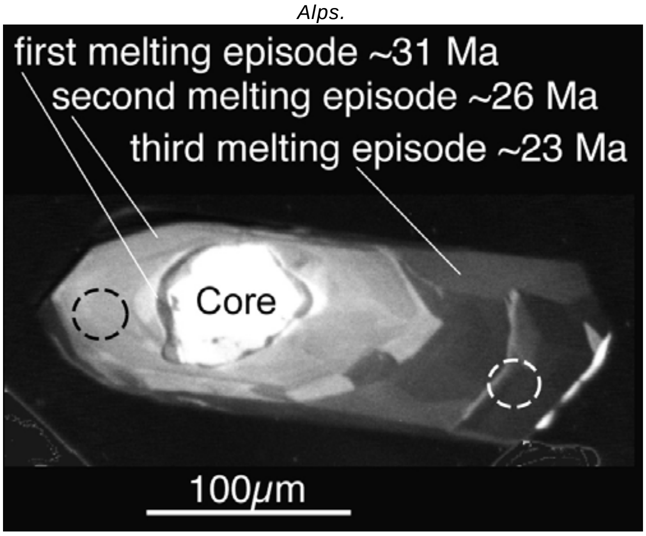


Figure 2. *Cathodoluminescene image of a dated zircon crystal from migmatite.*

This detail study has important implications for the dynamic of the crust during melting. Melting persisted over a long period, much longer than what previously thought, but was scattered throughout the terrain. The proportion of leucosome present in outcrops is the cumulative result of several melting episodes. During the protracted high temperature history, the migmatites in the Central Alps never contained significant amounts of melts at any given time. The lack of large melt volumes at any given time implies that the rheological behaviour of the crust was not profoundly affected by the melting process, opposite to what argued by some tectonic models.

Full details in the online article:
http://www.springerlink.com/content/38k0273620335873/

Age of volcanism and its migration in the Samoa Islands

Ian McDougall

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

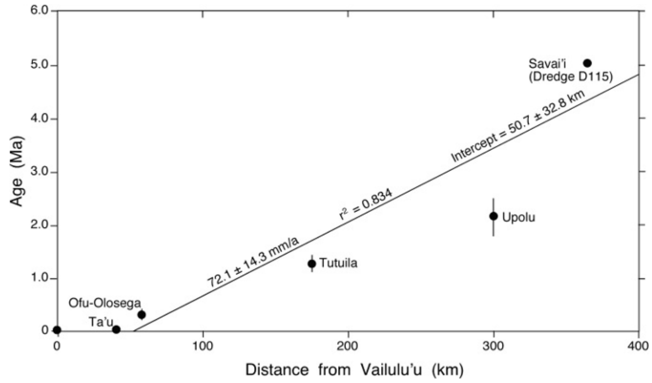


Figure 1. Average age for the subaerial shield building volcanism for Ta'u, Ofu/Olosega, Tutuila and Upolu, and the average age determined on samples from dredge D115 from the submarine edifice of Savai'i (cf. Koppers *et al*. 2008) in the Samoa Islands, plotted against distance from Vailulu'u, the site of current volcanism (Hart *et al.* 2004). A reasonable fit to a straight line is found, indicating that the migration rate of the volcanism to the ESE occurred at 72.1 ± 14.1 mm/a. Error bar for the mean age for each island is the standard deviation of the age population used in the calculation of the mean age.

Potassium-argon (K-Ar) ages on whole rock samples have been measured on lavas from the subaerial Samoa Islands, which form a broadly linear volcanic chain that extends from the ESE to the WNW for about 360 km. The Manu'a Islands near the southeast limit of the chain exhibit youthful ages, with most <0.4 Ma, in keeping with the geological observations. Tutuila consists of several volcanoes and previous work yielded a mean K-Ar age of 1.26 ± 0.15 Ma for the shield-building volcanism. Upolu, to the WNW of Tutuila, gives a mean age of 2.15 ± 0.35 Ma for the shield-building phase, represented by the Fagaloa Volcanics, with much of the island covered by significantly younger volcanic rocks. Savai'i, further to the WNW, is dominated by youthful volcanism, extending into historic times. In a restricted area, adjacent to the NE coast of Savai'i, previously thought to have volcanic rocks correlating with the Fagaloa Volcanics of Upolu, the ages are much younger than those on Upolu, lying between 0.32 and 0.42 Ma. Considering only the subaerial volcanism from Ta'u to Upolu, but also including Vailulu'u, the volcanism has migrated in a systematic ESE direction at 130 ± 8 mm/a over 300 km in the last 2.2 Ma. This rate is nearly twice that obtained from GPS measurements of Pacific Plate motion of 72 mm/a at N64ºW in this area. However, if the much older age of shield-building volcanism from the submarine foundations of Savai'i is included, the regression yields a volcanic migration rate of 72 ± 14 mm/a (Figure 1), in keeping with the measured GPS rate and consistent with a hotspot origin for the island chain. This suggests that the volcanic migration rates determined from the age of subaerial volcanism can be considerably overestimated, and this is now evident in other Pacific Ocean island chains. Clearly, the age of the main shield-building volcanism from subaerial volcanism are minima, and if the older submarine lavas can be measured, these may yield a migration rate more in keeping with current plate motions.

Hart, S. R. et al. (2004). Genesis of the Western Samoa seamount province: age, geochemical fingerprint and tectonics. *Earth and Planetary Science Letters* **227**, 37-56.

Koppers, A.A.P. et al. (2008). Samoa reinstated as a primary hotspot. *Geology* **36**, 435-438.

Earth Environment

Introduction

The year proved quite challenging for us all, especially with the Geochemistry, Mineralogy and Petrology Review. This forced us to examine our research directions and priorities including also our performance. Basically, Earth Environment's research is on the response of the Australian landscape and the oceans in our region to past, present and future climate change and human impacts, with four broad specific themes focussing on:

- Ocean chemistry and climate change
- Coral reefs and global change
- Landscape evolution and terrestrial impacts of climate change
- Human evolution, linked to the environment, both in Australia and abroad.

These research themes reflect strengths that are based around a combination of leading expertise and analytical technologies, the latter predominantly developed or enhanced in-house. The recent addition of the new radiocarbon facility, a joint RSES-RSPhysE project funded through an ARC LIEF and ANU MEC grants, stands to play a vital role in understanding processes that operate in the oceans and in particular changes in carbon cycling within the Southern Ocean. Earth Environment houses outstanding analytical facilities, spanning multi-collector ICP-MS for high precision U-series dating and stable isotope geochemistry, laser ablation ICP-MS, TIMS, and oxygen/carbon-isotope mass spectrometry, to cosmogenic isotope, OSL, ESR and palaeomagnetic dating. All are vital for achieving current and new goals set by the Earth Environment. To further enhance our capabilities for environmental reconstruction and fundamental research into ocean processes, we are in the process of purchasing a new oxygen/carbon isotope mass spectrometer through the MEC and new state-of-the-art MC-ICPMS through the ARC LIEF grant scheme.

A new focus for Earth Environment is on culturing marine organisms [from microscopic calcareous and siliceous plankton to sponges, and perhaps corals] in controlled conditions to develop new and validate existing chemical proxies for the reconstruction of past environmental conditions. In combination with the development of new B isotope and trace metal proxies to link past changes in ocean carbonate chemistry and pCO2, these are providing new insights into the threat of oceanic acidification from anthropogenic CO2 under different emission scenarios.

Changes also occurred among our group with the departure of Professor Malcolm McCullogh who accepted the prestigious position of Premier's Fellow at the University of Western Australia. He is accompanied by Dr Julie Trotter. Several of his PhD students and Dr J-A. Mallela (Postdoctoral Fellow), appointed by Malcolm, remain at RSES. Dr Tim Barrows also left for a position at the University of Exeter and Dr K. Fitzsimmons is about to depart for a position in Germany. Dr B. Walther left for a position in Texas and was replaced by Dr Mallela. Dr Alibert recently rejoined our group to work with Dr Eggins.

Several PhD students submitted their thesis this year, and many have now been awarded their degrees.

With respect to teaching, Earth Environment provides a core component to the Marine Science undergraduate teaching program and to the BGOS degree, which is attracting high-performance undergraduate students. Other EE staff are involved in teaching and supervision of the newly established Master's course on Archaeological Science.

We are keen to investigate the possibility of developing a new MSc program in "Environmental Geoscience". This program would draw on the large pool of expertise within Earth Environment and provide the basis for pedagogic training for postdoctoral fellows and postgraduate students, and has the potential to attract significant numbers of full-fee paying students.

360 million-year-old giant predator discovered on the South Coast

Ben Young[1], Bob Dunstone[1], Tim Senden[2] and Gavin Young[1]

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

Figure 1. Impression of the body of a Devonian lobe-finned fish preserved in red mudstones of the coastal cliffs in the Eden-Merimbula area of SE NSW.

Sedimentary rocks of Devonian age (~416-360 million years ago) are well exposed along the south coast from near Bermagui to the Victorian border. This geological period has been called the 'Age of Fishes', because fossil vertebrate remains became abundant for the first time. During that period the first forests evolved, and our fish-like vertebrate ancestors moved onto the land. Reconstructions of ancient atmosphere indicates a dramatic drop in concentrations of CO_2 during the Devonian Period, as diverse terrestrial ecosystems became established.

Fossil fish and plant remains, and preserved trackways of unknown amphibians, have been discovered at a number of localities in SE Australia and adjacent Victoria (summarised by Young, 2007). The trackways represent the oldest definite evidence for land animals in the Southern Hemisphere. Under an Australian Research Council Discovery Grant (DP 0558499: '*Australia's exceptional Palaeozoic fossil fishes, and a Gondwana origin for land vertebrates*') we conducted new field investigations along the coastal outcrops, some of which were covered by scientific permits when within the area of Ben Boyd National Park.

Figure 2. Using a demolition saw to cut out a block containing fossil bones from the Devonian rocks of the coast cliffs south of Eden, NSW [December 2008]

In 2008 we excavated a near-complete specimen of a placoderm (armoured) fish from the coastal outcrop south of Eden, NSW. At the same time we exposed a large tooth about 45 mm long associated with adjacent large bones that extended deeper into the rock. In April, October, and December, 2008 we used rock saws and drills to remove numerous blocks and pieces. Over 100 collected samples and larger blocks were brought back to the laboratory, prepared mechanically, then glued together and reassembled into about 30 larger blocks. Where the bone was very weathered it was removed by treating with acid so impressions could be cast with rubber latex. Many hundred or hours work in the laboratory during 2009 demonstrated that we have collected the front half of a very large predatory lobe-finned fish, including most of the skull, palate, cheek, jaws, and shoulder girdle. The lobe-fins were the fish group that gave rise to the first land animals, the fleshy lobes in the fins being modified into limbs. Reassembly of the new specimen shows that the two jaws meet at the front in the midline, with other bones of the skull and cheek slightly displaced.

A total jaw length of 45-50 cm for these associated skull remains makes this the biggest such bony fish ever found in Devonian rocks from anywhere in the world. With fangs nearly 50 millimetres long, the fish was perhaps up to four metres in total length; it would have been the top predator in the big river system that deposited the red mudstones forming the coastal cliffs between Eden and Merimbula. It will be described as a new genus and species of lobe-finned fish.

Reference

Young, G.C. 2007. Devonian formations, vertebrate faunas, and age control on the far south coast of New South Wales and adjacent Victoria. *Australian Journal of Earth Sciences* 54: 991-1008. [DOI: 10.1080/08120090701488313]

Paper published in Australian Journal of Earth Sciences:
http://dx.doi.org/10.1080/08120090701488313

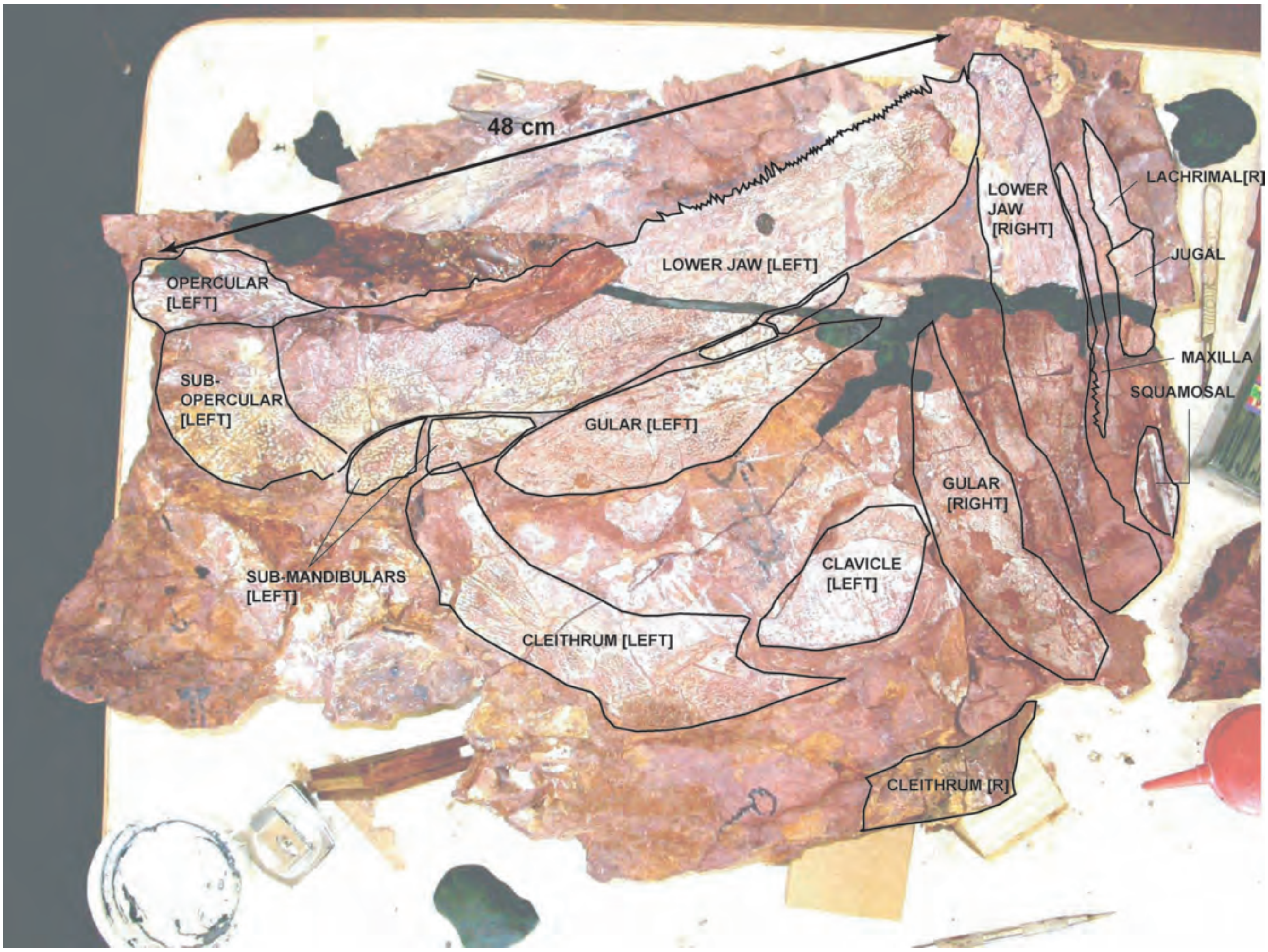


Figure 3. Blocks containing the lower jaws of the giant predator reassembled on a table, with some of the surrounding bones labelled.

Higher silicon concentrations in the Pacific sector the Southern Ocean during glacial times

Michael J. Ellwood[1], Martin Wille[1], William Maher[2] and Patrick De Deckker[1]

[1] Research School of Earth Sciences, 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

Fundamental to understanding changes in CO_2 variability across the last glacial-interglacial transition is the reconstruction nutrient concentrations in the deep Southern Ocean. Such reconstructions have typically been based on nutrient proxies such as d^{13}C, Nd isotopes, Cd/Ca, Ba/Ca, ^{231}Pa/^{230}Th, but with conflicting results. Glacial Cd/Ca and Ba/Ca benthic foraminiferal results suggest that there was little change palaeo-nutrient concentrations, whereas the d^{13}C and Nd isotope results suggest palaeo-nutrient concentrations were higher as a result of a reduction in Northern Component deep water feeding into the Southern Ocean. In our study we determined the silicon isotope (d^{30}Si) composition of sponge spicule and found that the distribution of silicon within the deep Southern Ocean not homogeneous during the last glacial period; rather the glacial concentration of silicon in the Pacific sector was higher compared to the Atlantic sector. At face value, this result suggests that the Antarctic Circumpolar Current (ACC) was less efficient in mixing Pacific and Atlantic deep and bottom waters. Possible scenarios leading to such heterogeneities may be linked to changes in the position and intensity of the ACC. A change in the position of the westerly winds may lead to increased stratification which would increase the invasion of nutrient-rich deep Pacific water into this region.

Polar forests on the edge of extinction

What does the fossil spore and pollen evidence from East Antarctica say?

E. M. Truswell [1] and M. K. Macphail [2]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, Australian National University, Canberra, ACT 0200, Australia*

Diverse pollen and spore assemblages, spanning the Late Eocene preglacial–glacial transition, have been recovered from Ocean Drilling Program cores from Prydz Bay, East Antarctica. These microfloras are mostly *in situ* and provide an unparalleled record of terrestrial plant communities growing in Antarctica during the earliest stages of ice-cap formation. The evidence provides a basis for assessing the phytogeographic relationships of the Antarctic floras with other high-latitude floras in the southern hemisphere, including possible migration routes for some taxa. Preliminary studies (Macphail and Truswell 2004*a*) suggested the Late Eocene vegetation at Prydz Bay was floristically impoverished rainforest scrub, similar to *Nothofagus*–gymnosperm communities found near the climatic treeline in Patagonia and Tasmania. Re-evaluation of the microfloras indicates the diversity of shrubs, especially Proteaceae, was underestimated and the Late Eocene vegetation was a mosaic of dwarfed (krumholtz) trees, scleromorphic shrubs and wetland herbs, analogous to the taiga found in the transition zone between the boreal conifer forest and tundra biomes across the Arctic Circle. Microfloras similar to although much less diverse than the Prydz Bay assemblages occur in coreholes from the Ross Sea region on the opposite side of Antarctica. Interpretation of the latter is complicated by reworking and low yields but the combined evidence points to the collapse of taller woody ecosystems during the Eocene–Oligocene transition and their replacement by tundra-like or fell-field vegetation during the Oligocene and Neogene. This temperature-forced regression seems to have been broadly synchronous across the continent. The high-palaeolatitude location (~70°S) means that the Prydz Bay flora was adapted to several months of winter darkness and short-summer growing seasons. The nearest living relatives of identifiable woody taxa suggest year-round high humidity, with an annual precipitation between ~1200 and 1500 mm. Palaeotemperatures are more difficult to quantify although the inferred humid microtherm climate is consistent with mean annual temperatures less than 12°C and freezing winters.

Lead isotopic evidence for an Australian source of aeolian dust to Antarctica at times over the last 170,000 years

Patrick De Deckker [1], Marc Norman [1], Ian D. Goodwin b, [2], Alan Wain c, [3] and Franz X. Gingele [1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Climate Risk CoRE, Department of Physical Geography, Macquarie University NSW 2109, Australia
[3] CAWCR - High Impact Weather Team, Bureau of Meteorology, PO Box 1636, Melbourne VIC 3001, Australia

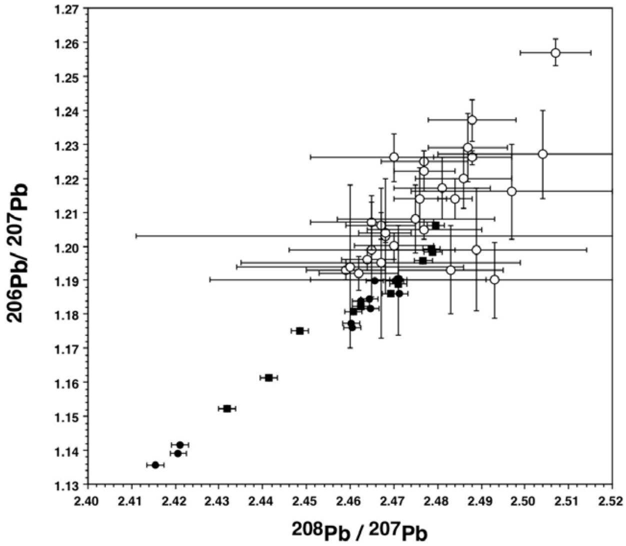


Figure 1. Plot of the $^{208}Pb/^{207}Pb$ versus $^{206}Pb/^{207}Pb$ values obtained from the fluvial clay fraction samples from 30 sites in the Murray Darling Basin [black dots represent Murray-sub-basin samples and black squares Darling sub-basin ones] and the same ratios obtained by Vallelonga et al. (2005; GRL32, L01706, doi:10.1029/2004GL021449) from dust in the Antarctic ice core from EPICA Dome C [open circles]. Note the large error bars for the EPICA samples due to their extremely small sizes.

Systematic analysis of Pb, Sr and Nd isotopes of 23 fluvial clay samples (<2µm fraction) from many of the major tributaries of the vast (1.10^6 km^2) Murray Darling Basin (MDB), located in semiarid southeastern Australia, display similar isotopic values between some MDB clays and dust from several ice core samples from the EPICA Dome C in Antarctica. Close scrutiny of several ratios of the four Pb isotopes, and in particular $^{208}Pb/^{207}Pb$ versus $^{206}Pb/^{207}Pb$, show that several samples from the Darling-sub-basin of the MDB display similar values for the same isotopes for Dome C samples [see figure1] from different ages, and more particularly during wet phases in Australia [Marine Isotopic Stages 5e, 3 and 1]. The combination of Nd and Sr isotopic ratios from the same MDB fluvial clays clearly eliminates the Murraysub-basin, and supports the Darling sub-basin as a potential source of aeolian material to Antarctica. Overall, the Australian dust supply to Antarctica predominantly occurred during interglacial periods.

Our work shows that aerosols generated in southeastern Australia can travel to parts of West Antarctica and this is supported by atmospheric observations and models using the HYPLIT program. In addition, evidence of Australian dust in Antarctic ice cores further implies dust deposition in the Southern Ocean would have occurred in the past. Current meteorological observations also imply that the east Antarctic sector of the Southern Ocean would frequently receive aeolian dust components originating from southeastern Australia.

Sediment transport in the Murray Canyons offshore South Australia

S. Schmidt[1,2], P. De Deckker[3], H. Etcheber[1,2] and S. Caradec[2]

[1] CNRS, UMR5805 EPOC, Avenue des Facultés, F-33405 Talence Cedex, France
[2] Université de Bordeaux, UMR5805 EPOC, F-33405 Talence Cedex, France
[3] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

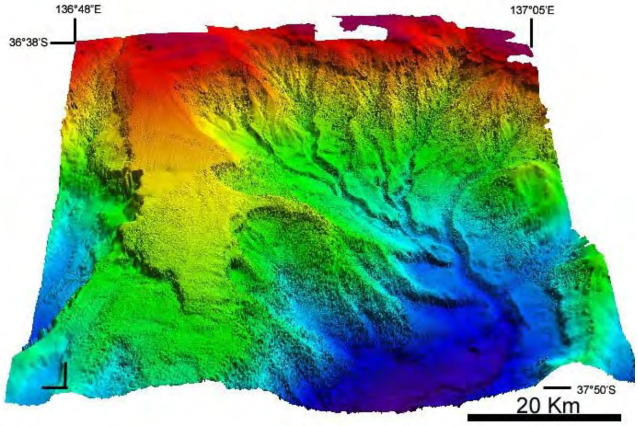


Figure 1. Detailed view, tilted by approximately 15 degrees, of the western side of Sprigg Canyon offshore Kangaroo Island, showing the entrenched underwater 'fluvial' channels that display evidence of erosion and underwater transport which therefore must still be effective today, otherwise the channels would have filled up. The Sprigg Canyon is named after Reginald Sprigg who was the first to document those under water features We studied a multicore taken on the "peninsula" on the western side of the canyon. On the image, the red colour indicates depths < 200 m, yellow >200 m and <1,000 m, green >1,000 m and <4,000 m, and blue >4,000 m.

We have examined some of the most spectacular canyons that are located offshore Kangaroo Island, and these are linked to ancient courses of the River Murray which would have flowed across the very wide Lacepede Shelf during periods of low sea level. During the AUSCAN-1 project held in 2003, modern sedimentation was assessed using a multi-tracer approach on interface sediments from 350 to 2,500 m water depth.

The presence of freshly deposited particles, tagged by ^{234}Th in excess, ^{210}Pb-based sediment accumulation (0.03 - 0.13 cm y-1) and 230Th-based focusing ratios support the occurrence of significant advection of marine sediments within these canyons. In the absence of direct riverine inputs, the shelf, being the site of intensive carbonate production, is the main supplier of material.

The presence of incised channels in the eastern portion of the Murray Canyons Group [MCG] [see figure 1] indicates recent to sub-recent activity along the courses. The presence of underwater slides in the western side of the MCG confirms that sediment transport to the abyssal plain does occur.

Based on our preliminary investigation and by synthesizing previous work on other canyons, we provide a conceptual model for sediment focusing and transfer within the canyons offshore Australia.

Kalkowsky's association of stromatolites and oolites - re-evaluation and geological significance

Robert V. Burne[1], Josef Paul[2] and Tadeusz M. Peryt[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Zentrum f. Geowissenschaften der Universität Göttingen, Goldschmidt-Str.3, D-37077 Göttingen, Germany; E-Mail: jpaul@gwdg.de
[3] Polish Geological Institute – National Research Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland; E-Mail: tper@pgi.gov. pl

Three world-wide used geologic terms derived from the area around the north German Harz Mountains: “Oolithi” [1] and nearly two hundred years later “Ooid” and ”Stromatolith” [2]. These terms all describe carbonate grains and rocks of the Lower Triassic Buntsandstein Group. The widespread Buntsandstein Group of cebtral Europe consists of red and variegated sandstones and mudstones which stretch from Lorraine in France to the Holy Cross Mountains in eastern Poland. It is a typical dominated by red beds deposited in a large inland basin, the Central European Basin. Braided and meandering rivers brought siliceous grains and mud from the hinterland towards the centre of the basin. At times the inflow of water led to large but shallow lakes at the centre of the basin. When the rainy seasons vanished, the water of the lake evaporated. Microbial calcite-producing communities flourished in the absence of higher organisms. Calcite ooids formed in the shallow environment under the impact of wind and wave action bars or shoals which are now preserved at the margin of the basin and palaeohighs from the Netherlands to Poland. Eventually the lakes vanished and small ephemeral rivers reached the centre and brought only mud with them.

Figure 1. Stromatolite in oolitic limestone, Buntsandstein, Heeseberg, Germany.

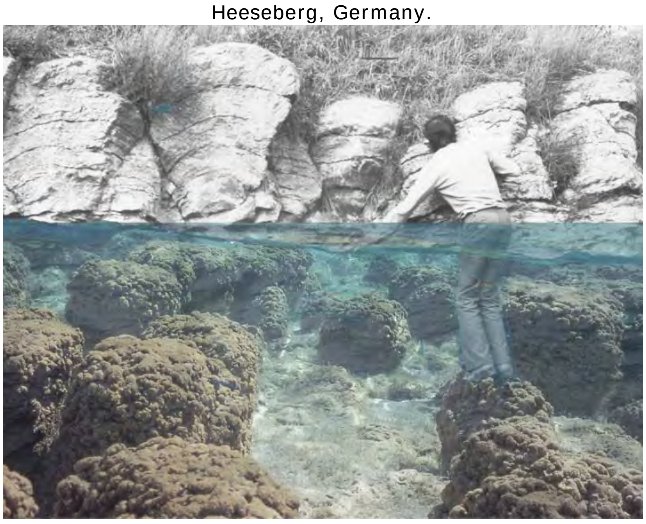


Figure 2. Photomontage combining (a) stromatolites growing in ooid sands, Hamelin Pool, Australia (lower half) and (b) stromatolites in oolitic limestone, Buntsandstein, Heeseberg, Germany (upper half).

The sediments of the Lower Buntsandstein, are nearly devoid of fossils, body fossils as well as trace fossils. The reason of this scarceness may be not abnormal salinity, but rapidly changing environmental conditions as the shallow playa lake has no buffer capacity against fluctuations of various environmental parameters. The etched surfaces of stromatolites are because of the decay of organic matter under a cover of clay or living mat led to formation of CO2, lowering the pH and consequently to acidification of the water and dissolution of carbonate.
Some prerequisites of stromatolitic growth can be deduced from observations in the field. Muddy water or mud layers excluded stromatolites or terminated their growth. The microbial community did not survive a mud cover or muddy water. This effect may be the reason for their restriction to the Eichsfeld Palaeohigh. Here, the sandy and muddy sediments were diverted west and east of the high on their way towards the basin. The more extended areas of oolites indicate that the ooid producing microbes are not so sensitive. The position of stromatolites at top of oolite beds seems to reflect a directional evolution, most likely of the water chemistry, e.g. alkalinity or supersaturation in respect of calcium carbonate.

The observed photoautotrophy points to cyanobacteria, at least as a component of the microbial community. There is a high potential of preservation by the absence of grazers and browsers and an early lithification, although the latter cannot be proved.
There was a long-lasting discussion in the scientific community about the formation of ooids. During the 19th and 20th century most scientists thought of inorganic origin, a precipitation due to supersaturation in regard of calcium and carbonate. Calcite or aragonite may precipitate around a nucleus of a quartz or carbonate grain. Only Kalkowsky (1908) thought of an organic origin produced by colonies of lime secreting phyto-organisms. During the last twenty years an increasing number of indications arewere found that organic biofilms are involved in the formation of ooids.
To summarize, Kalkowsky (1908) stated that
p. 100 § 64 Regarding the environment of the oolites in the north German Bunter Sandstone, it is generally assumed that they have formed in a shore facies.
One could easily be tempted to think already now of salt lakes as area of their formation.
p. 118 § 88 Stromatolites were always associated with oolites.
p. 123 § 94 Ooids resemble growing bacterial colonies as observed in a Petri dish. Ooids are therefore probably produced by colonies of lime secreting phyto-organisms.
p.124 § 96 We have to assume that simple plants gave rise to limestone precipitation.

My aim has been to show that the *oolites and stromatolites of the north German Bunter Sandstone are inherently of organic origin.*

Fifty years after Kalkowsky published the classic paper Richard Chase recognized the first convincing modern analogues of "stromatoliths" around the shores of Hamelin Pool, Western Australia [6]. Recent investigations of both localities reveal a number of interesting parallels between the environment of Hamelin Pool and that of the Basin in which the association described by Kalkowsky. In both cases stromatolites grow on stable or firm ground in turbulent environments characterized by low sedimentation rates, little fine grained sediment, virtually no terrigenous input, rapid cementation and abnormal or fluctuating salinity.
Kalkowsky's stromatolites occur on the surface of oolite beds. Laminated crusts (called stromatoid by Kalkowsky and interpreted as being formed by syndepositional cementation) also occur in these rocks. Both stromatolites and laminated crusts are concentrated in specific layers traceable throughout quarry faces. In places the stromatolites are clearly syndepositional with rippled ooid sand. Spongy-fenestrate and fan-like stromatolitic microstructures can be distinguished, and both have undergone intense sparitization. The upper surfaces of some stromatolites are pitted due to syndepositional dissolution. The stromatolites may incorporate variable amounts of ooids, quartz grains and other material.
Hamelin Pool stromatolites also occur associated with ooid sands [3,8]. Subtidal stromatolites grow on rock substrate or crusts formed by penecontemporaneous cementation of marine sands, and are surrounded by mobile oolitic rippled sands and sand waves. The subtidal stromatolites have a laminoid fenestral fabric consisting of ooid and other carbonate sand grains cemented by micritic cements [3]. Micritisation of sand grains begins soon after deposition and gradually destroys the original structure of the incorporated ooids and other grains [9,10]. Stromatolites in the intertidal zone are thought to be subtidal forms stranded by sea-level fall and modified by intertidal microbial communities [11]. While the Buntsandstein stromatolites originated in a hyposaline and alkaline lake environment during the high stand of water level, and the Hamelin Pool stromatolites a forming in a hypersaline marine embayment during a period of regression, there are many environmental similarities. In both cases conditions favourable for ooid formation precedes the initiation of stromatolite growth, but the stromatolites co-exist with ooid sands, and incorporate ooid grains into their structures. The morphology of the many of the subtidal Shark Bay stromatolites is clearly influenced by the erosive effects of ooid sand waves migrating around them. Once formed, early diagenesis progressively obliterates the structure of ooid grains incorporated into the stromatolites. The association of stromatolites and ooid sands is of considerable geological significance. In another present-day environment the stromatolites of Lee Stocking Island in the Bahamas show a similar association with migrating ooid sand waves to that found in Hamelin Pool [12]. The association of stromatolites and oolites dates back to the Archean. One of the oldest occurrences of the association is known from the 2, 72 Ga. Tumbiana Fm., Fortescue Gr. Pilbara Block in Western Australia.
Even the first stromatolites known to science are associated with oolitic limestones, for, 25 years before Kalkowsky's work was published, James Hall had formally named Cryptozoon proliferum, from the oolitic Cambrian Hoyt Formation of Saratoga Springs, New York State [13].

References

[1] Brueckmann F.E. (1721).- Specimen physicum exhibens historiam naturalem, oolithi seu ovariorum piscium & concharum in Saxa.- Mutatorum, Helmestadii, Salomoni & Schnorrii, 21 pp.
[2] Kalkowsky E. (1908): Oolith und Stromatolith im norddeutschen Buntsandstein. – Zeitschrift der deutschen geologischen Gesellschaft, 60, p. 68–125.

[3] Logan B.W., Hoffman P. & Gebelein C.D., (1974): Algal Mats, Cryptalgal Fabrics, and Structures, Hamelin Pool, Western Australia. – In: Logan B.W., Read J.F., Hagan G.M., Hoffman P., Brown R.G., Woods P.J. & Gebelein C.D., (eds.): Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Tulsa, Oklahoma, Memoir 22, p. 140 – 194.
[4] Brehm U., Palinska K.A. & Krumbein W.E. (2004).- Laboratory cultures of calcifying biomicrospheres generate ooids - A contribution to the origin of oolites.- Carnets de Géologie Notebooks on Geology, Maintenon, Letter 2004/03 (CG2004_L03), 6 pp.
[5]De Vries Klein G. (1965): Dynamic Significance of Primary Structures in the Middle Jurassic Great Oolite Series, Southern England. In Middleton G.V., (ed.): Primary Sedimentary Structures and their Hydrodynamic Interpretation. SEPM Special Publication 12, p. 173-192.
[6] Chase Richard, Personal Communication to RVB 1/8/2007
[7] Paul J. & Peryt T. M. (2000): Kalkowsky's Stromatolites Revisited (Lower Triassic Buntsandstein, Harz Mountains, Germany). - Palaeogeography, Palaeoclimatology, Palaeoecology 161, p. 435-458
[8] Davies G.R. (1970): Carbonate Bank Sedimentation, Eastern Shark Bay, Western Australia. – In: Logan B.W., Davies G.R., Read J.F. & Cebulski D.E. (eds.): Carbonate Sedimentation and Environments, Shark Bay, Western Australia. - The American Association of Petroleum Geologists, Tulsa, Oklahoma, Memoir 13, p. 85-168.
[9] Monty C.L.V. (1976): The Origin and Development of Cryptalgal Fabrics. – In: Walter M.R. (ed): Stromatolites. Elsevier Amsterdam, Developments in Sedimentology 20, p. 193-249.
[10] Reid R.P., James N.P., Macintyre I.G., Dupraz C.P. & Burne R.V. (2003): Shark Bay Stromatolites: Microfabrics and Reinterpretation of origins. - Facies 49, p. 45–53.
|[11] Burne R.V. (1991-92): Lilliput's Castles: Stromatolites of Hamelin Pool. Landscope 7. p. 34-40.
[12] Dill R.F. (1991): Subtidal Stromatolites, Ooids and Lime Encrusted Muds at the Great Bahama Bank Margin. Contributions in Marine Geology in Honour of Farncis Parker Shephard. In: Osborne R.H. (ed.): From Shoreline to Abyss. - SEPM Special Publication 46, p. 147–171.[13] Hall J. (1883): Plate VI and explanation: Cryptozoon , N. G., Cryptozoon proliferum n. sp. - In: PIERSON, H.R. (ed.): Thirtysixth annual report of the trustees of the State Museum of Natural History to the legislature. - N. Y. Senate paper 1883/53, Albany.

Fate and transport of chemicals in an ACT municipal wastewater treatment plant, its effluent, and receiving waters

An Actew/ANU initiative

Jenna Roberts

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

In times of changing climate, increased urbanization, industrial development, and changes in land use practices, the Australian Water Industry faces a significant challenge to maintain a safe and sustainable water supply in the midst of an overall reduction of water quality via anthropogenic contamination. Aquatic wildlife is particularly at risk, as the aquatic environment is a natural sink for waterborne contaminants derived from human activity. These can enter waterways via several sources, however wastewater treatment plant (WTP) effluents are thought to be a major contributor of contaminants to riverine systems. Most conventional WTP's are not specifically designed to remove EDC's and pharmaceuticals from wastewater. Detailed chemical characterization of WTP effluents is especially important for inland systems, as they are often a primary source of water for downstream users, especially in low-flow scenarios; aquatic wildlife and population centres down-catchment are directly impacted by WTP effluent quality.

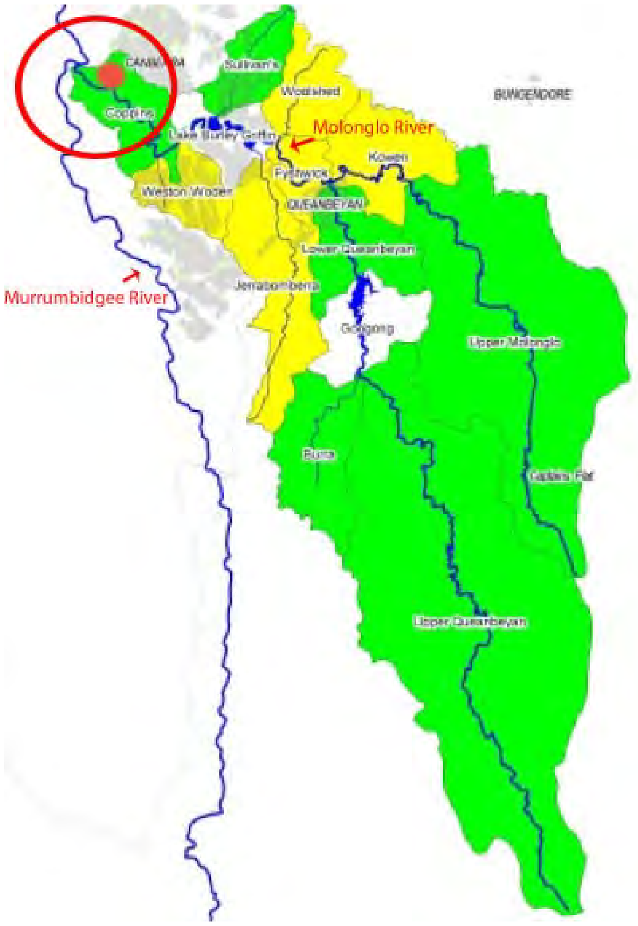


Figure 1. Area of interest within the Molonglo Catchment for environmental sampling. The location of the Lower Molonglo Water Quality Control Centre is highlighted in orange. Original image supplied by Molonglo Catchment Group, 2009.

Contaminants of concern include a wide range of endocrine disruptive compounds (EDC's) such as industrial chemicals, pharmaceutical and personal care products, pesticides, natural and synthetic estrogens and organochlorine compounds. Endocrine Disrupting Compounds have been formally defined by the World Health Organisation as 'exogenous substances that alter function(s) of the endocrine system and consequently cause adverse health effects in an intact organism, or it's progeny, or subpopulation(s)'. The detection and removal of these potentially harmful substances is essential for the water industry to maintain an adequate supply of potable water to Australian communities; the major concern associated with the presence of EDC's in surface waters is not necessarily acute effects on human health, but imperceptible effects on aquatic life and humans resulting from chronic, low-dose exposure. Ultimately, these endocrine effects effects can accumulate to induce profound changes.

This work will investigate a representative set of EDC's (and their metabolites) that contribute to the total estrogenic activity of LMWQCC effluent measured by previous researchers, and the movement and fate of these compounds through the sewage treatment works and in the Molonglo catchment (see Fig 1). Chemical analysis of wastewater and biosolids using novel, advanced mass spectrometric methods will be undertaken with the aim of ultimately constructing a detailed mass balance for target analytes around the STP. It is anticipated that more specific information on the chemical signature of LMWQCC effluent, as well as the concentration, movement, transformation and sorption characteristics of priority compounds will be of value to Actew Corporation water quality officials, ecotoxicologists, engineers and policymakers alike, and may assist in decision making regarding the need to modify current treatment practices.

Currently, laboratory training for complex pre-analysis sample treatment is underway, and a full 12 month sampling program is being assembled to begin in 2010. From the beginning of the project in March 2009 to present (nine months), much reading and research has been undertaken to establish the research direction, alongside detailed planning of laboratory work. This has been accompanied by conference attendance, Actew workshops and the organisation of ANU National Water Week.

The boron geochemistry of biogenic silica

Andrea de Leon, Martin Wille, Steve Eggins and Michael Ellwood

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

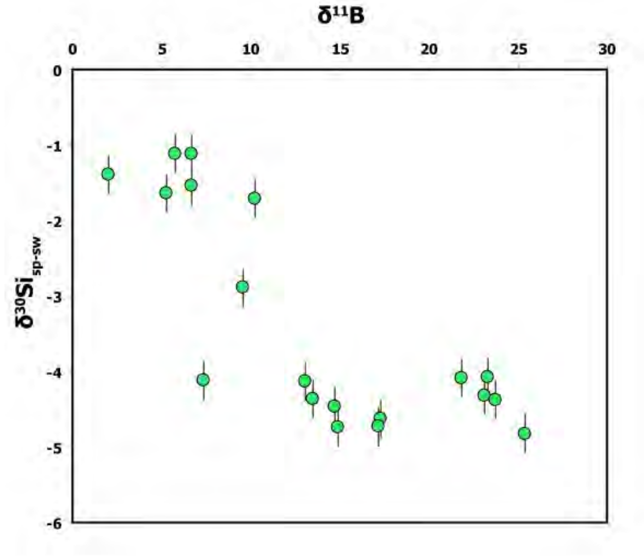


Figure 1. Boron isotope (δ11B) vs silicon isotope (δ30Si) signatures of siliceous sponges from Southern Tasmania and George V Land, Antarctica. Si isotope fractionation corresponds with the uptake and deposition of silica; the correlation between δ11B and δ30Si suggests that B uptake is related to these silica formation processes in sponges.

The boron content and isotopic composition (δ11B) of marine carbonate organisms can be linked to the pH of the seawater in which they have grown, making carbonates a useful tool for palaeo-seawater pH reconstruction. A study by Furst (1981) documented unusually high boron concentrations in siliceous sponge spicules, in range from hundreds to a thousand ppm. This observation and the potential for preferential incorporation of the tetrahedral borate species into biogenic silica raises the question as to whether the boron chemistry of biogenic silica might also be influenced by seawater pH. We have measured the boron concentration and isotopic composition of siliceous sponges from the Southern Ocean region, with a view to (1) confirming the observations of Furst (1981), (2) assessing the factors that control boron incorporation and isotopic compositions of sponge silica, and (3) investigating the potentially significant role of siliceous sponges in the marine boron cycle. The measured boron concentrations in a diverse range of both demosponge and hexactinellid sponges confirm the high boron concentrations previously reported. The boron isotope compositions of these sponges vary from around +2 ‰ to +25 ‰ and greatly exceed the range in marine carbonates. This isotopic variation is inconsistent with seawater pH control but is correlated with ambient seawater silicon concentration, in a manner that suggests a link to silicon uptake kinetics and demand by sponges.

Direct dating of fossil human remains

Renaud Joannes-Boyau and Rainer Grün

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

Our research focuses on decomposing the ESR spectra observe in fragments of human tooth enamel crystal from the CO_2- radicals defect. Studies on tooth enamel fragments have shown that the ESR spectra are significantly more complex than previously assumed (Figure 1A, Joannes-Boyau et al. in press).The ESR signal of the CO2-radical in hydroxyapatite has been used for the assessment of the past radiation dose, which in turn is converted into numerical age estimates, once the dose rate parameters are assessed. ESR dating studies are conventionally carried out on powdered samples, and it has repeatedly been demonstrated that the ESR spectra recorded from fossil samples are qualitatively similar to those generated by laboratory irradiation.

However, when attempting non-destructive ESR analysis, which is essential when working on fossil human remains, measurements are carried out repeatedly on tooth enamel fragments. Because of the anisotropic nature of hydroxyapatite, the ESR spectra show strong angular dependencies (Figure 1B Joannes-Boyau et al. 2009). In contrast to powders, the ESR spectra of fossil samples are significantly different to those generated by laboratory irradiation. Because of unstable components, it was initially suspected that all ESR age estimations could be underestimated (Joannes-Boyau et al. 2009). At the present point, the study focuses on the enamel structure to understand where the different components are located within the crystal.

The enamel structure is exceptionally complex. Our studies have so far revealed a composite organisation of crystal clusters, in prismatic and inter-prismatic configurations, both having different ESR responses (Figure 1C). At the same time Kinetics studies undertaken are showing complex transfer process and radicals disappearance that could threaten the fundamentals of ESR dating of tooth enamel (Grün et al., 2008).

Grün, R., Joannes-Boyau, R., Stringer, C. 2008. Two types of CO_2- radicals threaten the fundamentals of ESR dating of tooth enamel. Quaternary Geochronology 3, 150-172.

Joannes-Boyau, R., Grün, R. 2009. Thermal behavior of orientated and non-orientated CO_2- radicals in tooth enamel. Radiation Measurements 44, 505-511.

Joannes-Boyau, R., Bodin, T., Grün, R. submitted. Decomposition of the angular ESR spectra of fossil tooth enamel fragments. Radiation Measurements.

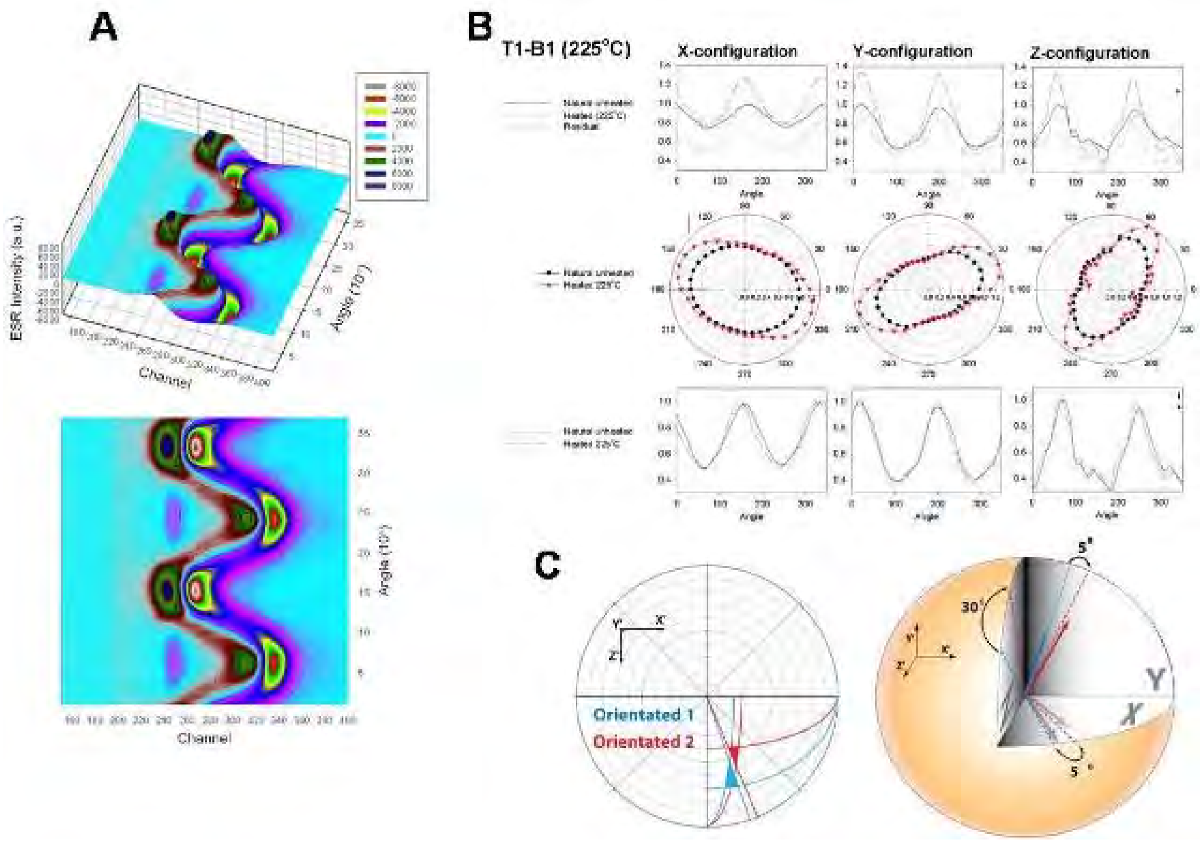


Figure 1. (A) ESR Spectra of human tooth enamel fragment; (B) Angular dependency of ESR spectra; (C) Differing ESR responses based on crystal structure.

Extinction implications of a chenopod browse diet for a giant Pleistocene kangaroo

Gavin J. Prideaux[1], Linda K. Ayliffe[2,3], Larisa R. G. DeSantis[4], Peter F. Murray[5], Michael K. Gagan[3] and Thure E. Cerling[2]

[1] School of Biological Sciences, Flinders University, Bedford Park, South Australia 5042, Australia

[2] Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah 84112, USA

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

[4] Department of Zoology and Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611, USA

[5] Museum of Central Australia, Alice Springs, Northern Territory 0871, Australia

Kangaroos are the world's most diverse group of herbivorous marsupials. Following late-Miocene intensification of aridity and seasonality, they radiated across Australia, becoming the continent's ecological equivalents of the artiodactyl ungulates elsewhere. Their diversity peaked during the Pleistocene, but by ~45,000 years ago, 90% of larger kangaroos were extinct, along with a range of other giant species. Resolving whether climate change or human arrival was the principal extinction cause remains highly contentious.

In this study we combine craniodental morphology, stable-isotopic and dental microwear data to reveal that the largest-ever kangaroo, *Procoptodon goliah*, was a chenopod browse specialist, which may have had a preference for *Atriplex* (saltbushes), one of a few dicots utilizing the C4 photosynthetic pathway. Furthermore, oxygen isotope signatures of *P. goliah* tooth enamel show that it drank more in low-rainfall areas than its grazing contemporaries, similar to modern saltbush feeders. Saltbushes and chenopod shrublands in general are poorly flammable, so landscape burning by humans is unlikely to have caused a reduction in fodder driving the species to extinction. Aridity is discounted as a primary cause because *P. goliah* evolved in response to increased aridity and disappeared during an interval wetter than many it survived earlier. We suggest that hunting by humans, who were also bound to water, may have been the more decisive factor in the extinction of this giant marsupial.

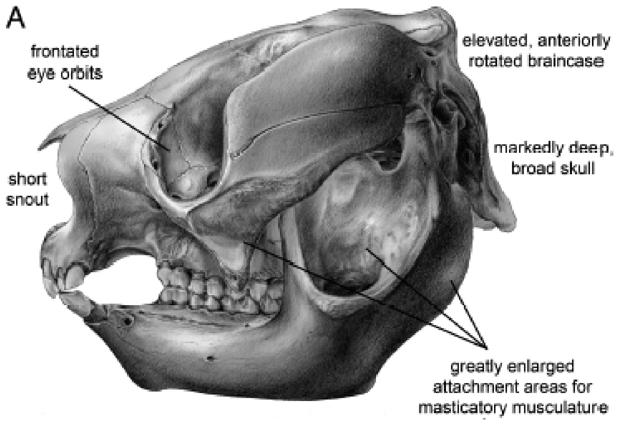


Figure 1. Skull of *Procoptodon goliah* showing anatomical features consistent with that of a browser.

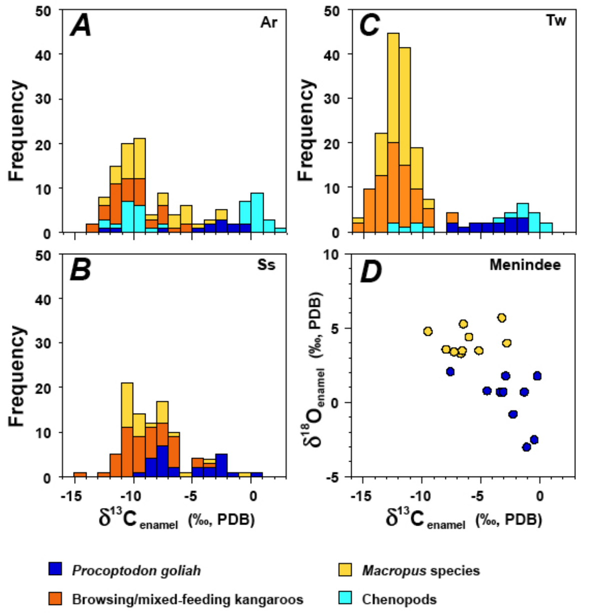


Figure 2. Carbon-isotope data for Pleistocene kangaroos from souteastern Australia. (A-C) Frequency histograms of enamel $\delta^{13}C$ values of *Procoptodon goliah*, grazing kangaroos (*Macropus* species), browsing / mixed-feeding kangaroos and modern chenopods (e.g., *Atriplex, Maireana*) from Arid, Ss and Tw climate zones. Chenopod vegetation samples are expressed as equivalent enamel $\delta^{13}C$ values and have been corrected by +1.5‰ for the effects of fossil fuel burning over the past century. (D) Enamel $\delta^{13}C$ vs $\delta^{18}O$ for Menindee fossil grazing kangaroos. Note markedly depleted $\delta^{18}O$ values for *P. goliah* compared to contemporary grazing kangaroos.

PNAS, Vol 106:11646-11650.
www.pnas/cgi/doi/10.1073/pnas.0900956106

Biological Germanium Discrimination in Diatoms

Jill Sutton[1], Michael J. Ellwood[1], William A. Maher[2] and Peter Croot[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Ecochemistry Lab, Applied Science & Institute for Applied Ecology, University of Canberra
[3] FB2: Marine Biogeochemistry, Leibniz-Institut für Meereswissenschaften (IFMGEOMAR)

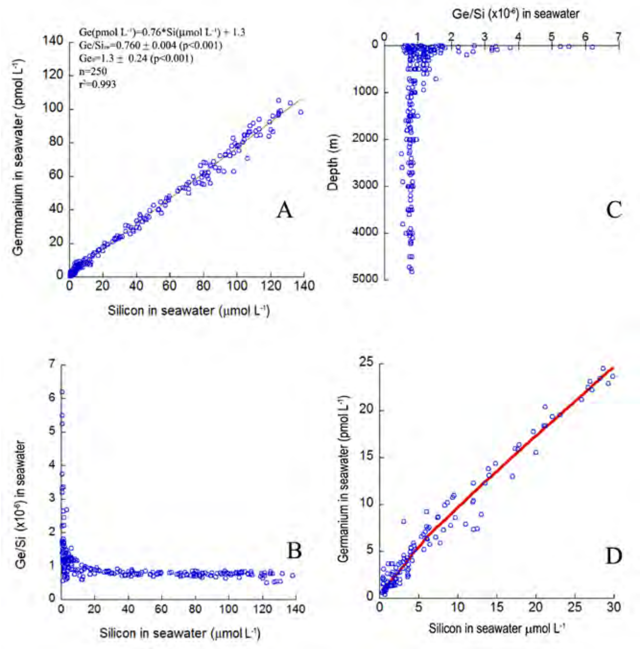


Figure 1. Global oceanic relationship of inorganic germanium vs. silicon concentration. A. Oceanic germanium versus silicon concentration (Ge = 0.760 x10-6 ±0.004[Si] + 1.27 ±0.24, p<0.001, r2 = 0.993). B. Ge/Si x10-6 versus depth. C. Ge/Si x10-6 versus silicon concentration. D. Oceanic germanium versus siliconconcentration less than 25 pmol L-1 and 30 μmol L-1, respectively. Curve is fitted using a second order polynomial (r2 = 0.99, p<0.001).

Seventeen inorganic germanium and silicon concentration profiles from the Atlantic, the Southwest Pacific and the Southern Oceans were collected. A plot of germanium concentration versus silicon concentration produced a near-linear line with a slope of 0.760 x10-6 (± 0.004) and an intercept of 1.27 (± 0.24) pmol/L (r^2=0.993, p<0.001). When the germanium to silicon ratios (Ge/Si) were plotted versus depth and/or silicon concentrations, higher values are observed in surface waters (low in silicon) and the ratio decreased with depth (high in silicon). Germanium to silicon ratios in diatoms (0.608-1.03 x10-6) and coupled seawater samples (0.471-7.46 x10-6) collected from the Southern Ocean show clear evidence for Ge/Si fractionation between the water and opal phases. Using a 10-box model (based on PANDORA) Ge/Si fractionation was modelled using three assumptions: (1) no fractionation, (2) fractionation using a constant distribution coefficient (KD) between the water and solid phase and (3) fractionation simulated using Michaelis-Menten uptake kinetics for germanium and silicon via the silicon uptake system. Model runs indicated that only Ge/Si fractionation based on differences in the Michaelis-Menten uptake kinetics for germanium and silicon can adequately describe the data. The model output using this fractionation process produced a linear line with a slope of 0.76 x10-6 and an intercept of 0.92 (± 0.28) pmol/L thus, reflecting the oceanic dataset. This result indicates that Ge/Si fractionation in the global ocean occurs as a result of subtle differences in the uptake of germanium and silicon via diatoms in surface waters.

Coral calcification and ocean acidification in the central region of the Great Barrier Reef

Juan-Pablo D'Olivo[1], Malcolm McCulloch[2], Stephen Eggins[1], Patrick De Deckker[1], Michael Ellwood[1] and Bradley Opdyke[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] School of Earth and Environment, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Perth, Australia

Coral reefs are exceptional rich environments of great commercial and natural value. The construction of these reefs relies on the accumulation of limestone skeletons from corals and other organism. Coral reefs are at risk to climate change and human imposed stresses including increased nutrient and sediment loading, direct destruction, overfishing, habitat modification, and contamination. In addition, ocean acidification, caused by the increase in atmospheric CO2, has recently been added as a possible coral stressor. Laboratory experiments have shown that a decrease in pH causes a decrease in calcification rates.

This project aims to analyze the effects of ocean acidification during the last ~50 yrs in coral calcification across a transect from inshore to offshore in the central section of the Great Barrier Reef. Emphasis will be placed on the possible effects of the "acidic" flood plume from the Burdekin River in inshore corals.

Changes in coral calcification, will be obtained from three growth parameters including; (1) skeletal density (gr cm^{-3}), (2) annual extension rate (cm yr^{-1}), and (3) calcification rates (gr cm^{-2} yr^{-1}). The boron isotopic composition ($\delta^{11}B$) will also be measured in selected coral samples along the growth axis and can be used as a proxy for pH changes. This information will be complemented with trace elements analyses by LA-ICP-MS of some coral samples.

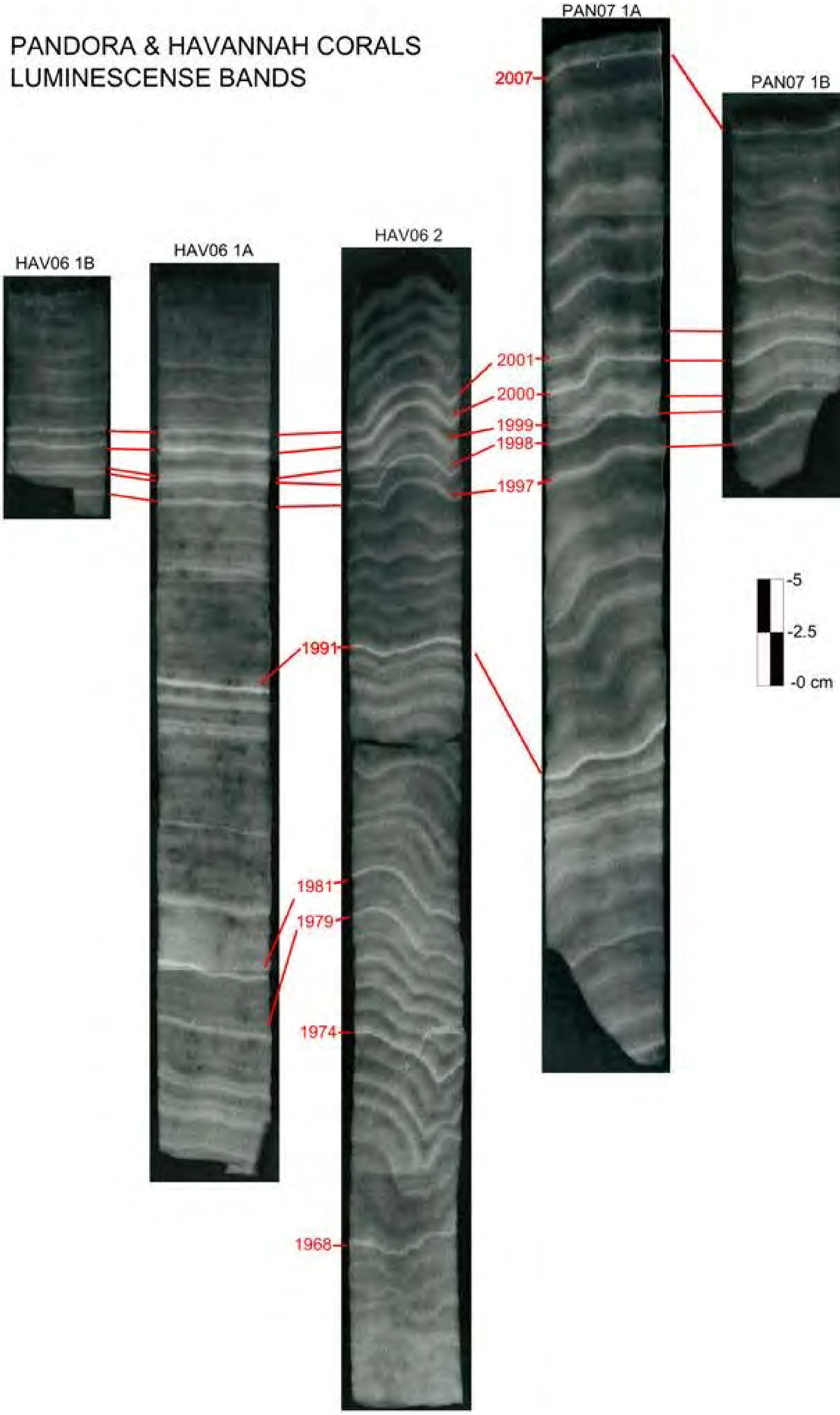


Figure 1. Black and white images of five corals from the inshore reefs of Havannah and Pandora showing the luminescent bands used to measure the linear extension rates. Some high intensity bands related to high river discharge episodes are highlighted.

Late Quaternary radiolarians as proxies for past environmental conditions in the eastern and southern sectors of the Indian Ocean

John Rogers and Patrick De Deckker

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

I examined the silica tests (the hard parts or "skeletons") of a group of plankton called *Radiolaria*. Firstly, I counted the tests appearing in the tops of sediment cores taken from 100 sites in the eastern and southern sectors of the Indian Ocean - around 600 tests per core-top and about 400 species in all. I was able to relate the distributions of the species to the currents in the eastern Indian Ocean (EIO) and to the inter-frontal zones of the southern Indian Ocean (SIO). I was also able to establish statistical relationships between the radiolarian counts and a number of physico-chemical oceanic variables (temperature, salinity, etc) over a range of depths from the surface to around 500 metres below sea level.

Next, I performed census counts on samples taken from four SIO sediment cores from between the Kerguelen Plateau and the Southeast Indian Ridge. From these data and the relationships established with the present-day physico-chemical environment, I was able to reconstruct the palaeoceanic conditions at the core sites over approximately the last 40,000 years and, hence, an indication of how the ocean fronts moved over that period. In addition, I attempt to find reflections of interactions between the Southern Ocean and the North Atlantic as reported by Sicre *et al.* (2005). There was some evidence in the radiolarian-based reconstructions of sea-surface temperature that warming in the SIO coincided with Heinrich Events H1 and H2 but the possible associations with earlier Heinrich Events were tenuous.

I also examined the statistical techniques commonly used for the analysis of plankton census counts and concluded that a number of the traditional methods are unsuitable for regions as complex as the Indian Ocean and that Weighted-Averaging - Partial Least Squares (ter Braak and Juggins, 1993; ter Braak *et al.*, 1993) was the most efficient technique available given the number of core-tops I investigated.

Sicre, M.-A., Labeyrie, L., Ezat, U., Duprat, J., Turon, J.-L., Schmidt, S., Michel, E., and Mazaud, A., 2005. Mid-latitude Southern Indian Ocean response to Northern Hemisphere Heinrich events. Earth and Planetary Science Letters, 240:724-731.

ter Braak, C. and Juggins, S., 1993. Weighted averaging partial least squares regression (WA-PLS): an improved method for reconstructing environmental variables from species assemblages. Hydrobiologia, 269/270:485-502.

ter Braak, C., Juggins, S., Birks, H., and van der Voet, H., 1993. Weighted averaging partial least squares regression (WA-PLS): definition and comparison with other methods for species-environment calibration, in Multivariate Environmental Statistics, 6, G. Patil and C. Rao (eds), pp. 525-560. Amsterdam: Elsevier Science Publishers.

doi:10.1016/j.marmicro.2007.07.001

Silicon isotopic fractionation in marine sponges: A new paradigm and model for understanding silicon isotopic variations in sponges

Martin Wille[1], Jill Sutton[1], Michael Ellwood[1], Steve Eggins[1], William Maher[2] and Michelle Kelly[3]

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

[2] Insitute for Applied Ecology, University of Canberra, ACT 0200, Australia

[3] National Centre for Aquatic Biodiversity & Biosecurity, NIWA, New Zealand

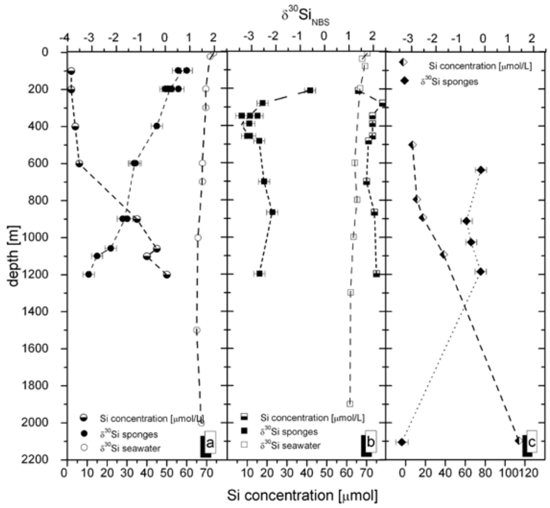


Figure 1. Depth profiles of Si concentration in seawater, d^30 Si in seawater (d^29 Si values from Cardinal et al. (2005) for Stations CTD17 and CTD124,64 were divided by 0.5092 to obtain d^30 Si values) and d^30 Si in sponges from 3 locations in the Southern Ocean; Tasmania (a - circles), Antarctica (b - squares), and New Zealand (c - diamonds). Si concentration in the New Zealand profile were obtained from the WOCE database for location 173.49E, 30.086S

The modern Southern Ocean plays a pivotal role in determine the air-sea balance of CO_2 and global biological production. However, there is debate regarding nutrient utilisation in Southern Ocean surface waters and how this transfers through to the deeper Southern Ocean, especially during the past. To fill this gap we have determined the silicon isotope composition of deep-sea sponges collected from near Antartica, subantarctic waters (Tasmania Seamounts) and subtropical waters north of New Zealand with the aim of developing a new paleo-nutrient proxy. For deep-sea sponges, δ^{30}Si values widely between 0.87 ‰ and -3.40 ‰ (vs NBS). Depth profiles show that sponge δ^{30}Si compositions trend to lighter values with increasing depth. This is exemplified by sponges from the Tasmanian Seamounts which vary from 0.87 ‰ to -3.13 ‰ over a depth range from 100 to 1200 m. We find that silicon isotope fractionaion (δ^{30}Si sponge - δ^{30}Si seawater) varies with seawater silicon concentration with more fractionated (lighter) isotope values being associated with specimens collected from water high in silicon. A mass-balance based model for silicon isotope fractionation is consistent with δ^{30}Si fractionation driven by changes in the difference between the silicon influx and efflux from the sponge. At higher seawater silicon concentrations efflux is correspondingly higher, and with δ^{30}Si having an apperant greater internal fractionation, this results in lighter δ^{30}Si spicule values. This model can also explain δ^{30}Si fractionation in diatoms and be used to reconstruct past seawater silicon concentraions from the δ^{30}Si signature of fossil sponges and diatoms.

The Quaternary comes in from the cold

Brad Pillans

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


Figure 1. Brad Pillans with Pleistocene woolly mammoth tusk recovered during alluvial gold mining at Bonanza Creek, Yukon, northern Canada

Although the name "Quaternary" has long been used by geologists to describe the period of time known as the Ice Ages, it was only in 2009 that the Quaternary Period was finally ratified as a formal subdivision of geological time by the International Union of Geological Sciences (IUGS).

The Quaternary Period, comprising the Pleistocene and Holocene Epochs, is marked by the waxing and waning of large continental ice sheets in the Northern Hemisphere during the last 2.6 million years. At the height of the most recent glacial period, about 20,000 years ago, large ice sheets covered Canada and northern USA, Scandinavia and northern Europe (including most of Britain) and Siberia - the Greenland Ice Sheet is the last remaining remnant of these once extensive Northern Hemisphere ice sheets. Small mountain glaciers also existed in the highest parts of Kosciuszko National Park and over large areas of central and western Tasmania, and with world sea levels up to 150 m lower than present, it would have been possible to walk across Bass Strait, Bering Strait and across the English Channel. Some 50 such glaciations, and subsequent interglaciations (such as the present, or Holocene interglaciation) occurred during the Quaternary, the period of time which also saw the rise and spread of the human species. During the last glaciation, iconic animal species, such as woolly mammoths, roamed across vast areas of the northern continents (Fig 1).

Ratification of the Quaternary came after intense lobbying by the International Union for Quaternary Research (INQUA), particularly over the last 5 years, and prolonged negotiations between INQUA and the IUGS commission that is responsible for managing the geological timescale, the International Commission for Stratigraphy (ICS) – see Pillans & Naish (2004), Aubry et al. (2005), Pillans (2007) and Ogg & Pillans (2008).

A paper describing the formal ratification of the Quaternary is about to be published (Gibbard et al. in press).

References

Aubry, M.P., Berggren, W.A., van Couvering, J., McGowran, B., Pillans, B., Hilgen, F., (2005) Quaternary: status, rank, definition, survival. *Episodes*, 28, 118-120.

Gibbard, P., Head, M.J., Walker, M., Alloway, B., Beu, A.G., Coltorti, M., Hall, V.M., Liu, J., Knudsen, K.-L., Van Kolfschoten, T., Litt, T., Marks, L., McManus, J., Partridge, T.C., Piotrowski, J.A., Pillans, B., Rousseau, D.-D., Suc, J.-P., Tesakov, A.S., Turner, C., Zazo, C., (in press) Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.588 Ma. *Journal of Quaternary Science*.

Ogg, J.G., Pillans, B., (2008) Establishing Quaternary as a formal international Period/System. *Episodes*, 31, 230-233.

Pillans, B., (2007) Defining the Quaternary: Where do we go from here? *Stratigraphy*, 4, 145-149.

Coral and Speleothem Reconstructions of Ocean-Atmosphere Dynamics in Southern Indonesia during the 8.2 ka event

J. Mazerat[1], M.K. Gagan[1], H. Scott-Gagan[1], G.B. Dunbar[2], L.K. Ayliffe[1], L. Edwards[3], J.-x. Zhao[4], W.S. Hantoro[5] and B.W. Suwargadi[5]

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

[2] Antarctic Research Centre, Victoria University of Wellington, PO Box 600, Wellington 6012, New-Zealand.

[3] Dept. of Geology and Geophysic, University of Minnesota, USA.

[4] Centre for Microscopy and Microanalysis, The University of Queensland, Brisbane, Queensland 4072, Australia

[5] Research and Development Center for Geotechnology, Indonesian Institute of Sciences, Jalan Cisitsu No. 21/154 D, Bandung 40135, Indonesia

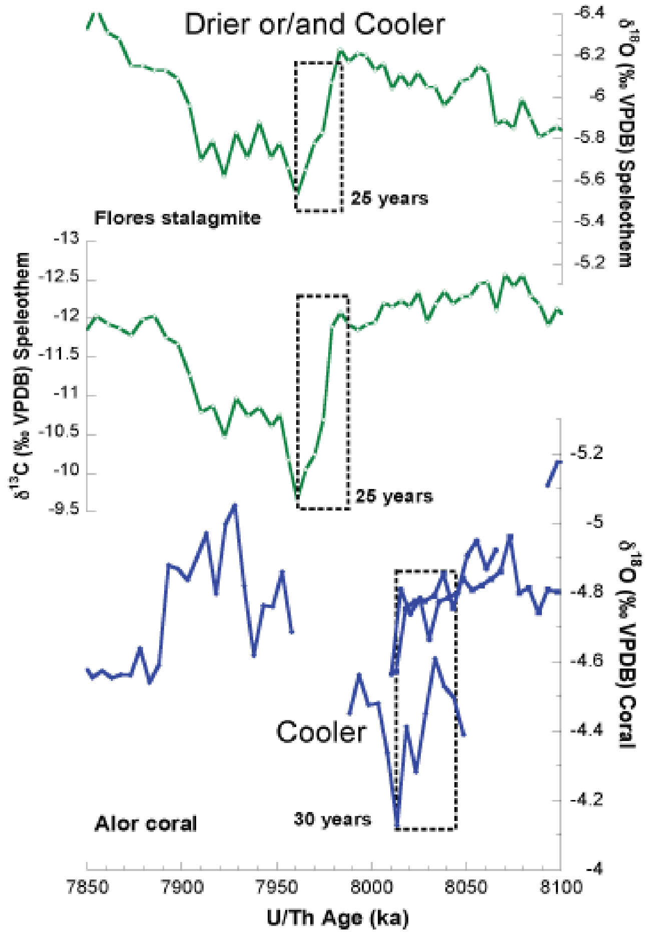


Figure 1. Similarities in length and strength of the 8.2 ka climatic event in the stalagmite $\delta^{18}O$ and $\delta^{13}C$ records from Flores and coral $\delta^{18}O$ from Alor, Indonesia.

A variety of natural archives have been interpreted as indicating major changes in the strength of the Australasian monsoon and El Niño-Southern Oscillation (ENSO) through the Holocene. Geochemical tracers in coral skeletons are particularly well suited for reconstructing coupled ocean-atmosphere climate systems at seasonal to interannual timescales. The high temporal resolution offered by corals is especially important to study the variability of parameters such as sea surface temperature (SST) and the hydrological cycle on ENSO-monsoon timescales. However, most coral studies have focussed on the past millennium because coral aragonite is prone to diagenesis, and it is difficult to find pristine corals in the early to middle Holocene when the monsoon and ENSO may have been quite different from what we know today.

In the first instance, we performed stable isotope ($\delta^{18}O$, $\delta^{13}C$) analysis of the corals at 5-year resolution to detect any changes in the mean climate state. Our preliminary results, from the analysis of several well-preserved massive *Porites* corals from Alor (southern Indonesia), with U-series ages of 8.5 to 7.9 ka (thousand years ago), show a double cool/dry-snap with SSTs reachingminima at 8.3 and 8.0 ka. These rapid coolings (2-3°C in 30 years)are synchronous in time, length and strength, with sharp increases in the $\delta^{18}O$ of speleothems from the nearby island of Flores.

Based on this result, specific periods have been targeted for high-resolution isotope analysis to document how ENSO and monsoonal rainfall change in response to abrupt changes in the mean climate state. With these high-resolution analysis, we were able to reconstruct the annual $\delta^{18}O$ cycle for several time periods during the modern time and the early Holocene (mean climate state, onset of the cold snap and the cold snap). These results show that during the early Holocene, the australasian monsoon was weaker than today, but there is no real evidence for a weaker monsoon during the 8.2 ka event.

Thus, it appears that the 8.2 ka event in the Australasian region would have been only a cold event and not a dry one as suggested by previous studies.

Climate change and coral reefs

Hurricanes and bleaching

Mallela, J[1] and Crabbe MJC[2]

[1] ARC Centre of Excellence for Coral Reef Studies & Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] LIRANS Institute for Research in the Applied Natural Sciences, Faculty of Creative Arts, Technologies and Science, University of Bedfordshire, Park Square, Luton LU1 3JU, UK

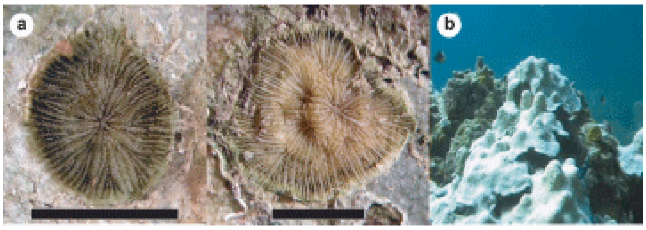


Figure 1. (a) Coral recruits (scale bar 5 mm); (b) 2005 coral bleaching in Tobago

Knowledge of coral recruitment patterns helps us understand how reefs react following major disturbances and provides us with an early warning system for predicting future reef health problems. We have reconstructed and interpreted historical and modern-day recruitment patterns, using a combination of growth modelling and in situ recruitment experiments, in order to understand how hurricanes, storms and bleaching events have influenced coral recruitment on the Caribbean coastline of Tobago.

Whilst Tobago does not lie within the main hurricane belt results indicate that regional hurricane events negatively impact coral recruitment patterns in the Southern Caribbean. In years following hurricanes, tropical storms and bleaching events, coral recruitment was reduced when compared to normal years ($p = 0.016$). Following Hurricane Ivan in 2004 and the 2005–2006 bleaching event, coral recruitment was markedly limited with only 2% ($n = 6$) of colonies estimated to have recruited during 2006 and 2007. Our experimental results indicate that despite multiple large-scale disturbances corals are still recruiting on Tobago’s marginal reef systems, albeit in low numbers.

CofE research page
http://www.coralcoe.org.au/people-postfellows.html

ANU research page
http://rses.anu.edu.au/people/mallela_j/

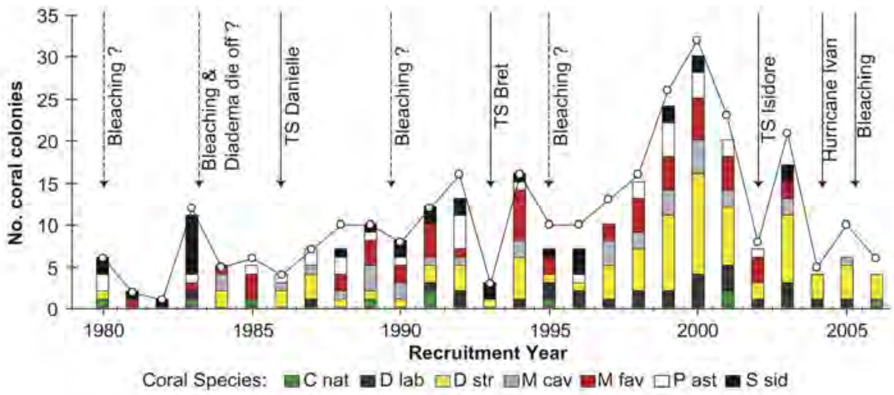


Fig. 2. The estimated year of recruitment for all coral colonies in this study 1980–2006 (solid black line), solid arrows indicate when hurricanes, tropical storms (TS) and bleaching events occurred. Dashed arrows indicate events which may have impacted Tobago's reefs but were not cited in records. The histogram underneath gives the estimated year of recruitment for dominant coral species: *Colpophyllia natans* (green), *Diploria labyrinthiformis* (dark grey), *Diploria strigosa* (yellow), *Montastrea cavernosa* (light grey), *Porites astreoides* (white), *Siderastrea siderea* (black). (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

Figure 2.

High resolution Sr concentration and isotope distributions in a Neanderthal tooth from Payre (Ardèche, France) using laser ablation ICP-MS

Rainer Grün[1], Maxime Aubert[1], Marie-Hélène Moncel[2], Richard Armstrong[1], Ian Moffat[1], Tegan Kelly[1], Manfred Thönnessen[3] and Ulrich Radtke[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Département de Préhistoire, Muséum National d'Histoire Naturelle, 1 Rue René Panhard 75013 Paris, France
[3] Geographisches Institut, Universität zu Köln, Albertus-Magnus-Platz, 50923 Köln, Germany

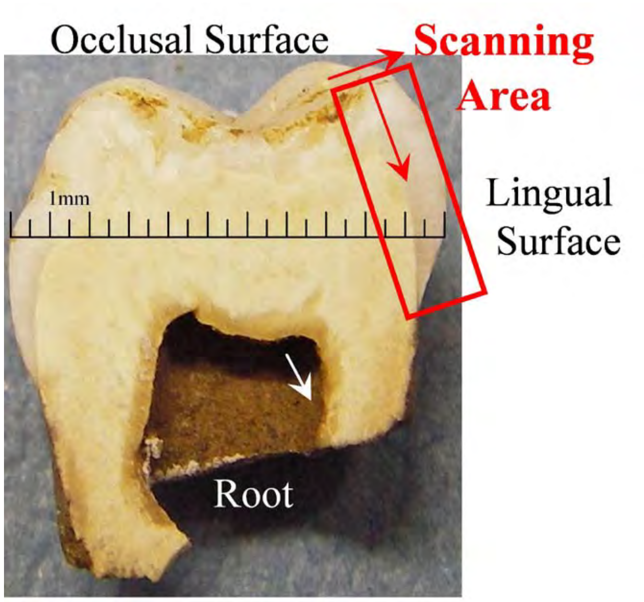


Figure 1. Photo of the Neanderthal tooth from Payre and position of the area that was scanned for Sr (^{88}Sr) elemental concentrations with a quadrupole ICP-MS and $^{87}Sr/^{86}Sr$ isotopic composition with a multi-collector ICP-MS.

We have mapped Sr elemental concentrations as well as $^{87}Sr/^{86}Sr$ isotope distributions in a Neanderthal tooth from the Middle Palaeolithic site of Payre using laser ablation ICP-MS. The tooth is an unerupted molar of a three year old child. The dentine shows a clear overprint of Sr with the isotopic composition of the Jurassic bedrock in which the site is located. In enamel we observe a relationship between Sr concentration and isotopic composition that also indicates a secondary overprint. Nevertheless, certain domains in the enamel seem to preserve the original isotopic signature. These results indicate that the individual grew up in a significantly different geochemical rock province to where it was found. Analyses of the bioavailable Sr in the surrounding areas of the site point to a metamorphic province, some 50 km to the SW of Payre, as possible origin of this Neanderthal individual who must have moved to the to the site shortly before its premature death.

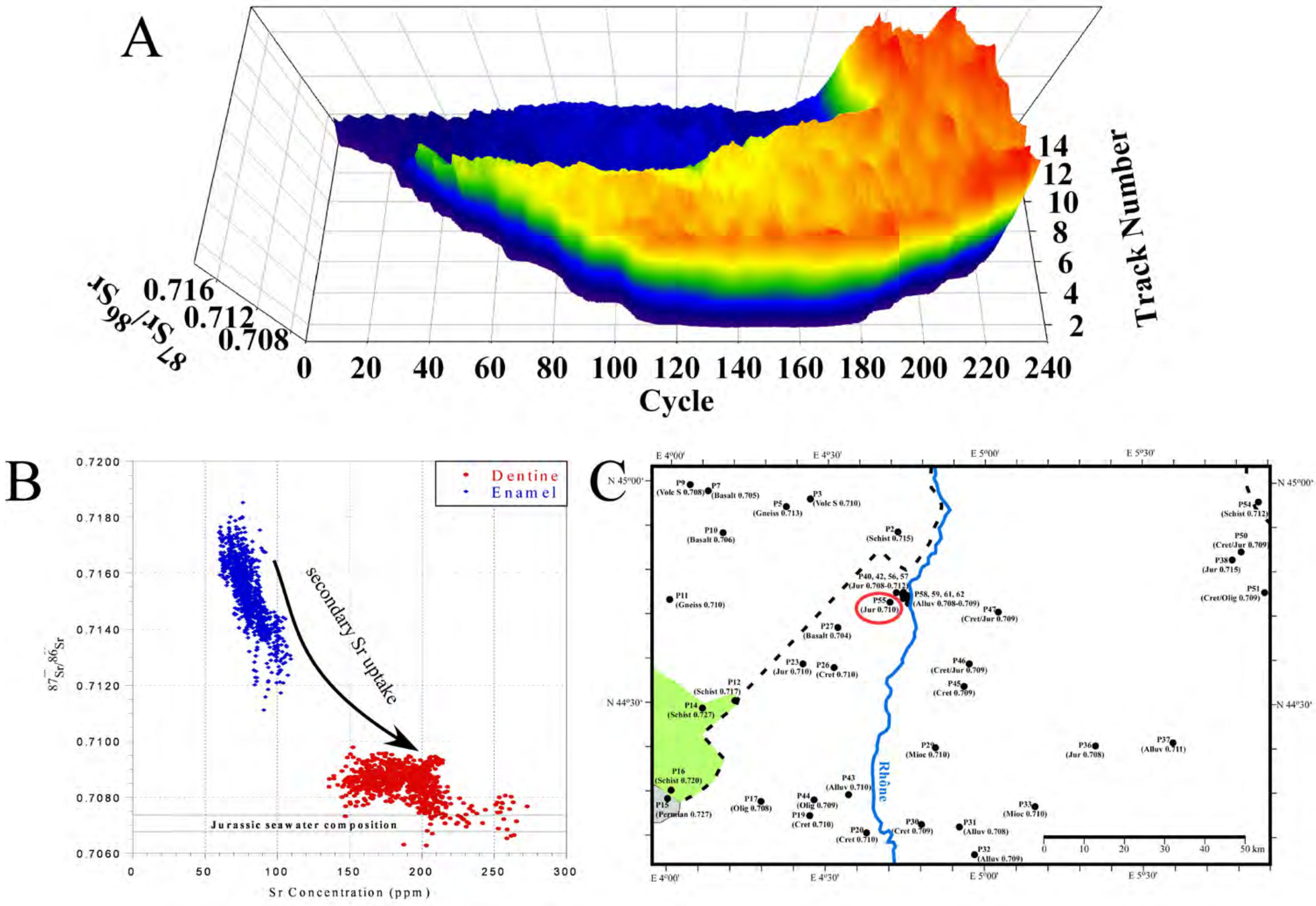


Figure 2. **A:** $^{87}Sr/^{86}Sr$ isotopic composition. **B:** Relationship between Sr concentration and $^{87}Sr/^{86}Sr$ isotopic composition. The general trend of lower $^{87}Sr/^{86}Sr$ ratios with increasing Sr concentration can be explained through a diagenetic overprint of soluble Sr with an $^{87}Sr/^{86}Sr$ composition close to the bedrock. **C:** Results of Sr analysis of plants of the rock provinces in the vicinity of Payre (circled). Abbreviations: Alluv: Alluvium, Cret: Cretaceous, Jur: Jurassic, Mioc: Miocene, Olig: Oligocene, Volc S: volcanic sediment. The dotted lines mark the approximate boundary between metamorphic rocks (Massif Central and Alps) and Triassic to Quaternary sediments. Areas of possible origin are coloured.

A new chronology for sea level highstands during the penultimate interglacial

Andrea Dutton[1], Edouard Bard[2], Fabrizio Antonioli[3], Tezer Esat[1], Kurt Lambeck[1] and Malcolm McCulloch[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] CEREGE, UMR 6635 CNRS, Aix-Marseille University, College de France, Aix-en-Provence, France
[3] ENEA, Rome, Italy

Figure 1. Fabrizio Antonioli discovers submerged stalagmites in Argentarola Cave, Italy.

Understanding the precise phase relationships of changes in sea level, temperature, and greenhouse gas concentrations during previous interglacial periods provides us with critical knowledge to evaluate the future response of the climate system to anthropogenic forcing. Absolutely-dated sea level archives that document the response of ice sheets to changes in temperature and atmospheric CO_2 become increasingly rare as we look beyond the last interglacial due to the combined effects of alteration, physical superposition of multiple sea level oscillations, and challenges related to temporal limitations of geochronometers.

We have studied a suite of submerged stalagmites from Argentarola Cave, Italy collected across a depth range of -18 to -21 m to improve the absolute chronology of several sea level highstands during MIS 7, also referred to as the penultimate interglacial (Fig. 1). The spectacular feature of speleothems recovered from Argentarola Cave is the occurrence of alternating layers of biogenic calcite and spelean calcite that result from multiple sea level oscillations in the past. The biogenic layers are composed of serpulid calcite secretions that encase the speleothems during seawater submergence while the spelean calcite growth only occurs when the cave is emergent, or above sea level. We have used U-series dating techniques to determine the precise timing of speleothem growth that brackets each serpulid calcite layer to ascribe a chronology to three sea level highstands during the penultimate interglacial. The second highstand, also known as marine isotope stage (MIS) 7.3, is observed to peak at a lower elevation than the other two highstands and appears delayed in timing relative to peak northern hemisphere insolation. We postulate that this behaviour results from the intense cold period preceding MIS 7.3 that was associated with significant development of ice sheets in the northern hemisphere.

Our findings underpin the importance of cryosphere state as a critical factor determining the sensitivity of sea level response to insolation forcing. While records from submerged speleothems such as this are rare, they are archives that have enormous potential to shed light on the dynamics of climate and sea level in the past, and also to inform us about the interplay of these variables as we head into the future.

More details can be found at Nature Geoscience.

Dutton et al (2009) Nature Geoscience
http://dx.doi.org/10.1038/NGEO470

Rhodoliths as environmental proxies in the marine realm,

or how red algae could help fill the climatic gap between the tropics and the poles.

Nicolas Darrenougue[1], Patrick De Deckker[1], Stephen Eggins[1] and Claude Payri[2]

[1] Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia
[2] Institut de Recherche pour le Developpement, Noumea, New Caledonia

Figure 1. Rhodolith bed covering the seafloor. Point Addis Marine National Park (Victoria). *Image courtesy of Parks Victoria.*

Rhodoliths are free-living forms of calcareous, coralline red algae that can be found worldwide, from low to high latitudes, in relatively shallow (0->250m) waters. They can live hundreds of years and form a high-Mg calcite skeleton that presents periodical growth bands.

Recent studies on rhodoliths-forming coralline red algae show that the variation of specific trace elements along these periodical growth bands appear to reflect, through time, the variations of ambient seawater temperature and river discharges. This project aims to assess this reliability of rhodoliths as a new proxy to record past environmental changes for subtropical to temperate waters. Two study sites were chosen, one in the lagoon of New Caledonia (subtropic) and one offshore Victoria (temperate) for comparison of environmental parameters. Trace elements analyses by Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA.ICPMS) and $\delta^{18}O$ by Sensitive High Resolution Ion MicroProbe (SHRIMP) will be performed across growth transects on selected rhodoliths to obtain this high-resolution record of past environmental conditions.

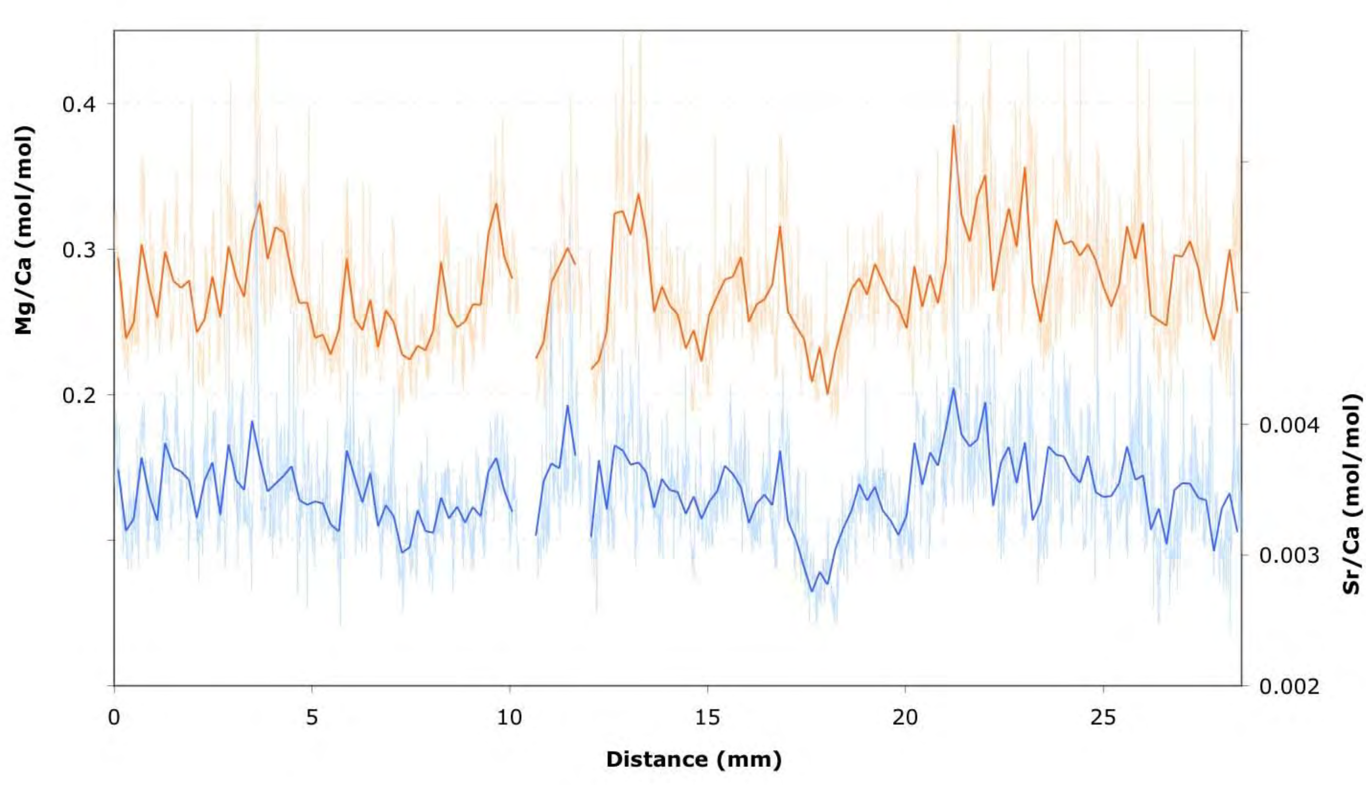


Figure 2. Preliminary results from LA.ICPMS, showing variations of Mg/Ca (orange) and Sr/Ca (blue) ratios along a rhodolith section of 28.5 mm, collected in New Caledonia. 24 points smoothed data are presented in plain lines.

Reconstructing the history of hydrologic change and drought in Australia

Evidence from Lake George, New South Wales

Kathryn E. Fitzsimmons[1], Timothy T. Barrows[2], Geoff A.T. Duller[3], Helen M. Roberts[3] and Ann G. Wintle[3]

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

[2] *School of Geography, Archaeology and Earth Resources, The University of Exeter, Exeter, Devon, EX4 4RJ, UK*

[3] *Institute of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, UK*

Temperate southeastern Australia is one of the regions hardest hit by the drought which has prevailed on the continent for more than ten years from 1997-2009. It is unclear how the present relatively arid, warm conditions relate to the cold, dry climate responsible for desert expansion during the late Quaternary period, or to the current severe droughts. This knowledge gap is primarily due to the fact that there are few systematic records of regional aridity and drought in Australia. The key to understanding the development of aridity is to produce a chronological framework for terrestrial aridification. Recent and continuing work at the luminescence dating laboratory in the Research School of Earth Sciences aims to produce such a chronological framework, focusing on key sites which preserve landscape features responsive to aridity, such as dunes and lake shorelines.

The Canberra region, in particular, has experienced record low precipitation in response to the current drought. Lake George, a closed basin located approximately 50 km from Canberra and once mainland Australia's largest freshwater lake, has completely dried in response to this recent drought. The lake has intermittently filled to a shallow depth, and dried out, eight times during the period since European arrival 200 years ago. The timing of these events matches that of historically documented droughts. The lake acts as a palaeo-rain gauge for the region, providing past context for present and future potential climatic conditions. Lake George therefore represents one of the most complete and valuable records of hydrologic variability as a response to drought and potentially increasingly dry conditions in southeastern Australia. However, regional hydrologic and environmental change over longer timescales - throughout the Holocene and Pleistocene - remains poorly resolved, lacking a comprehensively dated stratigraphic sequence. Consequently, it is difficult to identify how the present drought relates to past conditions.

At Lake George, hydrologic change brought about by climatic variability is expressed in lake shorelines. The lake has intermittently dried and filled to depths of up to 37 m several times during the late Quaternary period. Chronologies for lake level change fundamentally underpin interpretations of palaeoclimate. Our work addresses the existing limitations to reconstructing Holocene palaeoenvironmental change at Lake George by applying optically stimulated luminescence (OSL) dating to stratigraphic sequences along previously occupied shorelines. These represent the last phases of significantly high lake levels prior to present conditions and document changing hydrologic conditions through the Holocene. OSL dating circumvents many of the issues associated with earlier radiocarbon chronologies by directly dating when sediments were deposited. We construct a chronologic framework using OSL for hydrologic variability in southeastern Australia throughout the Holocene, and place the 1997-2009 drought conditions in the context of climate change (Fitzsimmons and Barrows, in press). We have assessed the luminescence behaviour of the samples with respect to depositional context and age (Fitzsimmons et al., in press). We are also presently seeking to extend the chronology beyond the limits of conventional SAR OSL dating through the use of thermally-transferred OSL (Tsukamoto et al. 2008), and are contributing to the development of this new technique.

The OSL chronology indicates three distinct periods of permanent lake conditions up to 15-18 m depth over the Holocene period, at approximately 10-8, 6-2.4 and 0.7-0.3 ka, with lower lake levels occurring in between those events (Fitzsimmons and Barrows, in press) (Figure 1). There appears to be a trend towards lake regression over this period despite relatively recent high lake levels. The chronology is broadly synchronous with comparable records of Holocene climatic variability across southeastern Australia. The preliminary OSL chronology for events older than the Holocene period shows a striking correlation between lake filling at Lake George and permanent lake conditions/ high water tables across humid, semi-arid and arid Australia. The Holocene and oxygen-isotope stage 5 filling events at Lake George correspond to warm sea-surface temperatures. Lake filling events also appear to correspond to relatively humid periods between major arid episodes in the desert dunefields of central Australia, also identified by OSL dating in the luminescence laboratory at the Research School of Earth Sciences (Fitzsimmons et al. 2007).

Fitzsimmons, K.E., Barrows, T.T. (in press) Holocene hydrologic variability in temperate southeastern Australia: An example from Lake George, New South Wales, The Holocene.

Fitzsimmons, K.E., Rhodes, E.J., Barrows, T.T. (in press, 2009) OSL dating of southeast Australian quartz: A preliminary assessment of luminescence characteristics and behaviour, Quaternary Geochronology.

Fitzsimmons, K.E., Rhodes, E.J., Magee, J.W., Barrows, T.T. (2007) The timing of linear dune activity in the Strzelecki and Tirari Deserts, Australia. *Quaternary Science Reviews* 26: 2598-2616.

Tsukamoto, S., Duller, G.A.T., Wintle, A.G. (2008) Characteristics of thermally transferred optically stimulated luminescence (TT-OSL) in quartz and its potential for dating sediments. *Radiation Measurements* 43: 1204-1218.

Link to Fitzsimmons et al. (in press), Quaternary Geochronology
http://www.sciencedirect.com/science/article/B83WJ-4VNK6D3-3/2/4c57a7dab67559817446c66820f98cba

Link to Fitzsimmons et al. (2007), Quaternary Science Reviews
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VBC-4P9T9VH-1&_user=554534&_coverDate=10%2F31%2F2007&_alid=1083904081&_rdoc=1&_fmt=high&_orig=search&_cdi=5923&_sort=r&_docanchor=&view=c&_ct=2&_acct=C000028338&_version=1&_urlVersion=0&_userid=554534&md5=c0ea3123deaebc41e87c55327ff6b499

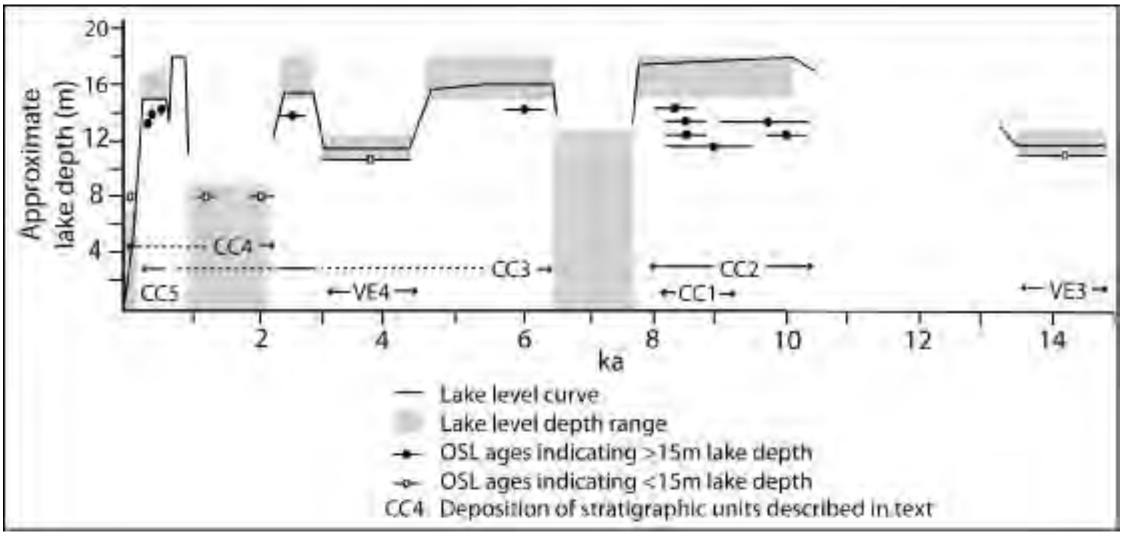


Figure 1. Holocene hydrological variability at Lake George.

Which climate signals are captured in tropical speleothem records?

Sophie C. Lewis[1], Allegra N. LeGrande[2], Maxwell C. Kelley[2] and Gavin A. Schmidt[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] NASA Goddard Institute for Space Studies and Centre for Climate Systems Research, Columbia University, 2880 Broadway, New York, NY, 10025, USA

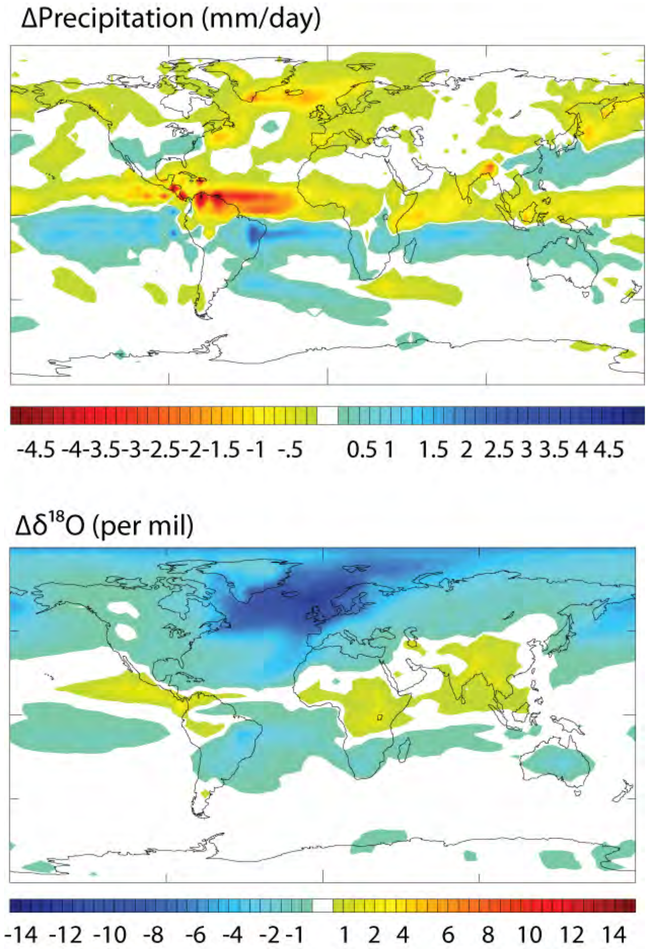


Figure 1. Changes in precipitation (mm/day) and $\delta^{18}O$ (per mil) during the Heinrich-like simulation

Speleothems are calcium carbonate cave deposits, such as stalagmites, which potentially yield annual to decadal records of past climate change. In the tropics, changes in the oxygen isotopic composition ($\delta^{18}O$) in speleothems, which is related to the composition of local rainfall, indicate that rapid shifts occur in tropical hydrology during the so-called "Heinrich events." The last glacial period (between 100 and 200 thousand years ago) was punctuated by these abrupt cool periods that result from massive iceberg discharges into the North Atlantic. Changes in oxygen isotopic ratios in speleothems are often interpreted in terms of changes in rainfall amount. Throughout the monsoon regions, isotopic shifts in speleothems during these climatic excursions have been interpreted as a widespread drying though the Northern Hemisphere and a wetting in the south.

We examine the climatic controls of oxygen isotopes in tropical precipitation using the GISS ModelE general circulation model. Using this climate model, we simulate a collapse of the North Atlantic overturning circulation as an analogue to a Heinrich event. Figure 1 shows the changes in precipitation amount and isotopic composition of rainfall during this simulation. A decrease in monsoon intensity is simulated over East Asia and India and an increase in intensity is simulated over South America and Australia. The drivers of variability in isotopic compositions are found to be complex and dynamic, linked to large-scale changes in monsoon strength, water vapour transport, atmospheric mixing and changes in the source of precipitation to a site, and do not simply reflect local precipitation amount and temperature effects. Ultimately, oxygen isotopes are a useful recorder of tropical hydrological changes, which can be understood in more detail using climate models that include water isotope tracers.

Earth Materials and Processes

Introduction

The Earth Materials and Processes area comprises research groups in Rock Physics, Experimental Petrology, and Structure & Tectonics. Our research centres around laboratory based measurements under controlled conditions, simulating those occurring in nature, but these activities are complemented by a rich array of analytical equipment and are supported by extensive field-based observations, often in collaboration with scientists from other institutions, nationally and internationally. Through such investigations we aim to develop understanding of the structure and chemical composition of planetary interiors, and the processes by which planets evolve. Our interests start at the very beginning of solar system history with how the Earth and other rocky planets accrete, and then cover the ongoing processes of 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.
- Oxidation state and coordination of metal ions at high temperatures. Studies of crystals, melts and hydrothermal solutions by X-ray absorption spectroscopy, using synchrotron radiation. Studies of silicate glasses and melts to very high temperatures under controlled redox conditions. Analysis of hydrothermal solutions trapped in synthetic fluid inclusions is providing important basic information on metal complexes at high temperatures.
- Coupling between fluid flow and fault mechanics in the continental crust. Field-based studies of a normal fault system in Oman, along with complementary stable isotope and other geochemical studies of associated calcite vein systems, are being used to explore how fault-controlled fluid flow is localized among components of regionally extensive fault networks. Field-based and microstructural studies in two examples of intrusion-related ore systems (Porgera, PNG, and North Parkes, NSW) are providing insights about the dynamics of growth of fracture-controlled hydrothermal systems and localization of ore deposition in these settings. Laboratory studies of the seismic properties of the cracked and fluid-saturated rocks of the upper crust
- The mission to planet Earth in which we construct a virtual time machine (in collaboration with U. Sydney) to provide a spatio-temporal context that will allow a greater understanding of planetary tectonics from the point of view of plate-scale physical processes. This infrastructure development is supported by the NCRIS AuScope initiative. To provide critical data for the tectonic reconstructions, "listening posts" are being established that provide samples that can be analyzed and dated using 40Ar/39Ar and U-Pb geochronology in the Earth Chemistry.

Environmental Tracers in Waters of the Lower Murrumbidgee Catchment, New South Wales

Kyle N. Horner[1], D.C. "Bear" McPhail[1], Marc D. Norman[1], Wendy McLean[2] and John G. McDonald[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Parsons Brinckerhoff, Ernst & Young Centre, Level 27, 680 George St., Sydney, NSW 2000, Australia

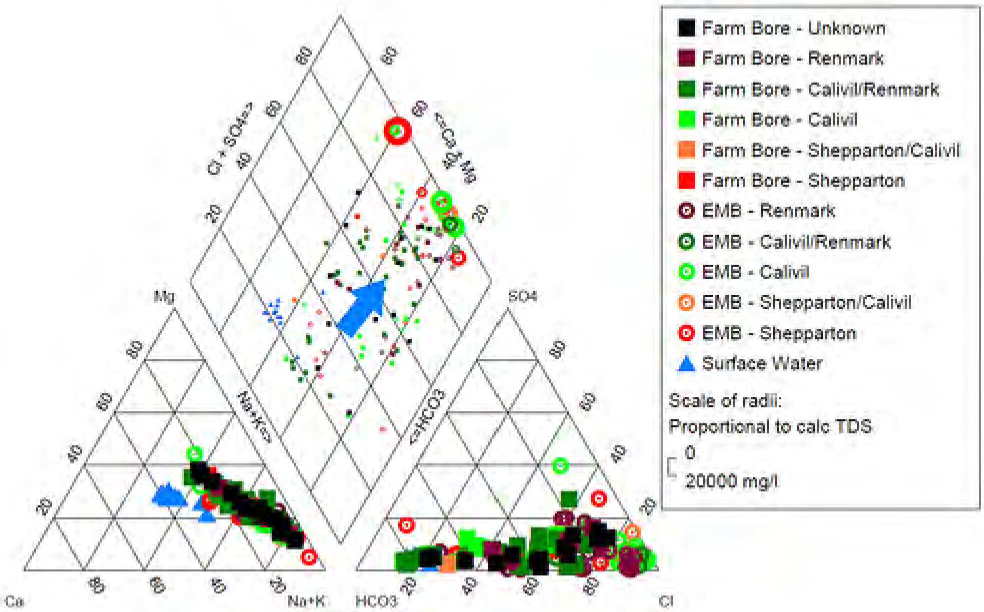
Figure 1. Extensive irrigated agriculture occurs on the alluvial sediments of the Lower Murrumbidgee catchment.

The semi-arid Lower Murrumbidgee catchment in south-central New South Wales hosts agricultural and horticultural industries that generate more than one billion dollars in crops annually. Irrigation water in the region is predominantly sourced from the Murrumbidgee River, with supplemental water extracted from local aquifers.

During the first year of a three-year ARC-Linkage grant held by ANU and Parsons Brinckerhoff, a field program was initiated in 2009 to sample water from irrigation extraction bores, environmental monitoring bores, and rivers throughout the Lower Murrumbidgee to characterize and quantify groundwater dynamics in the region. To date, over 150 water samples have been collected and analysed for a major, minor, and trace elements as well as select stable and radio isotopes. This research has produced the most comprehensive and largest-scale hydrogeochemical data set available for the region.

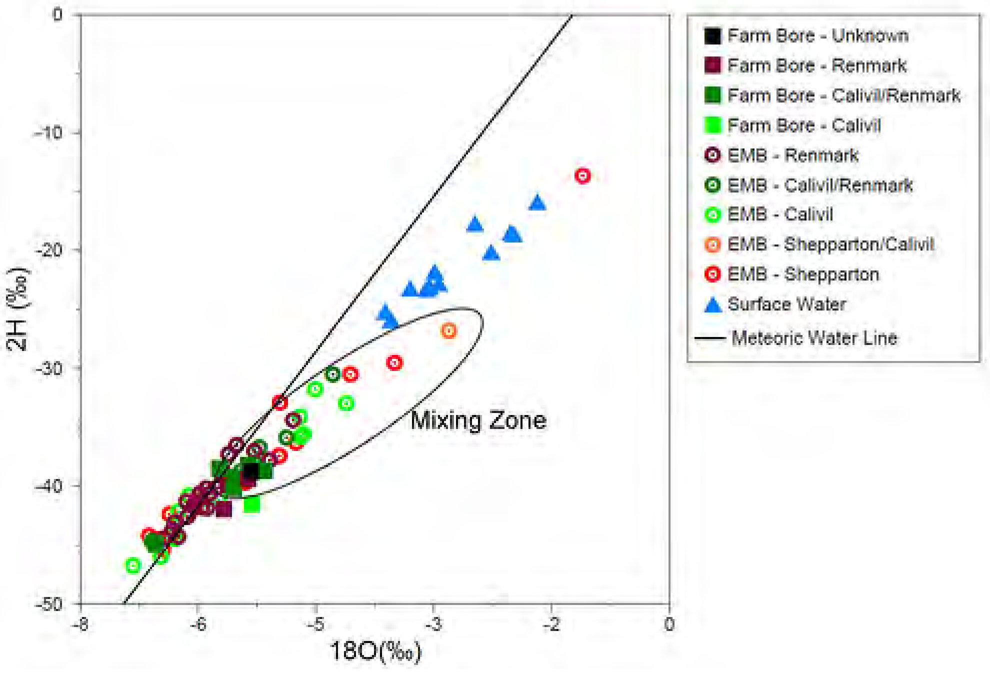
Figure 2. To date, more than 150 samples have been collected from water bodies across the study area, including irrigation bores, some of which pump more than 20 ML/day during the irrigation season.

Environmental tracer concentrations in water samples have been reviewed for insight into processes influencing groundwater quantity and quality. Analytical results illustrate that groundwater chemistry evolves in the direction of groundwater flow from an Na-HCO3-Cl type water to an Na-Cl type water at higher TDS concentrations.



Cl/Br ratios and $^{2}H/^{18}O$ isotope concentrations indicate that the increase in groundwater TDS is primarily the result of evaporation and transpiration of meteoric waters, consistent with the findings of studies conducted in adjacent catchments. A significant finding is that mixing of surface waters and shallow groundwater is most pronounced in aquifers under the main irrigation areas, adjacent to the

Murrumbidgee River, and in areas of groundwater discharge. Regions outside of the irrigation areas exhibit no significant evidence of surface water/groundwater mixing.



Preliminary results from this research were presented at the 10th Australasian Environmental Isotope Conference & 3rd Australasian Hydrogeology Research Conference held from 1-3 December 2009 in Perth, WA. Future research includes the continuation of the current sampling protocol to identify seasonal trends in water quality, and the selection of characteristic sites within the Lower Murrumbidgee for higher-frequency sampling.

ANU Author Websites:

Kyle Horner

Bear McPhail

Marc Norman

Dynamic permeability and the evolution of fluid pathways in fault networks

Stephen F Cox[1], Paul Stenhouse[1] and Janos Urai[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] RWTH-Aachen, Germany

At elevated temperatures, and especially in the presence of reactive pore fluids at depth in the Earth's crust, permeability in rocks may be destroyed rapidly by compaction, pore cementation and crack healing and sealing processes. The repeated re-generation of fracture-controlled permeability therefore plays a critical role in governing fluid escape from overpressured reservoirs (such as prograding metamorphic crust, subducting slabs, crystallizing magmatic bodies and compacting sedimentary basins), and redistribution of those fluids within the crust.

The migration of aqueous fluids through active fault networks impacts on a number of important Earth processes. These include the generation of hydrothermal ore deposits and the deformational response of the crust to tectonic plate interactions. For example, fluid overpressures can play a critical role in driving brittle failure and are implicated in earthquake processes in some geodynamic settings. However, our fundamental understanding of growth and behaviour of fluid pathways in active fault systems at depth in the crust is limited. Key questions concern the relative roles of stress and fluid pressure in driving the formation of fracture-controlled permeability networks at various scales, and how these different drivers influence the evolution of hydraulic connectivity and fluid pathways.

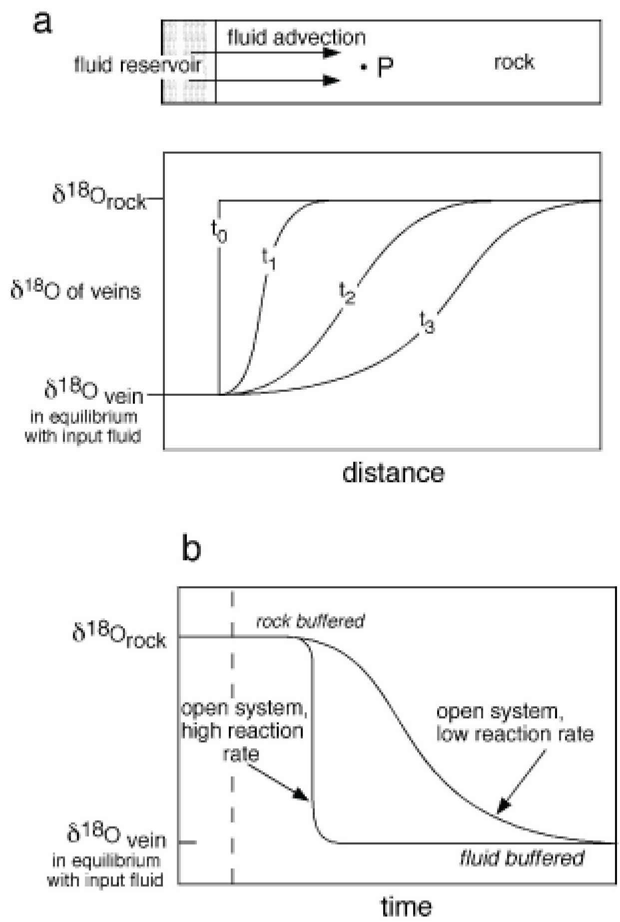


Figure 1. (a) Changes in $\delta^{18}O$ composition of veins as a function of distance from fluid inlet during continuous advective transport and reaction involving kinetically-controlled isotopic exchange. Isotopic profiles are given for times t_0 to t_3. Note that the isotopic front migrates in the flow direction with time. (b) Evolution of isotopic composition of veins with time at one point (P) in the flow path. Isotopic compositions of veins are very dependent on flow rates. After Cox (2007).

In actively deforming, reactive fluid-rock systems, permeability is a dynamic, time-variant parameter controlled by competition between various permeability-destruction processes and deformation-induced, or fluid-pressure-induced, permeability-creation processes (Cox, 2005). In seismogenic fault zones, for example, large and sudden permeability enhancement can occur during earthquake rupture events. In contrast, the much longer interseismic period is characterised by gradual permeability destruction associated with fracture healing and sealing (Tenthorey & Cox, 2006; Giger et al, 2007). Repeated breaching of fluid reservoirs by earthquake ruptures, followed by hydrothermal sealing of pathways and shut-off of flow, should foster the development of episodic, rather than continuous, flow regimes. Little is known about how such "toggle-switching" of permeability (Miller & Nur, 2000) might impact on the evolution of fluid pathways during ore genesis in fault systems, and more generally in fracture-controlled flow networks during upper crustal deformation. "Toggle switching" of permeability should lead to repeated changes in fluid pathways as failure events migrate around fracture systems. This has important implications for network connectivity, and may result in segments of fracture-controlled flow networks switching repeatedly from above to below the percolation threshold. As there are likely to be feedbacks between localisation of fluid migration and nucleation of seismicity, understanding the nature of coupling between dynamic permeability, fluid flow rates, fluid pressure states and deformation processes is critical for understanding how fluid pathways may evolve in space and time. This knowledge is critical also for understanding what factors favour the extreme flow localisation required to form many types of hydrothermal ore deposits in brittle deformation regimes, and for understanding the possible roles of fluids in affecting how seismicity patterns evolve in space and time.

In light of these observations, key motivations for this project are the following questions:

- How do interactions between stress states, fluid pressures, permeability and fluid-rock reactions

influence the growth, time-dependent permeability structure, and evolution of fluid pathways in fault-related fluid flow networks?
• What are the implications of these interactions for fluid redistribution processes in the crust, especially in relation to their impact on epigenetic ore formation, the mechanical behaviour of the crust, and seismicity patterns?

Many vein systems that are preserved in exhumed fault zones represent ancient, fracture-controlled fluid pathways. Vein systems are developed at various scales, and range from localised arrays of veins associated with small faults to regional-scale vein networks or swarms. The chemistry of vein minerals has potential to reflect the composition of the fluids from which they grew. Importantly, changes in vein mineral chemistry during incremental vein growth can preserve a record of changes in fluid chemistry in space and time. Barker et al (2006) used high spatial resolution isotopic and trace element analyses to document progressive changes in isotopic compositions, rare earth element (REE) concentrations, and redox states during growth of one vein. In this project, this approach is being extended across a regionally-developed, fault-related vein system to explore spatial and temporal variations in vein mineral chemistry during advective flow, and thereby use geochemical tracers to explore aspects of the dynamics and evolution of fluid pathways during growth of a fault system.

A key factor in using geochemical tracers to explore the operation of flow systems is that, as fluids migrate downstream along pathways, isotopic and element exchange occurs between fluids and the rocks through which they percolate. As externally-sourced fluids react progressively with rocks along the flow path, their compositions become more rock-buffered towards the downstream parts of the system (Figure 1). Reactive transport modelling of isotopic profiles in veins and wall-rocks along flow paths can be used to constrain flow directions and fluid fluxes. The shapes and positions of geochemical fronts are influenced by parameters such as flow rates and net fluid flux, temperature-dependent exchange rate constants, and effective reactive surface areas. In continuous flow regimes, geochemical fronts migrate with time in the fluid flow direction (Figure 1). In contrast, in episodic flow regimes, each batch of migrating fluid may react separately with wall-rocks and the position of the geochemical front will be dependent on the fluid flux during each pulse of fluid flow (Cox, 2007).

Calcite-rich vein systems formed in upper crustal regimes in limestone sequences provide great potential for preserving the record of fracture-controlled flow. In low temperature (150-300ºC) environments, C/O isotope, trace element, and Sr-isotope signatures in veins and host rocks can exhibit negligible re-equilibration after vein formation (eg, Barker et al, 2006; Cox, 2007). Additionally, fluids derived from reservoirs outside limestone sequences are usually substantially out of chemical equilibrium with limestones, and leave a distinctive signature in vein calcite deposited prior to fluids becoming rock-buffered along their pathways. Finally, high precision, high spatial resolution analytical techniques now allow the chemical signature of fluids to be examined cost-effectively at very fine scales during incremental growth of veins. This opens the way to produce high resolution records of spatial and temporal variations in fluid chemistry during formation of vein systems in fracture-controlled, advective flow regimes.

Coupling geochemical tracer analysis with a physical understanding of how fracture-controlled percolation networks may evolve, accordingly has potential to provide new insights about how fracture-controlled flow networks evolve and influence fluid redistribution in the crust.

In this project, we are conducting structural and microstructural studies of exceptionally well-exposed, calcite-rich vein systems that are hosted by a system of normal faults in a limestone sequence in the Jebel Akhdar dome in Oman. The structural studies are being combined with high spatial resolution C/O stable isotope, Sr isotope, and trace element analysis of vein calcite, to map spatial and temporal variations in the chemistry of vein calcite throughout the fault system. The study uses the 4D variations in vein mineral chemistry to map the distribution of reactive flow paths as the fault system evolved. In particular, vein mineral chemistry will be used to map, at various scales, how the positions of geochemical fronts migrated with time within vein systems. The geometry and distribution of geochemical fronts will be used to constrain flow directions. Reactive transport modelling of geochemical profiles along fluid pathways will be used to map 4D variations in fluid fluxes.

In summary, the project is advancing understanding of:

• structural controls on the distribution of fluid flux within individual, fluid-conductive fault zones;
• how the dynamics of growth of fracture-controlled flow systems at depth in the crust influences hydraulic connectivity, the distribution of fluid flux, and changes in fluid pathways with time in flow systems associated with the growth of fault networks;
• feedbacks between fluid flow and rock mechanics in the seismogenic regimes of the continental crust;

• fundamental aspects of coupling between deformation processes, fluid transport and reaction, how these processes may influence redistribution of fluids during crustal deformation, and impact on seismicity patterns and flow localisation associated with ore deposition in fracture-controlled hydrothermal systems.

References

Barker, S.L.L., Cox, S.F., Eggins, S.M. and Gagan, M.K., 2006. Earth and Planetary Science Letters, 250, 331-344.
Cox, S.F., 2005. Economic Geology, 100th Anniversary Volume, 39-75.
Cox, S.F., 2007. Journal of Geophysical Research, 112, B08208, doi:10.1029/2006JB004734.
Giger, S.B., Tenthorey, E., Cox, S.F. and FitzGerald, J.G., 2007. Journal of Geophysical Research, 112, B07202, doi:10.1029/2006JB004828.
Miller, S.A., and Nur, A. 2000. Earth and Planetary Science Letters, 183, 133-146.
Tenthorey and Cox, S F , 2006. Journal of Geophysical Research, 111, B09202, doi:10.1029/2005JB004122.

Laboratory Studies of Rock Deformation, Dislocation Recovery and Attenuation

Robert J.M. Farla[1], Harri Kokkonen[1], Hayden Miller[1], John D. FitzGerald[1], Ulrich H. Faul[2], Mark Zimmerman[3], David L. Kohlstedt[3] and Ian Jackson[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Earth Sciences, Boston University, Boston, MA 02215, USA
[3] Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN, USA

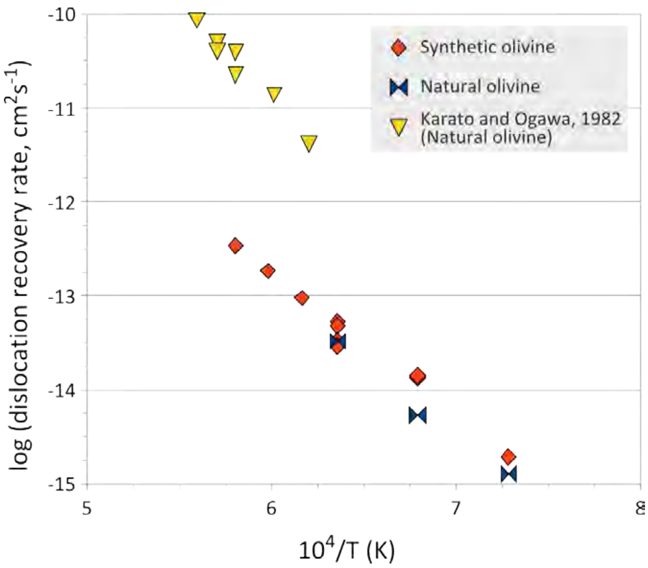


Figure 1. Dislocation recovery 'Arrhenius' plot. There is no statistical difference between the dislocation recovery rate of synthetic and natural olivine in this study compared with an older study for which the light microscope was used.

As part of an ongoing study of dislocation damping as a possible mechanism for seismic wave attenuation in the Earth's upper mantle, we focused this year on the preparation of natural (San Carlos) olivine cylindrical fine-grained polycrystalline specimens and their deformation by dislocation creep. These specimens differ significantly from their fully synthetic (sol-gel) counterparts by being more coarse-grained and containing a broad inventory of trace elements. Specimens of each type have been successfully deformed both in compression (ANU) and torsion (University of Minnesota). Infrared spectroscopy indicated that the specimens are essentially dry (< 20 wt ppm water). The specimens were deformed in torsion to a shear strain of 0.5 at 170 and 200 MPa shear stress (Fig. 2a). Micro-structures viewed under the light microscope show strong crystal preferred orientation - most notable in the fine grained sol-gel olivine (Fig. 2b).

We have also begun a study of the recovery of dislocation micro-structures in a compressionally deformed San Carlos specimen during high temperature annealing - designed to complement our previous work on the sol-gel material. Preliminary results show that the dislocation recovery rate is not affected by trace elements in olivine nor grain size (see Fig. 1). However, comparison with previous results on dislocation recovery in natural olivine conducted nearly 20 years ago using a light microscope and an older generation scanning electron microscope, reveals a marked contrast - possibly attributable to the significant difference in resolution at which dislocations are counted and measured at (1000x versus 8000x). Completion of the micro-structural study and planned attenuation measurements on both types of material, undeformed or pre-deformed in either compression or torsion, should contribute significantly to our understanding of dislocation damping and hence the interpretation of seismological models for the upper mantle.

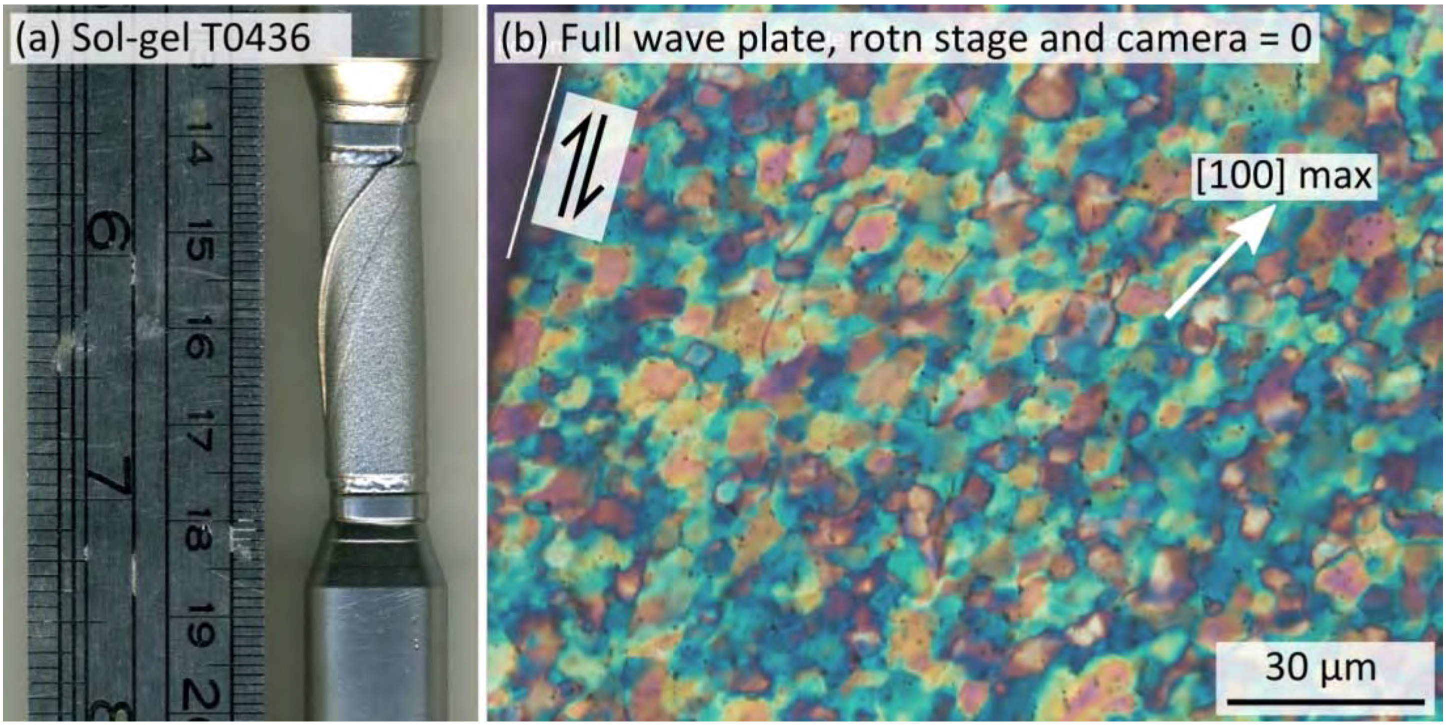


Figure 2. (a) Sol-gel olivine, specimen T0436, deformed in torsion. Twist direction is anti-clockwise when viewed from above. (b) Light microscope image of the torsionally deformed sol-gel specimen. The sense of shear and direction of preferred orientation of [100] crystal axis are indicated.

A versatile facility for rock physics research

Ian Jackson[1], Hayden Miller[1], Junjie Mu[2], Zbigniew H. Stachurski[2] and Douglas R. Schmitt[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Engineering, College of Engineering & Computer Science, Australian National University
[3] Department of Physics, University of Alberta, Edmonton, Canada

The presence of fluids is expected to profoundly influence the seismic properties of the cracked rocks of the Earth's upper crust in situations ranging from earthquake nucleation and recurrence, to geothermal power and CO_2 sequestration. In particular, the seismic wavespeeds and attenuation are expected to be strongly frequency dependent under these conditions, placing a special premium on laboratory measurements at seismic frequencies. To this end, we have modified unique equipment for low-frequency torsional oscillation studies of shear mode behaviour under high-pressure conditions to allow complementary work on compressional mode behaviour by flexural oscillation (Fig. 1, upper panel).

Another important change has been development of the capacity to perform such forced oscillation measurements under conditions of independently controlled confining and pore fluid pressures. Exploratory measurements have demonstrated the necessary sensitivity to low-amplitude flexural oscillation (Fig. 1, lower panel). In parallel with the development of the laboratory capability, we have undertaken finite-difference and finite-element modelling of the flexure of the experimental assembly that reveals close consistency with the experimental data. Having thus demonstrated the viability of the new technique, we are now planning exploratory studies of thermally cracked rocks and ceramic analogues, to be tested dry or saturated with a pore fluid - either argon or water in the first instance.

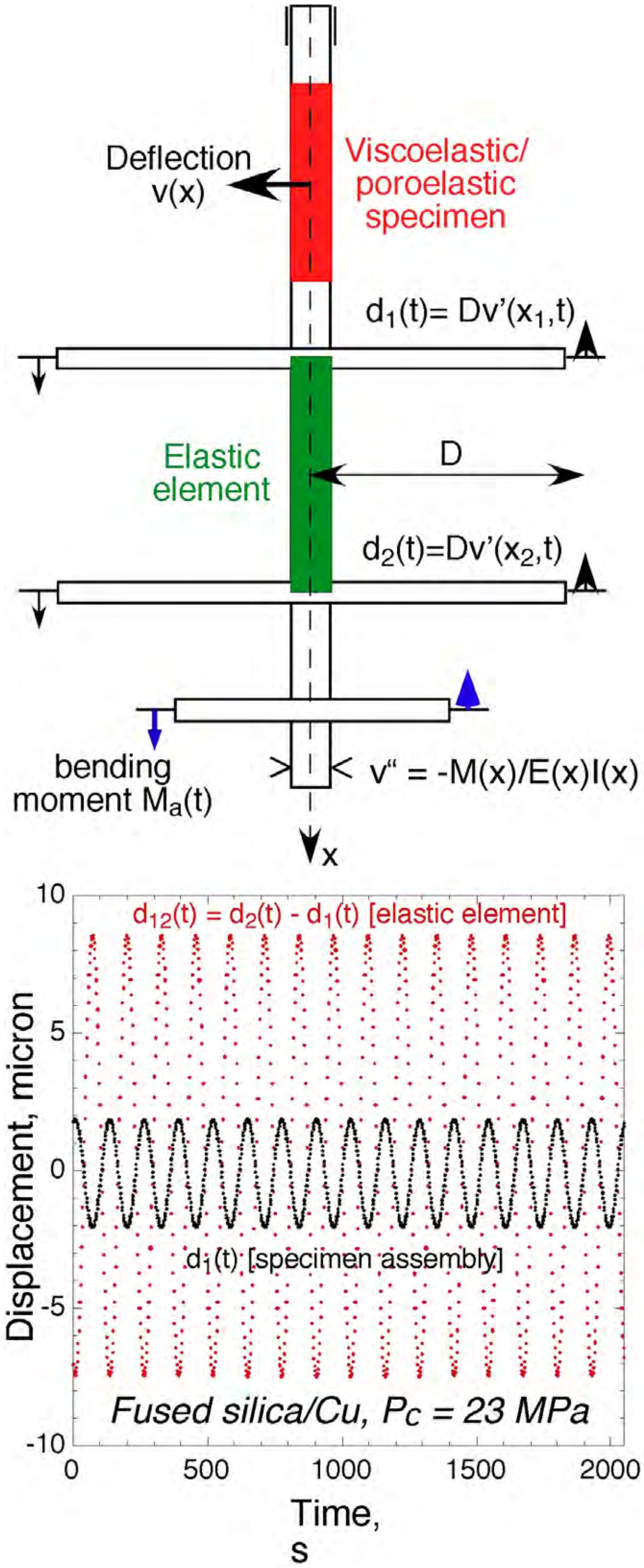


Figure 1.

Effects of stress states and fluid pressure regimes on fluid pathways and evolution of fluid compositions within intrusion-related hydrothermal systems.

Angela Halfpenny [1], Stephen Cox [1] and David Cooke [2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Centre of Excellence in Ore Deposits, CODES, University of Tasmania, Hobart, Tasmania 7001, Australia

Fluid pathways and hence localisation of ore in intrusion-related hydrothermal systems, are controlled by the development of fracture networks and by ongoing competition between (1) fracture sealing processes and (2) stress-driven and fluid-pressure-driven opening of fracture peameability. This project explores how stress fields evolve during gold mineralisation in the Porgera Intrusive Complex (PIC) and examines the controlling role that changes in both stress field orientations and failure modes have on mineralisation styles. The Porgera gold deposit is located in the Enga province at 2500m elevation in the highlands of Papua New Guinea. Emplacement of the PIC occurred at 6.0 ± 0.3 Ma at a depth between 2-4km (Richards, 1997). Mineralisation occurred between 6.0 Ma and 5.6 Ma and regional uplift commenced around 4 Ma.

On the basis of cross-cutting relationships, mineralisation at Porgera is separated into 4 main episodes: pre-stage 1, stage1, stage 2 and post-stage 2. Only stage 1 and stage 2 are economically significant. Stage 1 mineralisation is hosted by widely distributed extension veins. Most veins are moderatly to steeply dipping, but mutually overprinting relationships with a second population of gently dipping stage 1 veins indicates that there were repeated changes in the orientation of the near-field σ_3 from a gently plunging to steeply plunging attitude during Stage 1. Repeated reorientation of stress fields in the PIC during stage 1 is interpreted to be associated with either (1) magma inflation-deflation cycles in a deeper level magma chamber, or (2) inflation-deflation cycles driven by fluid leakage repeatedly interrupting accumulation and pressurization of volatiles in a reservoir at the top of the magma chamber.

The transition from stage 1, low grade, distributed mineralisation to stage 2 localized high grade mineralisation was associated with the growth of the Romane Fault network. This fault network accessed magmatic-hydrothermal fluids at depth and localized fluid flow through faults and their damage zones. Compositional banding in stage 2 veins indicates cyclic changes in fluid chemistry. The formation of implosion breccias is interpreted to indicate sudden fluid de-pressurisation associated with fault slip events. Microstructures indicating multiple episodes of opening and sealing of some veins and breccias suggest that episodic, fracture-controlled flow may have been controlled by co-seismic permeability enhancement and interseismic permeability destruction in the stage 2 fracture systems. Transiently high flow rates, large transitory fluid pressure gradients, and large chemical gradients, during pulses of fluid redistribution, were associated with repeated breaching of the deep-level magmatic-hydrothermal fluid reservoir and are interpreted to be key factors promoting flow localisation and efficient gold precipitation during stage 2.

Richards, J.P., 1997. Controls on scale of Porgera-type porphyry/epithermal gold deposits associated with mafic, alkalic magmatism. Transactions of the Institution of Mining and Metallurgy Section B-Applied Earth Science, 106: B204.

Angela Halfpenny webpage
http://rses.anu.edu.au/people/halfpenny_a/

Stephen Cox webpage
http://rses.anu.edu.au/people/cox_s/

Figure 1. The internal structure of a composite stage 1 and stage 2 vein. Sections 1 and 3 represent the stage 2 mineralisation, which exhibits quartz and roscoelite-rich bands. The gold is associated with the roscoelite-rich bands and a patch of gold is marked by the white arrow. Section 2 is a coarse-grained stage 1 vein.

Multi-element Comparisons of Natural and Anthropogenic Inputs into Pristine Estuarine Sediments, Merimbula, N.S.W., Australia

Fern Beavis, David Ellis, Stephen Eggins and Andrew Christy

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

In most areas of the world, high population centres and heavy industry are located along river systems and provide a catchment wide source of heavy metal pollution along the length of the river system. These anthropogenically derived heavy metal pollutants enter the freshwater river systems and are transported downstream as part of the suspended sediment load. Such metals combine with the suspended sediment such that there is a higher concentration of heavy metals with the finer grained, clay-rich component of the transported sediment. In such cases, the ultimate depositional environment of contaminated sediments bears little relation to the distant source regions of anthropogenic pollution.

In an arid country like Australia, there are numerous coastal estuaries that are supplied with sediment transported down catchments that lack both industry and significant population centres. However such coastal estuaries are undergoing rapid population growth, even though for such regions the upstream catchment is notably lacking in population centres and industry. This provides an opportunity to study heavy metal additions and contamination in a post-depositional estuarine saline environment, in which relatively uncontaminated freshwater sediments are input into the system, mainly during seasonal flood events.

We used a range of conservative elements, especially rare earth elements, to show that heavy metal contamination does not correlate wholly with sediment grain size, but also correlates with proximity to local townships surrounding part of an estuary. Heavy metals such as Pb can then clearly be discriminated in terms of original, transported sediment compositions and local pollutant sources in an estuary. This shows that heavy metal pollution correlates in proximity to urban development, rather than with upstream contamination and transported sediment type.

Experimental constraints on chlorine behavior in subducted sediments

Huijuan Li and Joerg Hermann

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

It is widely accepted that a fluid phase released from the subducted slab fluxes partial melting in the overlying mantle wedge, however, the nature of “subduction fluid agent” remains a matter of debate. The Cl concentration in “subduction fluid agent” is also poorly constrained, although experimental studies have shown that complexation with chlorine (and possibly other halogens) at high concentration might produce a strong effect on relative HFSE vs. REE/LFSE partitioning (Brenan et al., 1995; Keppler, 1996).

Detailed chemical analyses of oceanic crustal material have revealed that subducted sediments are the dominant host of LILE in the slab. The significance of such a role is further supported by considering that the composition of the “slab fluid agent” which migrates from the subducted slab to the mantle wedge is assumed to be buffered by the subducted sediment residue component located at the slab-mantle interface. Therefore, determining accurate sediment-derived fluid and melt compositions at high P are critical for understanding mass transfer from the slab to mantle wedge (e.g., Hermann and Spandler, 2008).

We have conducted an experimental study on hydrous Cl-brearing synthetic pelite over a pressure and temperature range of 25-45 kbar and 650-850°C respectively. The starting composition contains 6.65% water and 0.05% chlorine, equivalent to ~1wt.% NaCl solution. Apatite was found to be the major chlorine carrier with Cl concentrations ranging from ~0.1%-1.2%. While Cl in apatite shows a consistent trend of increasing concentration with increasing temperature, a decrease in Cl concentration was found to occur with increasing pressure. The chlorine content in the coexisting melt or aqueous fluid phase was determined by both analysis and mass balance calculations. From the resultant data we were able to obtain a set of chlorine partition coefficients between apatite and melt/aqueous fluid (D^{Cl}_{ap-liq}) and while these values show a general increase with increasing temperature, they are found to decrease with increasing pressure. Chlorine partition coefficients between apatite and melt, $D^{Cl}_{ap-melt}$, are found to vary from 1.5 to 14, while partition coefficient values for aqueous fluid are found to be less than 1, suggesting chlorine has a strong partitioning preference for aqueous fluid. Our results show that Cl in apatite can be a very useful sensor for the Cl concentration in subduction zone fluids.

References:

Brenan, J.M., Shaw, F.F., Ryerson, F.J., Phinney, D.L. (1995) Mineral-aqueous fluid partitioning of trace elements at 900 °C and 2.0 GPa: constraints on the trace element chemistry of mantle and deep crustal fluids. Geochimica et Cosmochimica Acta 59, 3331–3350.

Hermann, J., Spandler, C. (2008) Sediment melts at sub-arc depths: an experimental study. Journal of Petrology 49, 717-740.

Keppler, H. (1996) Constraints from partitioning experiments on the composition of subduction- zone fluids. Nature 380, 237-240.

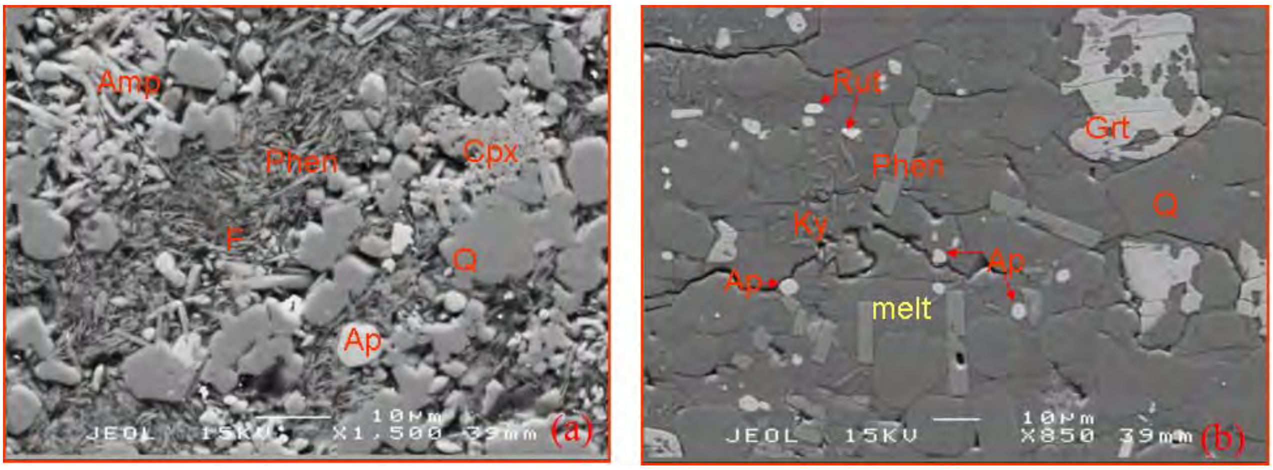


Figure 1. Backscattered electron images of experiment C3314 at 25kb, 660°C (a) and experiment C3269 at 25kb, 800°C (b). Abbreviations: Amp, amphibole; Phen, phengite; Q, quartz; Grt, garnet; Ky, kyanite; Rut, rutile; Ap, apatite; F, quench product from aqueous fluid. (a) Fine-grained hydrous quench powder was present in the run products. (b) Hydrous melt coexisting with phengite, garnet and accessory minerals.

The oxidation state of terrestrial basalts revisited

Guil Mallmann[1], Hugh O'Neill[1], Marc Norman[1], Steve Eggins[1], Dima Kamenetsky[2], Simon Turner[3], Ian Smith[4] and Chris Ballhaus[5]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] School of Earth Sciences, University of Tasmania, Hobart TAS 7001, Australia
[3] Department of Earth and Planetary Sciences, Macquarie University, Sydney NSW 2109, Australia
[4] School of Geography, Geology & Environmental Science, University of Auckland, 92019 Auckland, New Zealand
[5] Mineralogisches-Petrologisches Institut und Museum, Universität Bonn, 53115 Bonn, Germany

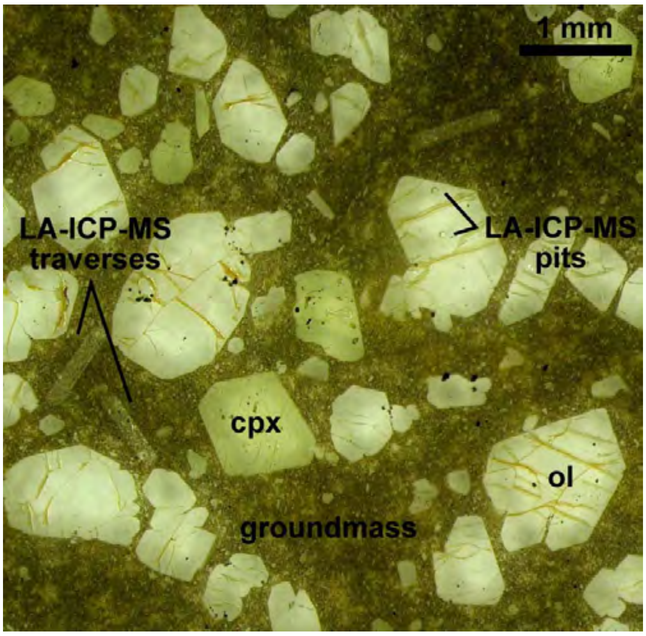


Figure 1. Example of a typical island arc basalt (Solomon Islands). The partitioning of V and Sc between olivine and melt (defined by the groundmass) can be used to estimate the oxygen fugacity of the rock.

In order to better understand the oxidation state of planetary mantles and their partial melting products, we have developed and calibrated a method to estimate the relative oxygen fugacity (fO2) of mafic volcanic rocks based on the relative partitioning of V and Sc between olivine phenocryst and basaltic melt (Fig. 1). The method relies on the high sensitivity of the partitioning of V on oxygen fugacity (Mallmann & O'Neill 2009) and has two fundamental advantages relative Fe wet chemistry analyses: 1) it records the oxidation state of a basalt at the time when olivine forms or, in other words, very early in its magmatic cooling history, and 2) it can be applied to any planetary olivine-phyric mafic rock independent of their oxidation state (either highly reduced or highly oxidized). Preliminary assessment indicates accuracy in relative fO2 between 0.2 to 0.5 log units, but precision typically better than ±0.2 log units.

The method was applied to 41 mid-ocean ridge (MORB), 34 ocean island (OIB), and 24 island arc (IAB) basalts from a variety of geographic locations. The results indicate that MORBs and OIBs record a very restrict range of relative fO2s, between QFM and QFM+1 (where QFM stands for the quartz-fayalite-magnetite oxygen buffer), with no clear distinction between them. On the other hand, IABs record consistently more oxidizing conditions, with relative fO2s ranging from QFM+1 to QFM+3 (average = QFM+1.6). The average relative fO2 determined for MORBs is about 1 log unit higher than previous results obtained by Fe wet chemistry (Fig. 2), but in excellent agreement with new Fe XANES measurements (Mallmann et al., unpublished data). The average relative fO2s of Hawaiian OIBs is in excellent agreement with previous determinations, but show much less variability, indicating that the ferric/ferrous iron ratios in these samples have been altered by late-stage processes. Whilst our results suggest that IABs are oxidized relative to MORBs and OIBs at the time they crystallize olivine, we believe these more oxidizing conditions are the result of late-stage (shallow depth) processes since no distinction exists in the bulk V/Sc ratios (which record the oxidation state of the source, Mallmann & O'Neill 2009) between these different types of terrestrial basalts. Hence, the oxidation state of the asthenospheric upper mantle must be uniform within 1 log unit.

Mallmann & O'Neill (2009)
http://petrology.oxfordjournals.org/cgi/content/abstract/50/9/1765

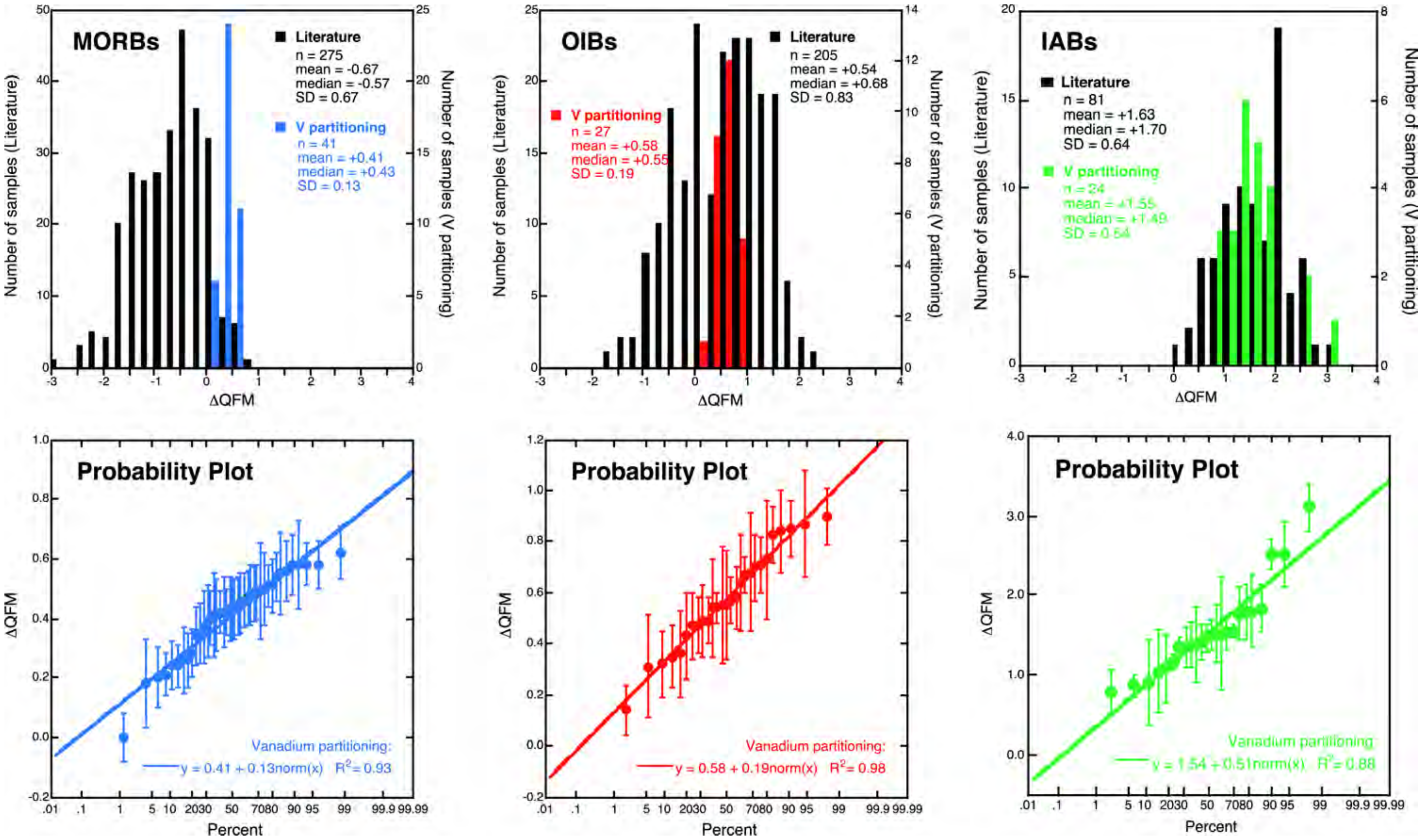


Figure 2. Histograms (top) and probability (bottom) plots for the oxygen fugacity (relative to the quartz-fayalite-magnetite buffer, QFM) of terrestrial mid-ocean ridge (MORB), ocean island (OIB) and island arc (IAB) basalts determined by V/Sc olivine-melt partition. Literature data obtained by other methods based on the oxidation state of iron are also shown.

Ni Partitioning Between Olivine and Silicate Melt

Compositional effects due to Fe variation

Jesse Jones and Hugh O'Neill

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

As the acquisition and interpretation of trace element partition coefficients has been pursued since the late 1960's it may be expected that, after countless studies regarding natural and experimental systems, the application of partitioning data for simple mineral-liquid pairings such as Ni in olivine and silicate melt, would be relatively uncontroversial. Such is not the case. It appears that a complete understanding of effects relating to all intensive parameters on divalent cation partitioning remains elusive.

By conducting a series of carefully designed one atmosphere experiments, we have investigated Ni partitioning between metal, silicate melt and olivine phases, over a range of (reduced) fO_2 conditions using a single starting composition and Fe:Ni:Co metal alloy components with variable Ni:Fe ratios.

While a significant negative dependence for D^{Ni} values on the MgO content of silicate liquids has been observed in several prominent studies (i.e. Hart & Davis, 1978; Leeman & Lindstrom, 1978), our results show a reverse trend (positive correlation).

Li et al. (2003) also reported a similar positive correlation between D^{Ni} and MgO glass content derived from analysis of a series of fresh MORB samples, a trend which they subsequently attributed to loss of available Ni^{2+} in total Ni figures due to NiS complexing in the melt.

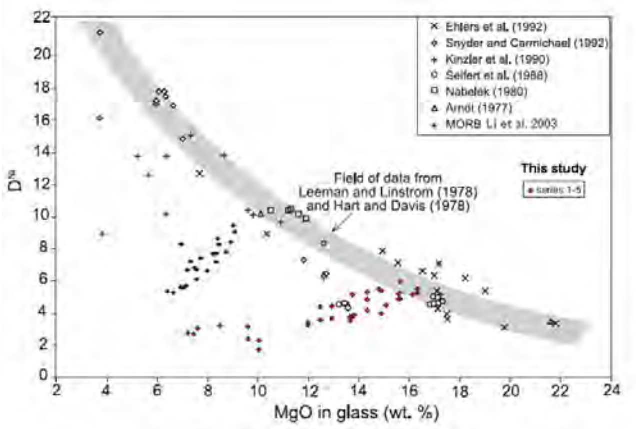


Figure 1. A comparison of suggested trends in D^{Ni} variation due to increasing MgO content of silicate liquid: All experiments other than those of Li et al. (2003) represent S-free systems, an observation which has been used to infer direct influence of NiS complexing. As can be seen from the trend determined in this study (red data points), a similar positive trend can arise in s-free systems under the influence of Fe variation (adapted from Li et al. 2003).

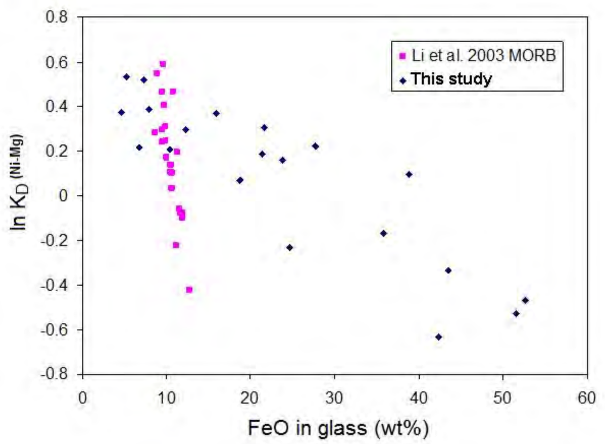


Figure 2. Compositional effects on the two element distribution coefficient ($\ln K_D^{Ni-Mg}$), when plotted against FeO, showing both the S-free glasses of this study and the Li et al. glasses.

As a further line of evidence, Li et al. (2003) present the correlation between the two-element distribution coefficient K_D^{Ni-Mg} ($K_D^{Ni-Mg} = [MgO^{melt}/MgO^{ol}]/[NiO^{melt}/NiO^{ol}]$) and Sulphur as being a function of NiS complexing in silicate liquids, thus reflecting its strong influence on D^{Ni} figures.

As can be seen in fig 1, the positive dependence of D^{Ni} on MgO-glass content shown in the S-free experiments (series 1-5) of this study reflect a similar trend to that produced by Li et al. (2003) from their MORB analyses; a compositional trait that was attributed to the effects of NiS in the liquid phase.

It has long been inferred from the sulphur contents of MORB glasses that the sulphur content at sulphide saturation (SCSS) of silicate melt increases with increasing FeO in natural magmas (Wallace & Carmichael, 1992, Mavrogenes & O'Neill, 2002). It appears that the S-related correlations observed by Li et al. (2003) may in fact be masking the underlying and controlling role of Fe, observed in the K_D^{Ni-Mg} values. The results determined (K_D^{Ni-Mg} vs. FeO^{glass}) in our S-free system, appear to support this conclusion.

References:

Hart, S.R. and Davis, K.E. (1978) Nickel partitioning between olivine ad silicate melt. *Earth and Planetary Science Letters*, 40, 203–219.

Leeman, W. and Lindstrom, D. (1978) Partitioning of Ni^{2+} between basaltic and synthetic melts and olivines—an experimental study. *Geochimica et Cosmochimica, Acta*, 42, 801–816.

Li, C. Ripley, E.M. Mathez, E.A. (2003) The effect of S on the partitioning of Ni between olivine and silicate melt in MORB. *Chem Geol.* 201, 295–306.

Mavrogenes, J.A. and O'Neill, H.St.C. (2002) The Sulfide Capacity and the Sulfur Content at Sulfide Saturation of Silicate Melts at 1400°C and 1 bar. *Journal of Petrology*. V, 43. 6, 1049-1087.

Wallace, P.J. and Carmichael, I.S.E. (1992) Alkaline and calk-alkaline lavas near Los Volcanes, Jalisco, Mexico: geochemical diversity and its significance in volcanic arcs. *Contrib. Miner. Petrol*. v. 111, p. 423-439.

The CO2 paradox in subduction zones

Laure Martin and Joerg Hermann

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

Understanding the carbon recycling into deep Earth reservoirs and its connection to the exogene carbon cycle is crucial to understand the evolution of climate throughout geological time. Along subduction zones, carbon from exogene reservoirs is buried into the deep Earth. The main input materials of carbon are sediments (organic matter and carbonate-rich sediments) and carbonates formed during seafloor alteration of the oceanic crust. Some of the carbon is recycled back to the Earth' surface as CO_2 via arc volcanism on a time scale of a few million years, whereas other parts can be subducted into the lower mantle and remain locked up for hundreds of millions of years. So the key question is: How much of the carbon goes deep down and how much is recycled through arc volcanism.

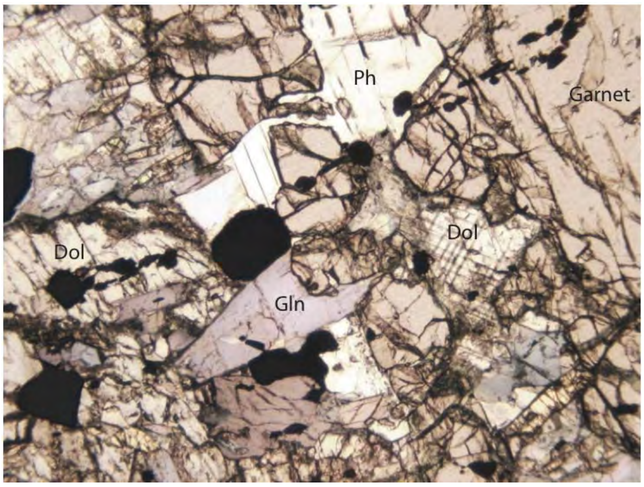


Figure 1. Dolomite (Dol)-bearing eclogite from the Italian Alps (Ph: phengite, Gln: glaucophane, width of the picture is ~2 mm)

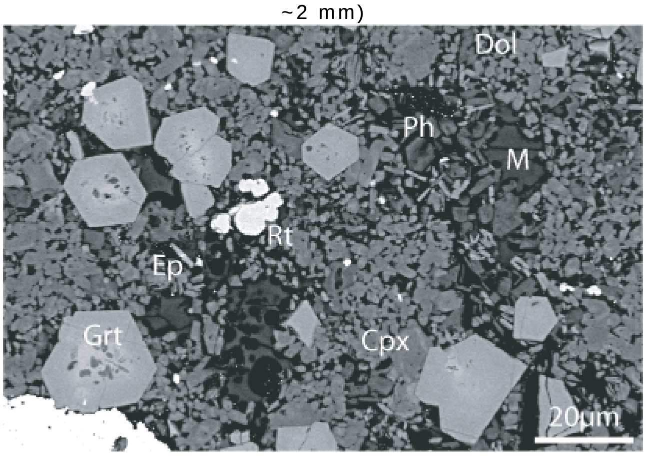


Figure 2. *BSE image of experimental run products at 3.5 GPa and 750°C, where dolomite (Dol) co-exists with melt (M), phengite (Ph), garnet (Grt), clinopyroxene (Cpx) and rutile (Rt).*

Two methods have been applied to understand if carbon in the subducting slab is transported into the deep mantle or recycled back to the surface. (i) The analysis of the $CO_2/^3He$ and isotopic composition of the volcanic gas have suggested that 80% of the carbon originates from the metamorphism of the down-going slab (Varekamp et al., 1992; Marty and Tolstikhin, 1998). (ii) Experimental studies of the stability of carbon-bearing phases in H_2O-CO_2-bearing basaltic compositions show that carbon remains trapped in carbonates up to 6 GPa and the fluid at sub-arc depth is, therefore, dominated by H_2O (Poli et al., 2009). Consequently, results from both methods contradict each other and the origin of CO_2 emitted in arc volcanoes is not well constrained.

During seafloor alteration, the oceanic crust is not only enriched in H_2O and CO_2 but also in K. At high pressures, such altered basalts are thus characterized by the assemblage garnet + omphacite + glaucophane + phengite + epidote + carbonate (Fig. 1). Solidus experiments were conducted with a starting material composition of K, CO_2 and H_2O-bearing basaltic composition as a proxy of the altered oceanic crust at 2.5 and 3.5 GPa, 750-850°C in order to study CO_2 liberation during subduction.

The experimental results indicate that the solidus occurs at a temperature below 750°C. At T ≥ 750°C, a high proportion of melt coexists with a carbonate phase, omphacite, garnet, epidote, rutile ± coesite and phengite (Fig. 2). Between 750 and 800°C, the carbonate phase is dolomite and above 800°C, it is replaced by Mg-rich calcite. The evolution of phase proportions with increasing temperature suggests the following melting reaction:

Epidote+Phengite+Carbonate+Omphacite+H_2O+Quartz/Coesite = Garnet + hydrous, CO_2 bearing melt

The following conclusions can be drawn from these results. (i) The solidus of the altered oceanic crust occurs below 750°C at 2.5 and 3.5 GPa, which is similar to the solidus in CO_2-free (700<T<750°C, Schmidt and Poli, 1998) basaltic and pelitic systems. (ii) Such a low solidus temperature suggests that the fluid composition is H_2O-rich at the solidus. (iii) The melting reaction is associated with the destabilisation of the carbonates phases, which leads to the release of CO_2, most likely dissolved in the hydrous melt. (iv) These results suggest that the altered oceanic crust, which is preferentially located at the top of the slab, may partially melt at sub-arc depths. This provides an explanation on how CO_2 is efficiently released from the subducted slab and suggests that a much larger portion of CO_2 can be recycled through arc volcanism than what previous experimental studies have predicted.

References

Marty, B., Tolstikhin, I., 1998, CO2 fluxes from mid-oceanic ridges, arcs and plumes, *Chemical geology*, 145, 233-248.
Varekamp, J.C., Kreulen, R., Poorter, R.P.E., Van Bergen, M.I., 1992. Carbon sources in arc volcanism, with implications for the carbon cycle. *Terra Nova*, 4, 363-373.
Poli, S., Franzolin, E. Fumagalli, P.,Crottini, A., 2009. The transport of carbon and hydrogen in subducted oceanic crust: an experimental study to 5 GPa. *Earth and Planetary Science Letters,* 278, 350-360

Accretion of seamounts and oceanic islands in subduction zones

David Buchs[1], Richard Arculus[1], Joerg Hermann[1], Sasan Bagheri[2] and Peter Baumgartner[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Geology, University of Sistan and Baluchestan, Zahedan, Iran
[3] Institute of Geology and Paleontology, University of Lausanne, 1015 Lausanne, Switzerland

Figure 1. Fringing reef in stratigraphic contact with a lava flow (Panama). The sequence forms the upper part of a Paleocene accreted oceanic island.

Figure 2. Mega-blocks of recrystallized reefal limestones from a Permian accreted oceanic island (backside) (Iran). The blocks are embedded in a schistose matrix of siliciclastic accreted sediments (front side).

Oceanic islands and seamounts are common products of intra-plate volcanism in the oceans, with recent estimates suggesting a population of ~95'000 seamounts in the Pacific Ocean (Hillier & Watts, 2007). Once formed, seamounts and oceanic islands migrate with plate tectonics toward subduction zones and are ultimately driven into the mantle at a present subduction rate of ~0.34 seamount km^{-1} Ma^{-1} along the Pacific. Subducting seamounts have a major impact along convergent margins and notably affect seismogenesis, supra-subduction magmatism and processes of accretion and subduction erosion. Although some of these effects are clearly of fundamental interest for the evolution of convergent margins, mechanisms controlling the subduction, accretion and extend of preservation of seamounts along subduction zones is still poorly understood.

Our study provides new constraints on subduction processes based on the characterization of fragments of seamounts and oceanic islands preserved in recent and ancient accretionary complexes. We studied accretionary complexes along the Middle American Trench through a multi-disciplinary approach that includes extended field mapping, geochemistry of the igneous rocks, remote interpretations based on satellite imagery and biochronologic dating. Our results indicate that the outer parts of the convergent margin include km-sized slices of accreted oceanic islands and seamounts, some of which represent unusually large fragments of ancient intraplate volcanoes (fig. 1). Based on the nature and arrangement of these slices we reconstructed the development of the margin from the subduction initiation (~75-73 Ma) to the Oligocene (~30 Ma). The margin underwent a ~45 Ma-long history of repeated shifts between accretion and subduction erosion.

More recently, we initiated a new study on a Permian accretionary complex exposed along the Paleo-Tethys Suture Zone in Iran. We identified distinct seamounts and oceanic islands that became exhumed during the closure of the Paleo-Tethys Ocean. Good exposures allowed efficient mapping of the accretionary complex by satellite (fig. 2). The results show that large slices of seamounts and oceanic islands can be subducted to considerable depth in subduction zones.

An experimental study of the upper mantle melting behaviour of recycled carbonate eclogite at 3.5-5.5 GPa

Ekaterina S. Kiseeva[1], Gregory M. Yaxley[1] and Vadim S. Kamenetsky[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] CODES and School of Earth Sciences, University of Tasmania, Hobart, TAS, Australia

Altered, carbonated oceanic crust may be recycled through subduction zones into the deeper convecting mantle, where it may contribute components to mantle-derived partial melts such as carbonatites, kimberlites and other silica-undersaturated magmas. We used a high pressures experimental approach to investigate the melting behaviour of carbonate eclogite (modelling high pressure, altered, carbonate-bearing, recycled oceanic crust) in the upper mantle at depths of 100-170 km, which correspond to pressures of 3.5-5.5 GPa. We aim to test the possible involvement of such material in formation of rare and exotic rocks as kimberlites and carbonatites.

The aim of the study is to locate the solidus positions, partial melt compositions and trace element partitioning of carbonate-bearing eclogite as functions of pressure, temperature and SiO_2 content. The initial composition GA1 [1] represents altered oceanic basalt (eclogite) to which 10% of calcite (10%cc) was added. The second composition Volga+10%cc is identical to GA1 but with 6.5% less SiO_2. This models subducted mafic crust which may have lost a siliceous component during dehydration and/or silicate melting in the subduction zone. Both mixes were doped with a mixture containing 30 trace elements in an average amount around 100-150 ppm.

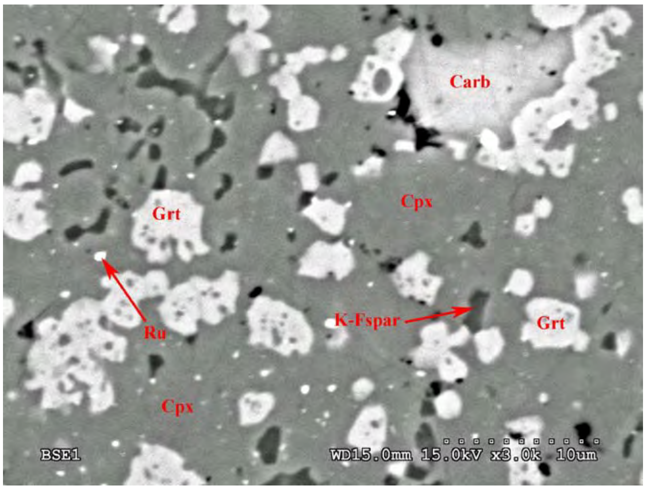


Figure 1. Fig. 1. A sub-solidus mineral assemblage at 1050°C and 3.5 GPa. Grt – garnet, Cpx – clinopyroxene, K-Fspar – K-Feldspar, Ru – rutile, Carb – carbonate.

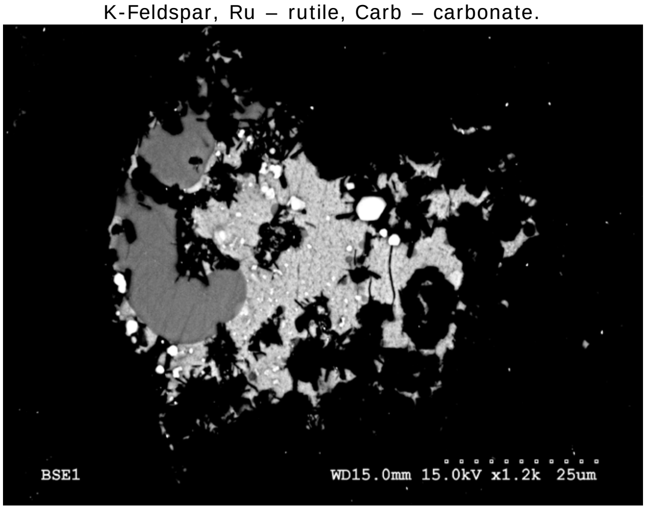


Figure 2. Fig. 2. Two immiscible liquids at 1150°C and 4.5 GPa. Dark grey is a silicate liquid and light grey is a carbonate liquid.

Experiments were conducted in piston-cylinder presses over the range of pressures (3.5-5.5 GPa) and temperatures (1000-1400 ºC). The main findings are:

- The mixes crystallize under sub-solidus conditions at 3.5 GPa as garnet + clinopyroxene + carbonate + rutile ± K-feldspar ± apatite (fig. 1)
- At 3.5 GPa the solidus of GA1 is less than 1050°C. At 4.5 and 5.0 GPa the estimated solidus is lower. The solidus of Volga+10%cc for all the examined pressures is at least 100°C lower than in GA1, which is in a good agreement with silica-undersaturated composition SLEC1 [2]
- Carbonate-silicate liquid immiscibility (fig. 2) is detected at all the pressures (3.5, 4.5, 5.0, 5.5 GPa) and its field expanded from low to higher pressures reaching 150°C at 5.0 GPa.
- Depending on the temperature and pressure, CO_2 or CO_3^{2-} may be present, dissolved in silicate melt, in carbonate melt; in solid carbonate or as a fluid, transporting incompatible elements from the crystalline run product into the graphite capsule
- Initial melts are highly siliceous, K-rich compositions, probably with considerable dissolved carbon. Early melting is probably dominated by components from accessory phases such as K-feldspar, coesite and carbonate. This is an important contrast with earlier, similar studies in low –K or K-free systems, in which initial melts were calcio-dolomitic carbonatites [1,3], and highlights the important influence on early melts of accessory phases such as coesite and K-feldspar.
- Trace element partition coefficients between garnet, clinopyroxene and silicate melt are similar to previously reported [3]. $D^{Cpx/melt}$ in equilibrium with carbonatitic melt reveals different patterns with high values for HFSE, as Ta, Zr, Hf and Ti.

References

1. Yaxley, G.M., and Green, D.H., 1994, Experimental demonstration of refractory carbonate-bearing eclogite and siliceous melt in the subduction regime: Earth and Planetary Science Letters, v. 128, p. 313-325.

2. Dasgupta, R., Hirschmann, M.M., and Withers, A.C., 2004, Deep global cycling of carbon constrained by the solidus of anhydrous, carbonated eclogite under upper mantle conditions: Earth and Planetary Science Letters, v. 227, p. 73-85.

3. Klemme, S., Blundy, J.D., and Wood, B.J., 2002, Experimental constraints on major and trace element partitioning during partial melting of eclogite: Geochimica Et Cosmochimica Acta, v. 66, p. 3109-3123.

Squeezing out the upper mantle: melt evolution of voluminous mafic layered intrusions

Oliver Nebel[1], John Mavrogenes[1], Richard Arculus[1], Tim Ivanic[2] and Richard Langford[3]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *Geological Survey of Western Australia, Department of Mines and Petroleum, WA 6060, Perth*
[3] *Flinders Mines Ltd, WA 6000 Perth*

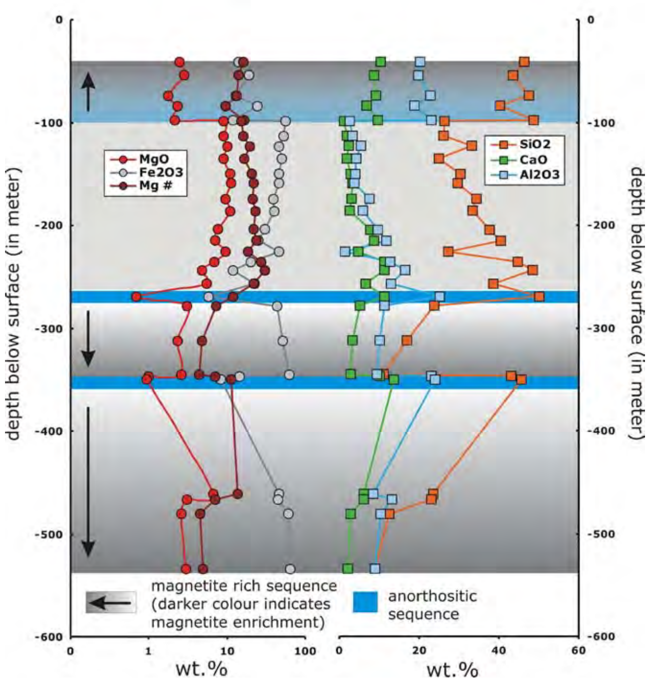


Figure 1. Major element depth profile of the UZ of the Windimurra MLI indicating two types of Fe enrichment, probably related to variable oxygen fugacity of magma pulses.

Many of our technological advances and devices that we take for granted in our daily life require noble metals, making these group of elements a substantial and highly valuable resource, and by that, a fundamental cornerstone of the world's economy. The majority of the world's noble metals that are stored near the Earth's surface - and thus accessible for mining - are hosted by mafic layered intrusions (MLI). These large igneous bodies comprise a stratified sequence of voluminous upper mantle-derived melts, with most of them predominantly Archean to early Proterozoic age. Despite decades of research on MLI, their genesis, including their tectonic settings, melting origins, evolution of melts, and the cause for specific noble metal distributions are still not completely understood. The key to unraveling these questions and to more efficiently access these ancient treasures is the study of MLI melt evolution using petrologic and geochemical investigations.

Our research is focusing on one of the world's largest MLI, the Windimurra-Narndee igneous complex (WNIC; ~ 2.8 Ga old) forming part of the Archean Yilgarn Craton, located in the West Australian desert. The Complex is unique among MLI as it was not affected by crustal contamination during magma ascent and opens a crystal-clear window in the long-gone, ancient mantle beneath Australia. We use petrogenetic tools (such as the electron microprobe for major elements chemistry, laser-ablation in-situ trace element analyses, and isotope investigations by isotope dilution for dating and source tracing) on two long drill cores of the upper sequences. One goal is to better understand the nature of iron enrichment in uppermost MLI, and its role in controlling the oxygen fugacity in melts, a parameter that is crucial for the distribution of some key elements such as V, S or e.g., the ferric-ferrous ratio. An important feature therein is the overall absence of water (or hydrous phases) in the melts. This is fairly uncommon in most MLI as many of them experienced various degrees of crustal assimilation. In the future, isotopic investigations will give us not only a better constraint on the emplacement age of the intrusion and its role in the formation of the Yilgarn Craton, but will also provide us with source information of the Intrusion. Its crustal contamination-free nature means it is ideally suited for study of the mantle source using Sr-Nd-Hf isotope systems. We can also study the effect of parent-daughter element fractionation during extensive mantle melting on crustal formation, and potentially discover the true nature of the depleted mantle at around 2.8 Ga before present.

Peridotites from a submarine volcanic front arc volcano: a global first

Sarlae McAlpine and Richard Arculus

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

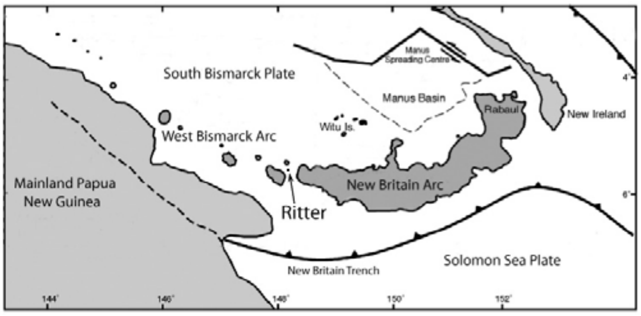


Figure 1. Geological Setting of Ritter Volcano, West Bismarck-New Britain Arc after Woodhead et al., 2009.

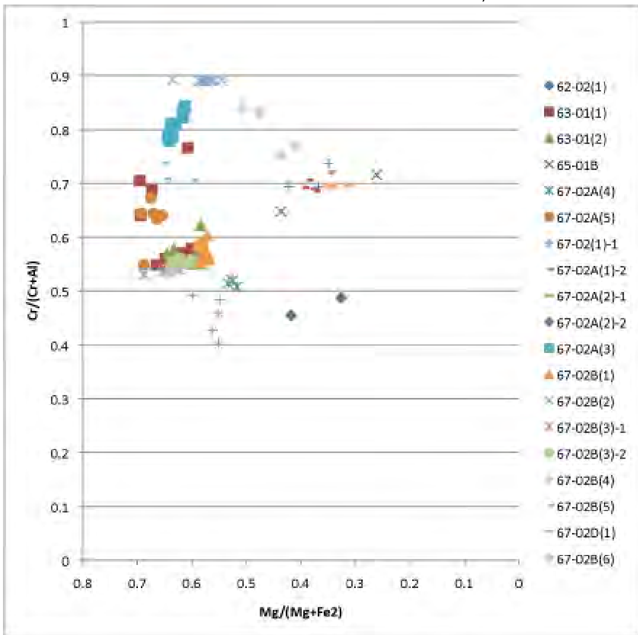


Figure 2. Cr/(Cr + Al) vs Mg/(Mg + Fe2+) for spinel in peridotite from Ritter Volcano

Research Voyage SS06/2007 (WeBiVE) of the Marine National Facility recovered a suite of basalt-coated peridotite xenoliths from three cones to the northwest of Ritter Volcano, on the volcanic front of the New Britain-West Bismarck Island Arc (Fig.1). The Ritter suite is the first global occurrence of peridotites sampled from an active submarine volcanic arc front edifice. In 1888, the former ~800m Ritter cone collapsed, triggering a tsunami that devasted the nearby islands of Sakar and Umboi. Since 1888, an active submarine vent has grown in the throat of the collapsed volcano.

The peridotites range from harzburgite to lherzolite in composition, are generally coated by basalt, and occur as rounded and angular blocks and fragments. The host basalt is a Cr spinel-olivine-bearing, medium-K, low-Fe tholeiite. It is the most MgO-rich basalt (~15wt%) discovered in the West-Bismarck-New Britain Arc system; the high-MgO might derive in part from the cumulative and/or xenocrystic nature of the olivine crystals. The mineralogy of the host basalt includes olivine ($Fo_{91.9-82.4}$), diospide-augite, and spinel. The spinel is highly refractory with Cr/(Cr+Al) > 0.8, akin to spinel in boninites. The peridotites have complex textural relationships between the main minerals olivine, orthopyroxene, clinopyroxene, and spinel; deformation textures are prominent, and include deformation banding in olivine and wavy deformation of exsolution lamellae in the pyroxene. The Cr/(Cr+Al) of the spinel ranges from ~0.4 to some of the highest and most refractory (0.9) values ever reported for peridotite assemblages. The mineralogy and geochemical characteristics of the peridotite suite will give insight into the lithospheric mantle forming the overriding plate of the New Britain-West Bismarck arc system.

Reference: Woodhead, J., et al., 2009, The Big Crunch: Physical and chemical expressions of arc/continent collision in the Western Bismarck Arc, *J. Volcanol. Geotherm. Res*. in press, corrected proof.

Melt transport in the mantle

Transition from dunite channels to pyroxenite dykes in the upper mantle section of New Caledonia

Cassian Pirard, Jörg Hermann and Hugh O'Neill

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

In oceanic spreading zones, new crust is formed by basaltic melts extracted from the mantle. Previous research has shown that dunite channels play a fundamental role in this magma transport (Kelemen et al. 1995). These channels are relatively porous and were thought to allow the transfer of large amounts of melts from the mantle to the crust. Once established, there is little interaction of melt passing through the channels with the surrounding peridotite rocks.

We have investigated in detail melt transport in the uppermost mantle section of the New Caledonia ophiolite. Dunite channels are widespread in the harzburgite and crosscut the dominant tectonite foliation. However, field studies of the uppermost part of the mantle section show an evolution of the channels as the crust mantle boundary is approached (Fig.1). In some places, dunite channels (Fig.2a), normally formed only of olivine, start to precipitate pyroxenes by consuming olivine. This reaction leads to the formation of proto-pyroxenite channels cross-cutting the mantle (Fig.2b). In the uppermost part of the mantle, the replacive proto-pyroxenite channels gradually transform into pyroxenite dykes indicating a more brittle behavior of the surrounding mantle rocks (Fig.2c). These dykes, which are widespread in many ophiolites all around the world, can occasionally show fractionation trends in the last few hundred meters below the crust-mantle boundary. Closer to the crust mantle transition, it is common to see gabbro dykes with pyroxenite walls (Fig.2d) cutting through the peridotite. Pyroxenes from the walls are identical to pyroxenite dykes whereas the gabbro has similarities with the cumulate gabbros forming the oceanic crust. These gabbro dykes are reaching the crust-mantle transition zone and act as feeders for mafic melts forming the oceanic crust. The evolution from dunite channels to pyroxenites to gabbro dykes shows that melt transport in oceanic spreading zone is highly focused. However, the variety of rocks observed provide evidence for multiple dissolution-precipitation processes acting during the melt transport. Additionally we show that fractionation of mafic magma can occur in the uppermost mantle before the melts reach the crust-mantle boundary.

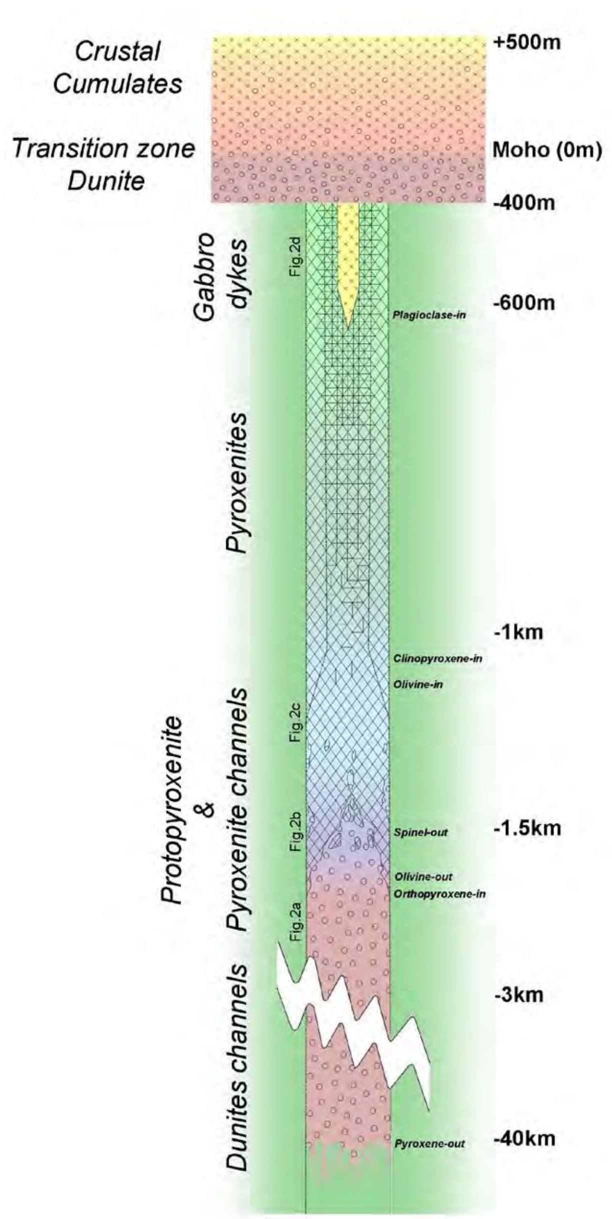


Figure 1. Stratigraphic column showing the evolution of discordant features caused by focused transport of mafic melts through the uppermost mantle. Lithology, appearance and disappearance of mineral phases and depth are shown in columns parallel to the drawing. Reference to pictures in figure 2 are also given.

Kelemen, P.B., Shimizu, N., Salters, V.J.M., 1995. Extraction of mid-ocean ridge basalt from the upwelling mantle. Nature, 358, p635-641.

Figure 2. a. Dunite channel (Dun) in layered harzburgite (Hzb). b. Proto-pyroxenite channel (PPx) in harzburgite. c. Pyroxenite dyke (Px) 25m from proto-pyroxenite 2b. d. Gabbro dyke (Gab) with pyroxenite walls (Px) in harzburgite (Hzb). All pictures taken in the Massif du Sud, New Caledonia.

Archaean asteroid impacts, banded iron formations and sulphur MIF-S anomalies.

Andrew Glikson

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

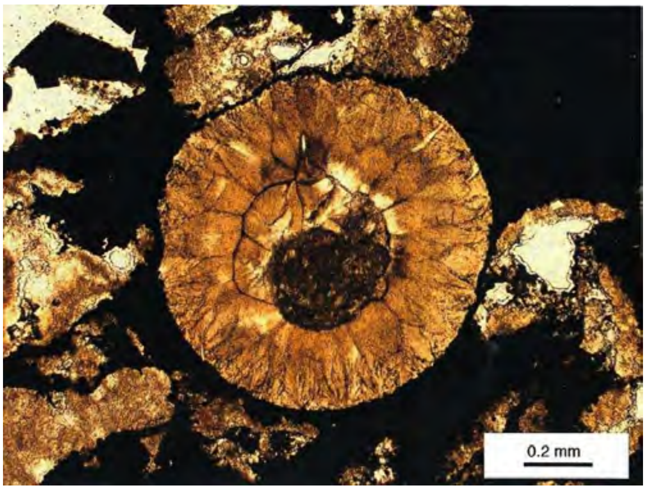


Figure 1. Impact spherule (microkrystite) from the Jeerihan Impact Layer, top of the c. 2.63 Ma-old Jeerinah Formation, Pilbara Craton, Western Australia. The spherule consists of radiating quench-textured chlorite surrounding an offset central vesicle.

The origin of the abrupt end-Archaean - early Proterozoic (c. 2.45 Ga) transition from an oxygen-poor to an oxygeneting atmosphere remains one of the outstanding problems in early Earth history. A change in mass-independent fractionation of sulphur isotopes (MIF-S) (δ33S) about 2.45 Ga is commonly interpreted in terms of the termination of UV-triggered chemical reactions under oxygen-poor atmosphere conditions. Late-Archaean (~2.7–2.5 Ga) and mid-Archaean (~3.2 Ga) sequences in the Pilbara craton (Western Australia) and Kaapvaal Craton (South Africa), in which MIF-S data were measured, contain asteroid impact ejecta units dated as 2.48, 2.56, 2.63, 3.24, 3.26 and 3.47 Ga-old. The scale of the impacts is estimated by mass balance calculations based on Iridium and 53C/52Cr isotopic anomalies and on impact spherule (microkrystites. see figure) size distribution, suggesting projectiles several tens of kilometsers in diameter. In view of an incomplete preservation of impact ejecta units, the above represents a minimum rate of the Archaean impact flux. High UV flux due to low ozone levels in the Archaean atmosphere may have been enhanced by large impacts, accentuating MIF-S anomalies. The appearance of iron-rich sediments above late and mid-Archaean impact ejecta units may be related either to to microbial oxidation of ferrous iron or, alternatively, photochemical oxidation of ferrous to ferric iron. Similar MIF-S anomalies may have been associated with Proterozoic and Phanerozoic impacts, although to date little evidence exists in this regard. Detailed sampling and isotopic analyses across the impact ejecta fallout units are required in order to test possible relationships between Archaean impacts and MIF-S anomalies.

A Monte Carlo study of short- and long-range order of tetrahedral cations in sapphirine and khmaralite

Andrew G. Christy

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

Stability of the mineral assemblage sapphirine + quartz is an indicator of metamorphism under ultrahigh-temperature (> 950°C) conditions, but it is still uncertain how far down in temperature this assemblage persists, or how it is affected when the major elements (Mg, Al, Si, Fe^{2+}) of sapphirine are substituted by minor amounts of components such as Fe^{3+} or Be. It is known that current thermodynamic databases do not correctly predict the stability of other exotic assemblages such as sapphirine+forsterite and sapphirine+kyanite, and that the problem is likely with the activity model used for sapphirine solid solutions: the complex sapphirine crystal structure has many distinct cation sites, some of which show full long-range order (LRO) while others show some disorder. However, NMR spectroscopy indicates that there is considerable short-range order (SRO) between neighbouring "disordered" sites. The enthalpy of the mineral is very sensitive to the degree of short-range order, which will also tend to reduce the entropy below what would be expected from long-range site occupancy data.

Al-Si order is made difficult in sapphirine because it has a chain of linked tetrahedrally coordinated cations which are 60–70% Al. Although energetically unfavourable Al-O-Al links and Si-O-Si can be minimised in number, they cannot be eliminated completely, as they can in many other rock-forming silicates. Because the chain has an unusual "winged" geometry, in which equal proportions of tetrahedra link to 1, 2 or 3 neighbours (Q^1, Q^2, Q^3), short-range linkage patterns couple strongly to long-range site occupancies. Favourable Al-O-Si links can be maximised if the minority component Si is concentrated in the Q^3 sites. However, since the two such sites are adjacent, there is a limit as to how much LRO is possible.

A computer simulation of the tetrahedral chain of sapphirine, with energy minimised by the Monte Carlo method, has been used to demonstrate that the observed amount of Al-Si order in sapphirine is much greater than can be driven by tetrahedral linkage enthalpies alone, even though the Al-Si exchange enthalpy is of the order of 2*RT*. Interactions with the surrounding octahedral (Al, Mg) are at least as important. However, substantial Be is readily incorporated in the chains via the substitution $(BeSi)(AlAl)_{-1}$, which ultimately leads to the mineral khmaralite, which shows rearrangement of the LRO scheme. The ordering pattern of khmaralite has also been simulated, as a minimum-energy solution for a small number of near-neighbour and chain-matrix interaction terms. Be outcompetes Si for the Q^3 sites

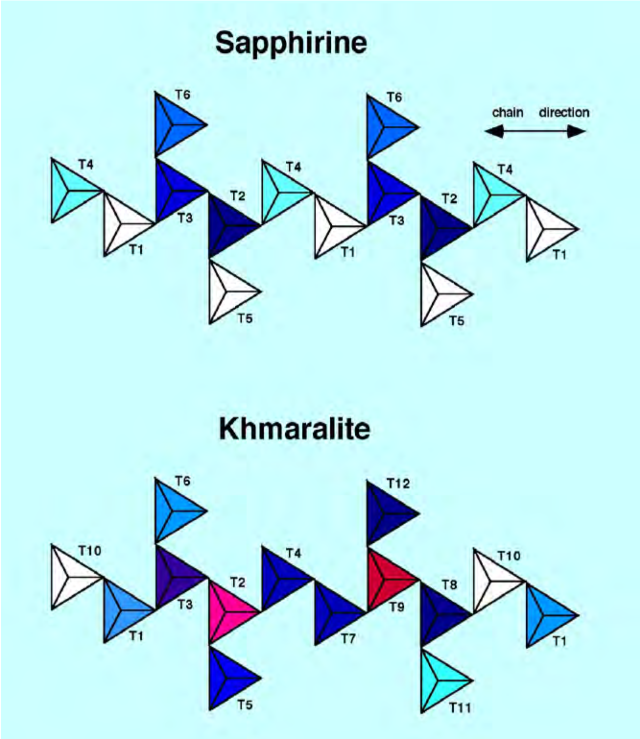


Figure 1. Tetrahedral chains of sapphirine and khmaralite, showing long-range site occupancy patterns. Increasing Si content indicated by deepening shades of blue, Be content by red shades. Minority component Si concentrates in the Q^3 sites T2/T3(/T8/T9), but Be does so even more strongly.

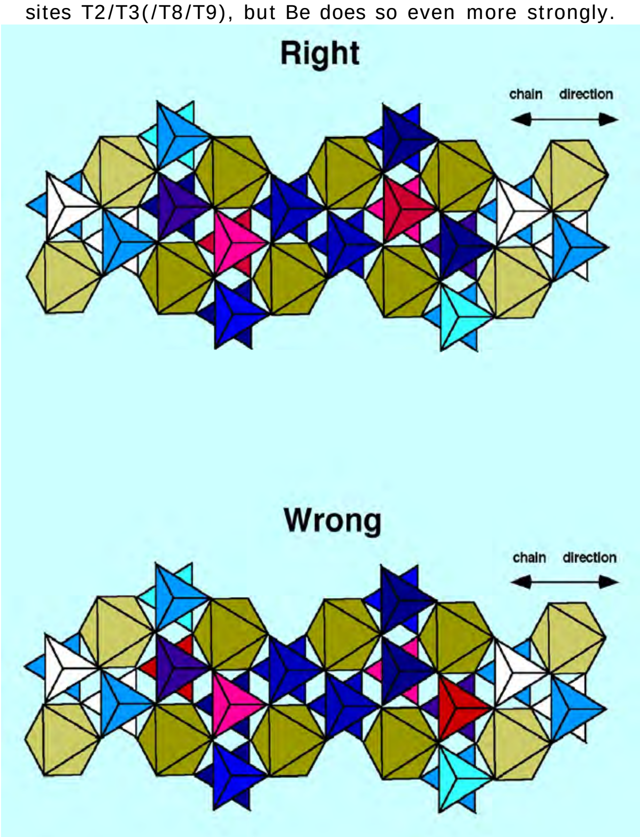


Figure 2. Back-to-back tetrahedral chains in khmaralite, linked by octahedra whose Fe content is indicated by olive shades. All the Be-rich tetrahedra are surrounded by Fe-rich sites if there is alternation of BeSi and SiBe pairs in the Q^3 sites, doubling the chain periodicity (top), but not if the periodicity of sapphirine is maintained (bottom).

because Be-O-Be avoidance is much more enthalpically significant (Be-Al and Be-Si exchange enthalpies = 7*RT*) than Al-O-Al/Si-O-Si avoidance. The model predicts a major reorganisation of site occupancies and increase in enthalpy when Be > 1.7 atoms per 12 tetrahedra, which is probably why the maximum observed content in nature is about half of this value. The chain-doubled superstructure in khmaralite is not due to within-chain interactions, but aligns the Be-rich sites of back-to-back chains and links them to a cluster of octahedral Fe^{2+}-rich sites.

The simulation can be used to calculate the effect of short-range order on configuration entropy, comparing chains with no SRO with those where SRO is maximised for a given state of LRO. It appears that SRO reduces configurational entropy by only 17-18% in either sapphirine or khmaralite

Reference: Christy, A.G. (2009) A Monte Carlo study of short- and long-range order of tetrahedral cations in sapphirine and khmaralite. *Amer. Mineral.* **94**: 270-282.

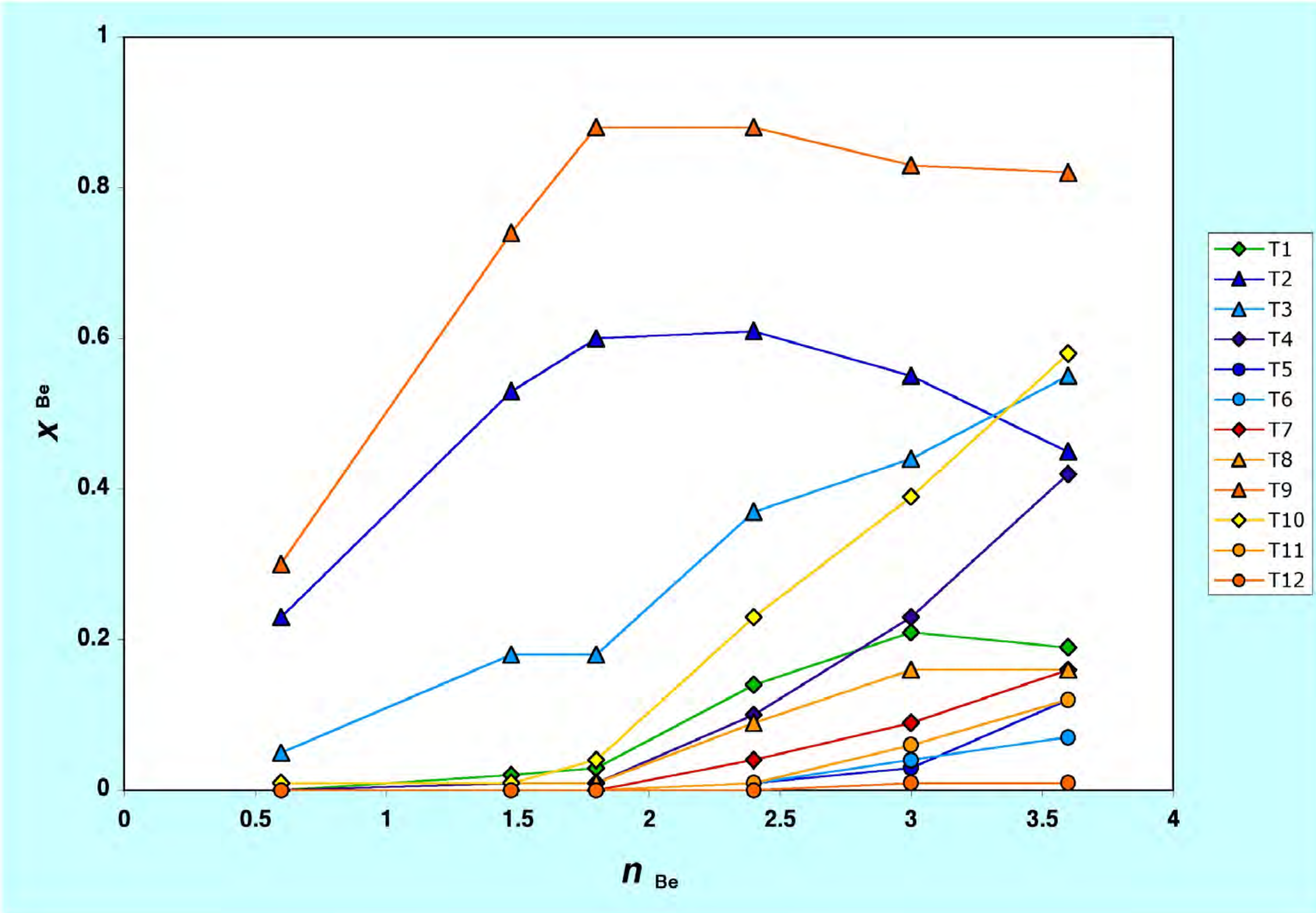


Figure 3. Predicted Be contents of the 12 tetrahedral sites of khmaralite as a function of the total Be. Q^1 sites indicated by circles, Q^2 by diamonds, Q^3 by by triangles. Below 1.7 Be per formula unit, the Be can be confined almost exclusively to two Q^3 sites. Above that threshold, this abruptly ceases to be the case, and the number of unfavourable Be-O-Be linakges grows rapidly.

Asteroid impact connections of crustal evolution

Andrew Glikson and John Vickers

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

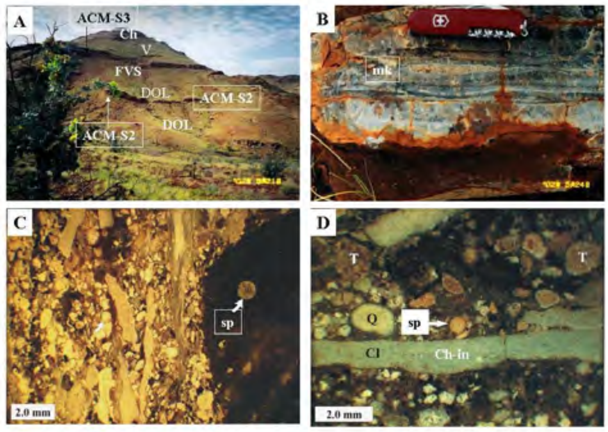


Figure 1. 3.24 Ga impact ejecta unit, Miralga Creek, central Pilbara Craton, Western Australia. A - ACM-S3 - Upper impact layer; ACM-S2 - Middle impact layer; Ch - chert; V - volcanics; FV - felsic volcanics/sill; DOL - dolerite. B - mk - Lens of impact spherules within chert. C - sp - impact spherule within black chert fragment in tsunamic breccia. D - sp - impact spherule in chert breccia; T - microtektite; Q - quartz fragment

Advances in isotopic age determinations increasingly point to an episodic nature of crustal evolution. Field and geochemical evidence indicate that at least some large impact episodes may have been associated with, and possibly triggered, magmatic and tectonic events. Corrrelations are observed between isotopic age frequency peaks and asteroid impacts records (~3.47, ~2.63, ~2.56, ~2.48, ~2.023 Ga [Vredefort] and 1.85 Ga [Sudbury]). Evidence for major dynamic and thermal effects of a large impact cluster on the early Precambrian crust is provided by ejecta fallout units associated with: (i) unconformities; (ii) tsunami boulder debris; (iii) compositional contrasts between supracrustal sequences that underlie and overlie the ejecta units; (iv) onset of episodes of iron-rich sedimentation; and (v) near-contemporaneous intrusion of granitoid magmas. An impact cluster at ~3.26–3.24 Ga, documented in the Barberton greenstone belt, South Africa, is associated with unconformities and granite activity correlated with unconformities and olistostromes in the Pilbara Craton, Western Australia. In both cratons a 300 Ma period of evolution of greenstone–granite terrains is abruptly terminated by unconformities overlain by impact ejecta, turbidite and banded iron-formation. The 3.26 and 3.24 Ga terminations involve major faulting, uplift, erosion, and the onset of high-energy sedimentation, which includes detrital components from contemporaneous granites. The onset of ferruginous sedimentation, including banded iron-formation, in the wake of the ~3.47,~3.26,~3.24,~2.63 and~2.56 Ga impacts, suggests weathering and soluble transport of ferrous oxide under low-oxidation atmosphere and hydrosphere conditions, possibly reflecting extensive mafic volcanic activity triggered by the impacts. Extensive dyke formation during 2.48–2.42 Ga (Matachewan, Scourie, Karelian, Widgiemooltha, Bangalore, Antarctica dykes) may be related to deep crust/mantle fractures triggered by the ~2.48 Dales Gorge mega-impact. Tentative observations are consistent with, but do not demonstrate, possible overlaps between Phanerozoic impacts and the onset of faulting and plate tectonics episodes.

A probable end-Eocene impact structure under the Timor Sea

Andrew Glikson[1] and Dariusz Jablonsky[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Finder Exploration Pty Ltd.

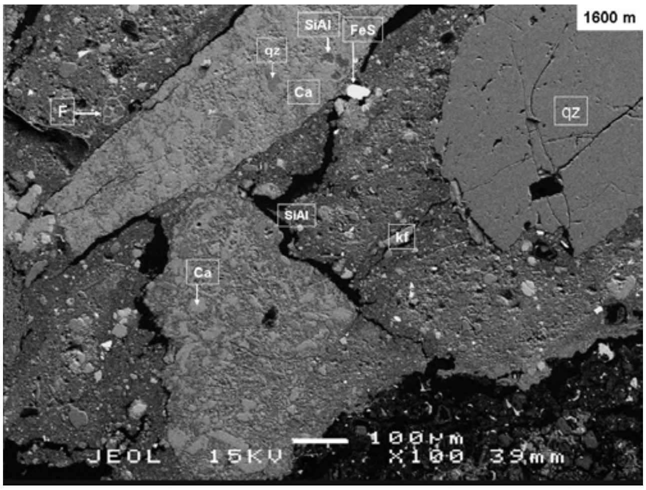


Figure 1. Scanning Electron Microscope image of Mount Ashmore pseudotachylite, showing fragments of microbreccia embedded in microbreccia. Qz - quartz fragments; kf - K-feldspar fragment; FeS - pyrite fragment; SiAl - Silica and alumina-dominated non-stochiometric fragments; Ca - Ca-dominated non-stochiometric fragment; F - fossil foram shell.

The end-Eocene (c. 35 Ma) constitutes a period of major extraterrestrial impacts, including the Popigai (D=100 km; 35.7 ± 0.2 Ma), Chesapeake Bay (D = 85 km; 35.3±0.1) and a major tektite strewn field in northeastern America. The end-Eocene is also a key period at which the Drake Passage (Chile - Antarctic Peninsula) opened, the Antarctic ice sheet began to form, sharp global cooling occurred accompanied with mass extinction of about 10 percent of species. Here we report the discovery of a new, hitherto unknown, asteroid impact structure of end-Eocene age. New seismic reflection data and petrological studies of drill cuttings from the Mount Ashmore structural dome, west Bonaparte Basin, Timor Sea, suggest the dome represents the central uplift of an extraterrestrial impact of end-Eocene, pre-Oligocene, age. The dome is located below a major unconformity. Isopach maps and reconstruction of structural depths reveal kinematic deformation patterns and structural orientations consistent with centripetal deformation toward the domal axis, as well chaotic megabreccia structures. A study of early Oligocene to early Jurassic drill cuttings from the Ashmore 1B petroleum exploration borehole reveals a dominance of flow-textured comminuted microbreccia with particles ranging to submicron scale, referred to as pseudotachylite. X-ray diffrcation analysis indicates the microbreccia includes about one third of poorly-diffracting particles, likely derived from carbonate and clay-dominated material. The microbreccia contains corroded relic quartz grains which display heavy irregular fracturing and incipient planar fractures. Similar pseudotachylite fragments occur in basal Oligocene sediments, likely representing erosion of the structural dome which protrudes above the pre-Oligocene unconformity. Scanning electron microscopy (SEM) coupled with Energy Dispersive Spectrometry (EDS) indicate the pseudotachylite consists of micron to tens of micron-size particles with low-totals and non-stochiometric heterogeneous compositions, including Si, Al-Si, Si-Ca-Al, Si-Al-Ca, Si-Mg, Fe-Mg-Ca, Fe-Mg-Ca, Fe-Mg and carbonate-dominated particles (see figure). No volcanic material or evaporites are encountered in the core, which militates against interpretations of the structure in terms of volcanic or salt dome origin. The chaotic seismic structure of the domal core, the centripetal sense of intra-domal deformation, the micro-brecciated flow-textured nature of the cuttings, the poorly diffracting nature of the pseudotachylite matrix and the heavily fractured state of quartz grains are consistent with an interpretation of the Mount Ashmore dome in terms of a central rebound uplift of an impact structure.

The Nb-Ta chicken-egg problem

Joerg Hermann and Daniela Rubatto

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

The continental crust is generally enriched in incompatible trace elements but shows a pronounced negative anomaly in Nb and Ta compared to Th and La. During partial melting of the mantle all these elements are similarly incompatible and thus are not fractionated. Hence, it has been speculated that the fractionation occurs during subduction of oceanic crust. Fluids liberated from the subducted slab trigger partial melting in the mantle wedge and impose a "slab signature" in terms of trace elements onto the volcanic arc rocks that represent newly formed continental crust. Nb and Ta highly partition into the high-pressure phase rutile (TiO_2) in deeply subducted crust and are potentially retained when these fluids are liberated from the slab.

We have performed high-pressure and high temperature experiments at conditions relevant for slabs at sub-arc depth in order to test whether such residual rutile is ultimately responsible for the negative Nb-Ta anomaly in the continental crust. The experiments were performed on a subducted sediment composition because these rocks dominate the incompatible trace element input into subduction zones. All the experiments contained residual rutile (Fig. 2). However, trace element analyses of the produced fluid phase showed that Nb and Ta are not depleted with respect to the starting material and showed a similar behaviour to Th and La (Fig. 1). The main reason for this is that the accessory phases allanite and monazite (Fig. 2) retain Th and La as efficiently as rutile does with Nb and Ta. Therefore, it seems that in subduction settings Nb and Ta are not easily fractionated from Th and La and we are faced with a chicken-egg problem. Detritus from the continents dominates the trace element composition of the subducted sediments, which are thus already characterized by a negative Nb-Ta anomaly. The partial melting of the subducted sediments and the interaction of these fluids with the mantle wedge will then transfer this negative Nb-Ta anomaly into newly formed crust at volcanic arcs. While our study shows how to maintain a "status quo" it also (re-)opens the question: When and how was the negative Nb-Ta anomaly in the continental crust established?

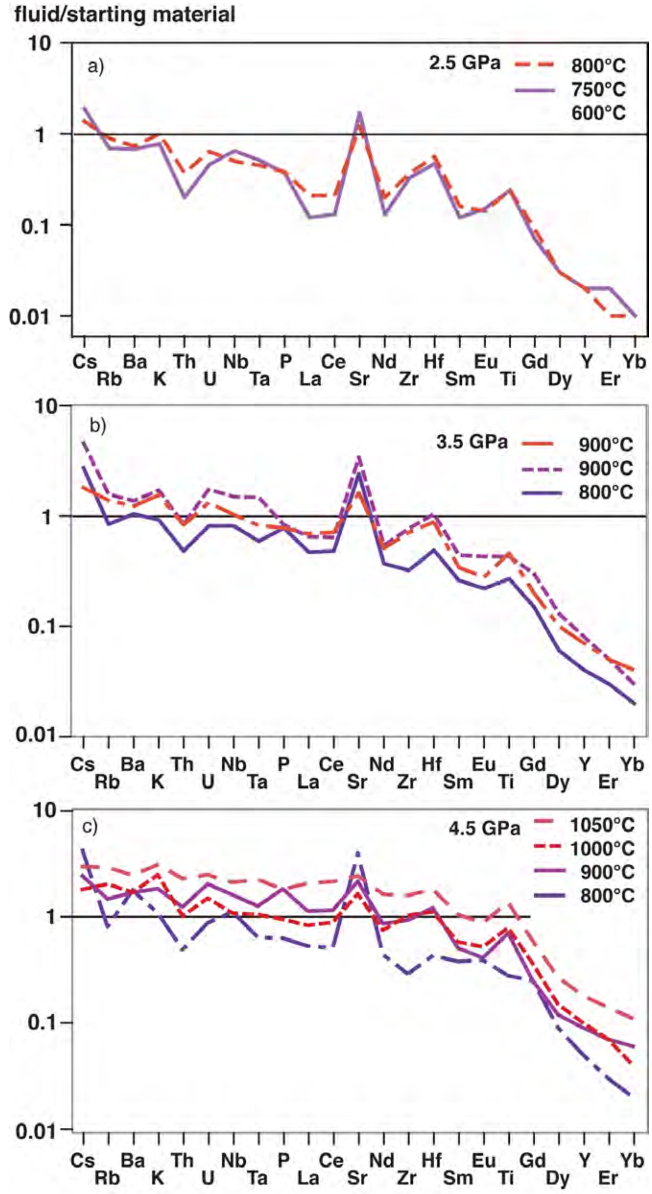


Figure 1. The trace element composition of experimentally produced hydrous melts derived from subducted sediments, normalized to the starting composition, at 2.5 (a), 3.5 GPa (b) and 4.5 GPa (c). The melts are enriched in incompatible elements (left side of the diagram), however, there is no significant fractionation of Nb and Ta from Th and La. Data from Hermann and Rubatto (2009), Chemical Geology 265, 512-526.

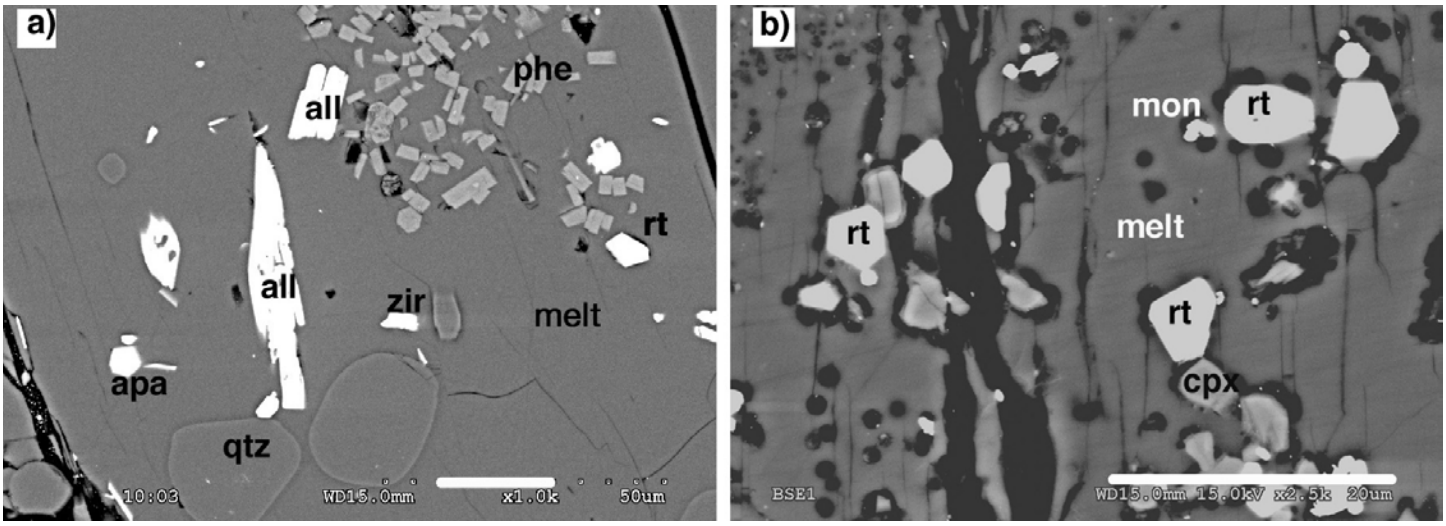


Figure 2. Electron back scatter images of experimental run products. a) Rutile (rt) coexists with partial melts at 800°C, 2.5 GPa. Also present are other important phases that control the trace elements such as phengite (phe), allanite (all), zircon (zir), and apatite (apa). b) Idiomorphic rutile is in contact with a hydrous melt at 800°C, 3.5 GPa. Monazite is stable instead of allanite. Scale bar represents 10 μm.

Variscan deformation of Australia – A heretic view of the Alice Springs Orogeny, Australia-Asia collision and tectonic extrusion

Chris Klootwijk

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

Paleomagnetic results from the ignimbrite-rich Carboniferous succession of the Tamworth Belt, Southern New England Orogen (SNEO), eastern Australia, indicate an Early Carboniferous northward excursion over about 30 degrees of latitude, culminating during middle-late Visean. The excursion is identifiable also in paleomagnetic data from the Australian craton and the Tasman Orogenic System (TOS) and may have started in Early Devonian. By middle-late Visean, the promontory of the Australian Craton in central New Guinea reached latitudes of 30 - 40 degrees N (Figure 1G), well within the paleolatitudinal range of the Central Asian Orogenic Belt (CAOB) of then southern Laurasia. Devonian-Carboniferous convergence and collision of Australia, as part of northeastern Gondwana, with the CAOB is proposed as the cause of contemporaneous, Variscan, tectonism along, and in the hinterland of, the northern and southern margins of the Paleoasian Ocean. That is within the CAOB of southern Laurasia and throughout Australia (Alice Springs, Quilpie and Kanimblan Orogenies).

Convergence-related compressional deformation of Australia was essentially confined to a “compression box”, extending southward from the central New Guinean cratonic promontory and bounded by the Lasseter Shear Zone in the west and the future East Australian Rift System in the east (Figure 1A). Convergence-driven north-south compression, weak heated crust in the Larapintine Graben and the oceanic basement of the TOS (Figure 1B), and the “free” oceanic boundary of the Paleopacific, constituted Variscan Australia-Asia conditions comparable to the Cenozoic India-Asia indentation and extrusion process (Royden et al. 2008, Burchfiel et al. 2008). Tectonic extrusion of ductile lower crust, and partial melt, from the Larapintine Graben caused eastward displacement of mainly the Thomson Orogen and the Northern New England Orogen (NNEO), perhaps in association with slab rollback of Paleopacific subduction. Upper crustal displacement was guided in the north by the Diamantina River Lineament-Clarke River Fault Zone and in the south, more complexly, by the Darling River/Cobar-Inglewood Lineaments and Cato Fracture Zone, and by the Lake Blanche-Olepoloko Fault Zones and Lachlan Transverse Zone (Figure 1B).

The tectonic extrusion hypothesis offers provocative new avenues for interpreting aspects of the Late Paleozoic evolution of Australia: (i) Different tectonic grains of the Alice Springs Orogeny (E-W) and the Quilpie and Kanimblan Orogenies (N-S) represent divers effects of the Australia-Asia convergence/collision on the brittle upper crust and on the ductile lower crust. Direct north-south compression through the upper crust led to the Alice Springs Orogeny of east-west tectonic grain, whereas in the ductile lower crust hydraulic fanning out of north-south compression toward alignment with the east-west pressure gradient near the free boundary of the Paleopacific, led to the Quilpie and Kanimblan Orogenies of north-south tectonic grain; (ii) East-west fanning out of azimuthal anisotopy (Figure 1E) and continental-like velocities in the lower crust/upper mantle of more internal parts of the TOS (Figure 1C, 1D), indicated by surface wave tomography, traces lower crustal tectonic extrusion from the Larapintine Graben into and through the TOS; (iii) Prominent negative magnetic anomalies in the Larapintine Graben and the TOS (Figure 1H) may represent hematite-residing Kiaman reverse polarity remanence (Figure 1F) in lower and upper crust and outline lower crustal flow throughout the TOS; (iv) Extent of lower crustal flow may be outlined further by mapping the extent of seismically highly reflective lower crust, assuming that its planar anisotropy represents horizontal ductile flow rather than vertical magmatic underplating; (v) The widespread Namurian sedimentary lacune may represent thermal expansion resulting from lower crustal ductile flow, with denudation products transported from the elevated “compression box” into the non-elevated New England Orogen (NEO) and western Australian basins; (vi) Formation of the Kanimblan Highlands during Late Carboniferous may reflect this thermal expansion process, with latest Carboniferous-Permian thermal relaxation leading to its demise; (vii) A Late Carboniferous heat flux may explain the fission track and low-temperature isotopic disturbance record without the need for extensive burial and denudation; (viii) A Stephanian change to clockwise rotation of Gondwana caused northward telescoping of the SNEO against the eastward displaced buttress of the NNEO, facilitated by structural detachment of the SNEO from the Lachlan Orogen along the northward progressing Eastern Australian Rift System, leading to formation of the Texas-Coffs Harbour and Manning Oroclines.

Burchfiel B.C., Royden L.H., van der Hilst R.D., Hager B.H., Chen Z., King R.W., Li C., Lü J., Yao H. &

Kirby E. 2008. A geological and geophysical context for the Wenchuan earthquake of 12 May 2008, Sichuan, People's Republic of China. *GSA Today* **18**, 4-11.

Debayle E. & Kennett B.L.N. 2000. The Australian continental upper mantle: structure and deformation inferred from surface waves. *Journal of Geophysical Research* **105**, 25423-25450.

Fishwick S., Heintz M., Kennett B.L.N., Reading A.M. & Yoshizawa K. 2008. Steps in lithospheric thickness within eastern Australia, evidence from surface wave tomography. *Tectonics* **27**, TC4009, doi:10.1029/2007TC002116.

Kennett B.L.N., Engdahl E.R. & Buland R. 1995. Constraints on seismic velocities in the Earth from travel times. *Geophysical Journal International* **122**, 108-124.

Klootwijk C.T. A heretic view of the Alice Springs Orogeny: Australia-Asia collision and tectonic extrusion. *Australian Journal of Earth Science*, in preparation.

Menning M. 1995. A numerical time scale for the Permian and Triassic Periods: an integrated time analysis. *In*: Scholle P.A., Peryt T.M. & Ulmer-Scholle D.S. eds. *The Permian of Northern Pangea 1*, pp. 77-97. Springer Verlag Berlin.

Roberts J., Wang X. & Fanning M. 2003. Stratigraphy and correlation of Carboniferous ignimbrites, Rocky Creek region, Tamworth Belt, Southern New England Orogen, New South Wales. *Australian Journal of Earth Sciences* **50**, 931-954.

Royden L.H., Burchfiel B.C. & van der Hilst R.D. 2008. The geological evolution of the Tibetan Plateau. *Science* **321**, 1054-1058.

Sabaka T.J., Olsen N. & Purucker M.E. 2004. Extending comprehensive models of the Earth's magnetic field with qrsted and CHAMP data. *Geophysical Journal International* **159**, 521-547.

Shaw R.D., Wellman P., Gunn P., Whitaker A.J., Tarlowski C. & Morse M. 1996. Guide to using the Australian crustal elements map. *Australian Geological Survey Organisation Record* **1996/30**.

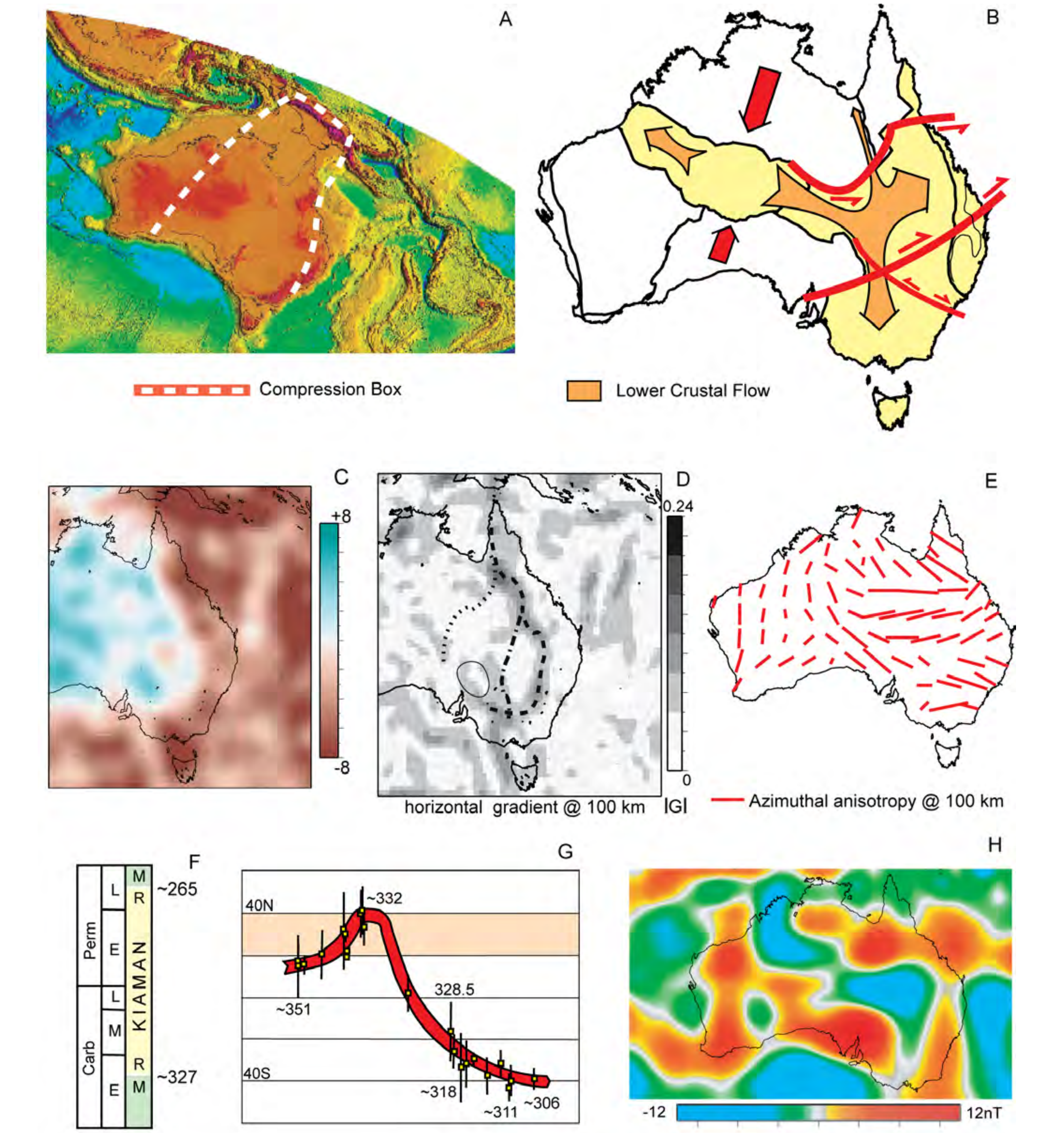


Figure 1 CTK RSES AR_2009

Figure 1. (a) Topographic and bathymetric image of the Australian plate in its surrounding setting, reproduced courtesy of Geoscience Australia, with the outline of the "compression box" hatched in white (Klootwijk, in prep., figure 12a). (b) Schematic overview of tectonic extrusion during the Alice Springs Orogeny. Red arrows indicate compression from Australia-Laurasia convergence during the Devonian-Carboniferous. Orange arrows indicate ductile flow of lower crust from the Larapintine Graben into mainly the Thomson and Lachlan Orogens. Major ENE-WSW fault zones, in red, guided up to 200 km upper crustal eastward displacement of the Thomson Orogen and the Northern New England Orogen. Yellow compartments (after Shaw et al. 1996) indicate at large the heated, weaker, crust of the Larapintine Graben and the weaker, originally oceanic, crust of the TOS (Klootwijk in prep., figure 12B). (c) Rayleigh wave speed anomalies of central and eastern Australia at 100km depth, relative to the ak135 model (Kennett et al. 1995), after Fischwick et al. (2008, figure 3a); (d) Image of the horizontal gradient of surface wave velocity of central and eastern Australia at 100 km depth, after Fishwick et al. (2008, figure 4a). (e) SV azimuthal anisotropy at 100 km depth (Debayle & Kennett 2000a, plate 2a). Azimuths of red line segments indicate fast directions, their lengths indicate strengths of anisotropy. (f) Duration of the "Kiaman" Permo-Carboniferous Reverse Superchron, after Menning (1995) and Roberts et al. (2003), (Klootwijk in prep., figure 22a). (g) Schematic view of paleolatitudinal evolution of the central New Guinean promontory of the Australian Craton during the Carboniferous (Klootwijk in prep. figure 22b). (h) Comprehensive model of the Oersted and CHAMP scalar residual field model CM4 at 400 km altitude, after Sabaka et al. (2004, figure 14b).

Tectonic reconstruction using deformable plates

Joe Kurtz, Sam Hart and Gordon Lister

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

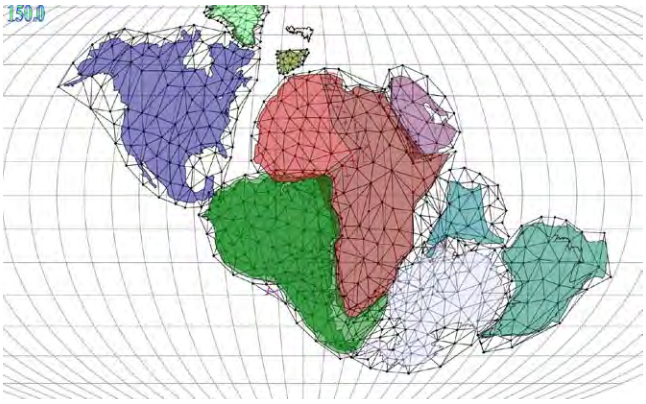


Figure 1. A global reconstruction currently under development which includes deformation of South America and Africa. This figure shows continental positions at 150 Ma relative to the South African craton.

AuScope is part of the National Collaborative Research Infrastructure Strategy (NCRIS). As part of that effort the simulation, analysis and modelling community (AuScope SAM) is constructing a "sofware machine" consisting of several interoperable components. The tectonic reconstruction component is being developed at U.Syd. and ANU. The RSES component is ***Pplates***, the first ever deformable-plate, global- to regional-scale, tectonic reconstruction code.

The workflow is illustrated here.

The ***Pplates*** code is now almost fully functional, and is available for download as a ".dmg" disk image. Click here to obtain a working copy of the program along with elementary datasets. New in ***Pplates*** v 1.3 (a new release) are many improvements that enhance the user experience and modified implementation of many of the features of ***Pplates*** with an eye to moving to new API libraries. In particular:

1) Faster handling of gridded data.
2) Higher screen resolution for topography.
3) Performance improvement with larger projects.
4) Better menu design for handling project files - including a "Save All" option.
5) Improved mesh shaper performance -- moving a mesh shaper has been enabled.
6) Stress eigenvector calculation and display where previously only strain eigenvectors were available.
7) Map window viewing preferences stored with project.

Please Email *joe.kurtz@anu.edu.au* or *sam.hart@anu.edu.au* with comments and suggestions.

Dating a major shear zone in the Central European Alps - The Forcola Fault

Clemens Augenstein[1], Marnie Forster[1], Gordon Lister[1] and Jean-Pierre Burg[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Earth Sciences, ETH Zurich, 8092 Zurich, Switzerland

Figure 1. Photograph with view towards South, taken from the Forcola pass at the Swiss/Italian border. The Forcola fault runs along the valley and disappears under the quaternary valley fill of the Chiavenna plane.

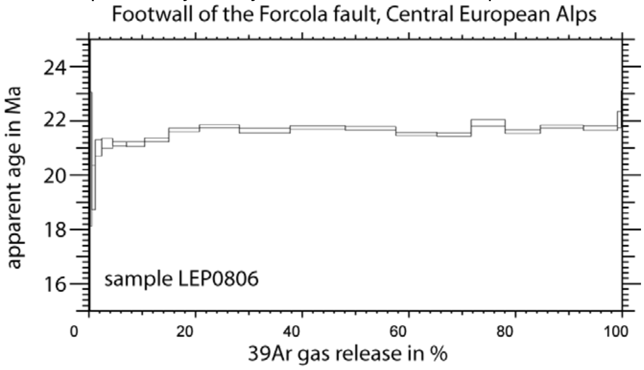


Figure 2. Apparent age spectrum gained from 40Ar/39Ar furnace step-heating dating experiments of white micas of a mylonite in the footwall of the Forcola fault. The spectrum suggests a defromation age of the mylonites of 21-22Ma.

The Central European Alps have been subject to geological studies for now more than 150 years with a prolific array of data available. Even though the timing of deformation is one of the most important keys to resolve the geological history of a mountain belt few studies have focused on ascertaining the timing of major movement zones in the area. The Forcola normal fault is a major displacement zone in the Central European Alps and is often regarded as the Eastern boundary of the Lepontine gneiss dome. This dome is a window into deeper crustal levels of the Alpine nappe pile and the most prominent structure in the Central Alps, but the origin of this gneiss dome is still contentious with several hypothesis proposed during the last decades. We suggest that none of the present hypotheses explain either the published observations, or our observations, in a satisfactory manner. One important step towards a better understanding of the formation of the Central European Alps, is the direct dating of deformation events inside and around the Lepontine dome. The $^{40}Ar/^{39}Ar$ geochronology furnace step-heating dating technique on K-bearing minerals like micas or K-feldspar, enables us to date recrystallisation of major fabric forming minerals, and thus determine the timing of deformation directly.

Preliminary results from $^{40}Ar/^{39}Ar$ geochronology experiments on white micas from rocks deformed in the Forcola fault are now available from samples collected during the field summer 2008. Results show that these rocks recrystallised between 21 and 22 million years ago (see apparent age spectra) during an intense deformation event (mylonitization of an orthogneiss). The relative flat “plateau” in the spectra indicates that the white micas in the sample recrystallised completely and lost all their previous accumulated radiogenic argon during the deformation event. This complete resetting of the argon system correlates with the last event that can be verified at the microstructural-scale. These ages are the first direct evidence for the timing of shearing events at the Eastern border of the Lepontine gneiss dome.

This study on the deformation of the Forcola Fault is just the beginning of a greater project. The overall aim is to analyse several of the major movements zones in the Central Alps, helping to understand the complicated processes of mountain range formation, continental collision and continental convergence in greater detail.

Evolution of the subducting Solomon Sea Plate

Tomas O'Kane[1], Simon Richards[2], Gordon Lister[1], Marie-Aude Bonnardot[3] and Louis Gauthier[4]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] School of Earth and Environmental Sciences, James Cook University, Townsville, 4811, Australia
[3] FrOGTech Pty Ltd, Canberra, 0200, Australia
[4] Barrick Gold of Australia Limited, Perth, 6000, Australia

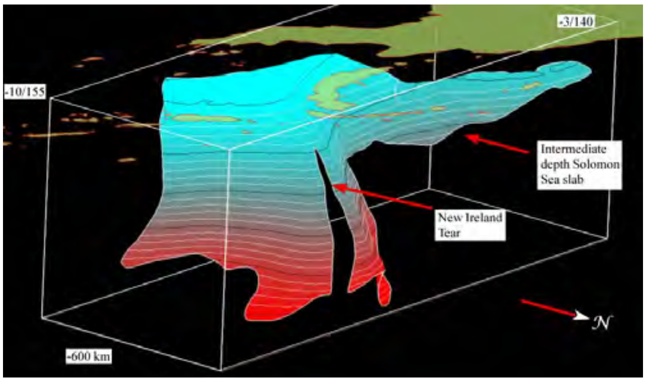


Figure 1. 3-D model of the Wadati-Benioff zone associated with the subducting Solomon Sea plate, developed by Tomas O'Kane under the supervision of Dr Simon Richards. This required the interpretation of the earthquake hypocentre dataset Engdahl et al., (1998), kindly provided by Robert Engdahl via personal communication. We have recently been examining the geodynamic implications of this inferred slab geometry.

The Papua New Guinea and Solomon Islands region is located within the transition zone between SE Asia and the SW Pacific, one of the best-endowed metallogenic belt and most actively deforming areas on Earth. Interactions between the WNW-moving Pacific Plate and the NNE-moving Australian Plate give rise to a complex convergent zone exhibiting numerous micro-plates, volcanic provinces, island arcs and some of the fastest relative plate motions on Earth.

Some of this complexity has been unravelled using earthquake hypocentre data to create a 3-D model of the Wadati-Benioff zone associated with the subduction of the Solomon Sea Plate at the New Britain Trench. We report the presence of a large aseismic zone, herein termed the New Ireland aseismic zone, located in the 'apex' of the subducting slab, the margins of which initially record a dip of 30°, before steepening to over 75° at depth. Steeper slab dips are seen both to the east and west of the slab apex, particularly the eastern section of the slab, which appears to have been overturned (i.e. dip exceeds 95°).

In the light of this discovery existing tectonic models must be reassessed. The 3-D geometry appears to require slab-tearing during roll-back, and by implication must have stranded formerly attached segments of the subduction zone. Alternative models for the aseismic zone, such as the subduction of an aseismic ridge, do not provide a satisfactory explanation for the inferred geometry, and implicit deformation, of the Solomon Sea slab. In contrast, the roll-back and slab-tearing hypothesis is consistent with the current 3-D geometry, although it has significant ramifications for the tectonic evolution of the region. Roll-back and slab-tearing require a modification of palaeogeography and 3-D structure with time.

Evidence of (subduction-related?) magmatism after "the collision" of India and Eurasia

Lloyd White[1], Talat Ahmad[2], Trevor Ireland[1], Marnie Forster[1] and Gordon Lister[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Deparment of Geology, University of Delhi, Delhi, India

The concept of “the collision” in relation to the accretion of India to Eurasia dominates the literature on the Himalayan orogen. Current controversy surrounds its timing. One hypothesis suggests that this event took place at ~54-50 Ma, whilst other hypotheses suggest that it occurred earlier (~75 Ma), or later (~35 Ma). Most of this controversy is associated with the simplified view that the accretion of India to Eurasia was more important in terms of magmatism, metamorphism and deformation than the accretion of other island arcs and terranes during the closure of Tethys. The current paradigm suggests that Indus Suture Zone marks the boundary between the Indian and Eurasian plates (Figure 1).

New U-Pb SHRIMP dating of zircons from a granodiorite in the Karakorum Batholith indicate crystallization occurred north of the Shyok Suture Zone at 32 Ma. There is also other evidence of magmatism at this time along strike of the Shyok Suture Zone, this includes porphyry Cu, Mo and Au deposits in eastern Tibet. Various models are invoked to account for this magmatism. However, as the evidence of magmatism at these times does not fit the paradigm of “the collision” marked at the Indus Suture Zone at ~54-50 Ma, tectonic models that suggest this magmatism could be the result of partial melting caused by dehydration of a down-going slab at (or before) this time are ignored. We therefore suggest that the Indus Suture Zone (at least in NW India) may not mark the boundary between the Indian and Eurasian plates, and the concept of “the collision” needs to be revised.

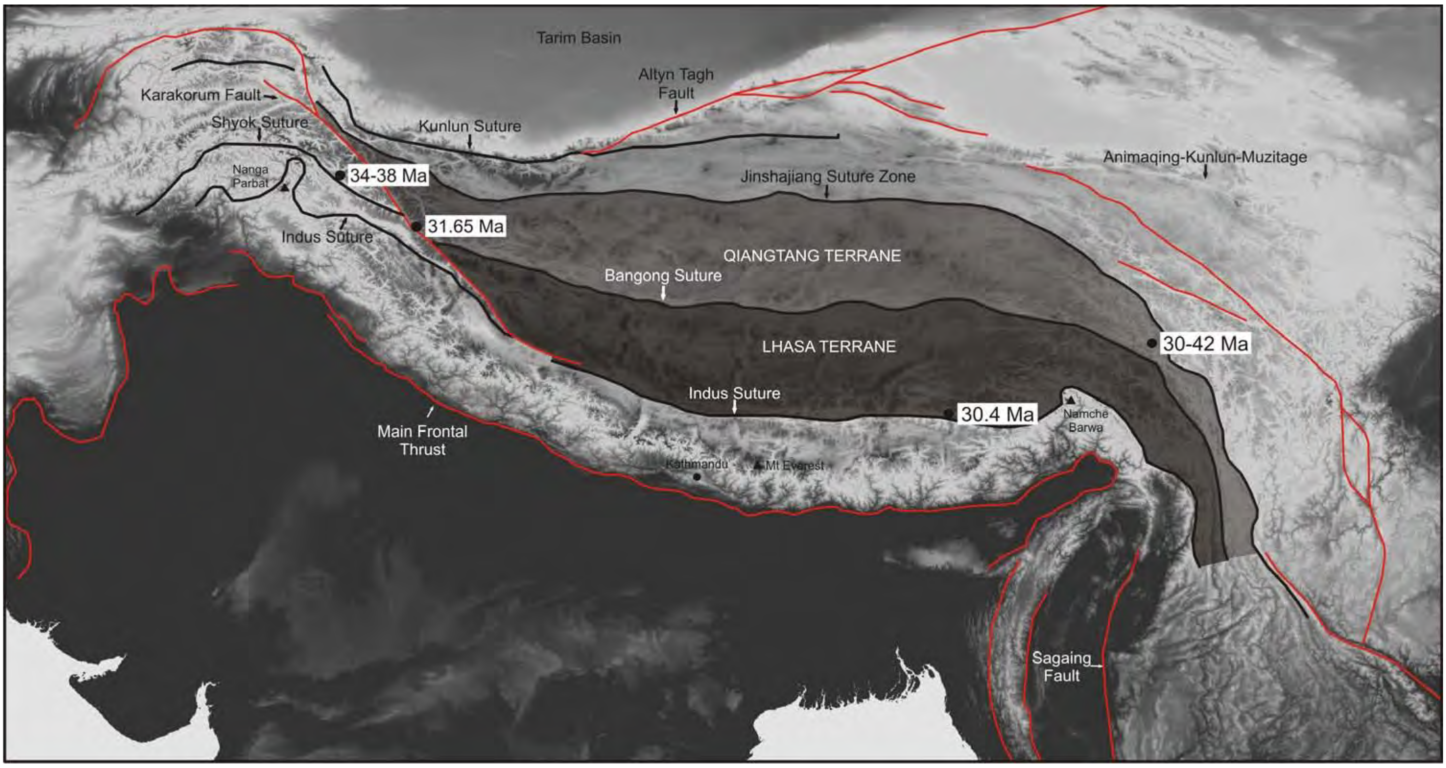


Figure 1. Digital elevation model of the Himalaya derived from Shuttle Radar Topography Mission (SRTM) data showing the location of major structures and suture zones, as well as the location of crystallization ages of granites, granodiorites and porphyry Cu-Mo-Au deposits north of the Indus and Shyok Suture zones.

Diffusional rims and moats around ilmenite inclusions in garnet and their significance for garnet geospeedometry

Iona R. Stenhouse, Gordon S. Lister, Hugh St. C. O'Neill, Daniel R. Viete and Robert Rapp

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

Geospeedometry is a rapidly developing field. The technique is used to constrain the duration of thermal pulses during metamorphism. For example, diffusion modelling of element profiles in garnet. Garnet geospeedometry involves measurement of diffusive loss of an element during the entire heating and cooling history, giving information as to the time-integrated thermal response to the heating and cooling history. Currently, garnet geospeedometry is plagued by the difficulty of differentiating between growth zoning, as a result of Rayleigh-Taylor fractionation, and diffusion profiles. Development of a new geospeedometer that utilises the exchange of Fe-Mn between garnet and ilmenite inclusions will aid in solving this problem.

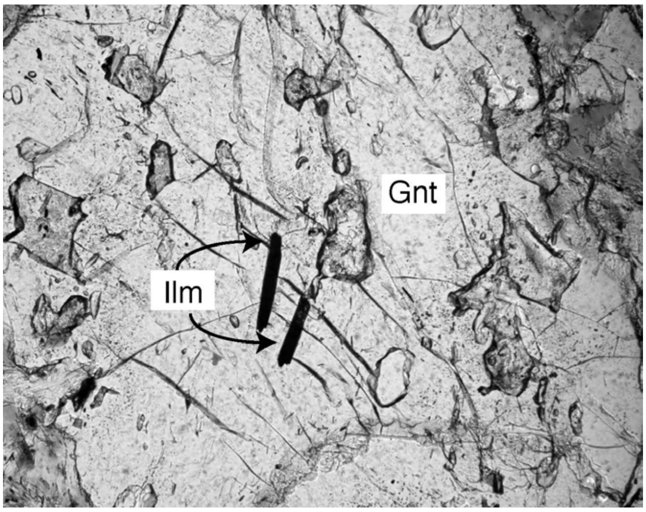


Figure 1. Ilmenite inclusions in garnet (Image width 1.2mm).

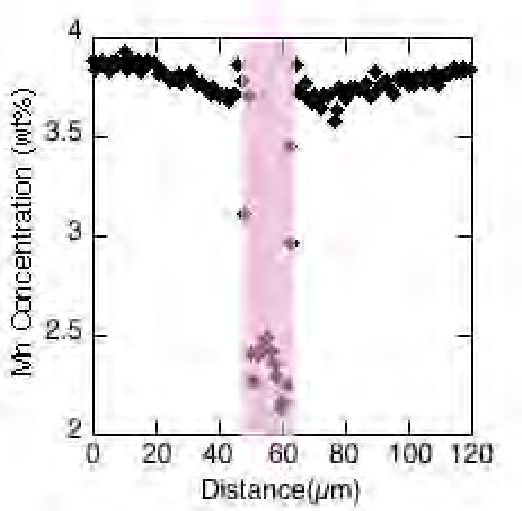


Figure 2. Electron Microprobe transect across an ilmenite inclusion (pink) in garnet.

The garnet-ilmenite system, if properly calibrated, will allow the determination of the duration of both heating and cooling during the tectonometamorphic evolution of a particular rock. This is possible because of the temperature dependence of the Fe-Mn partition coefficient of the garnet-ilmenite system (Pownceby et al. 1987). This allows exchange of Fe and Mn at the boundary between garnet and ilmenite with the diffusion coefficient of garnet controlling the efficiency of exchange; the diffusivity of ilmenite does not need to be taken into account due to its rapidity. The rate of diffusion dictates the efficiency of exchange, with a quadratic relationship between the length of the diffusion profile and timescale. Ilmenite operates as a sink for Mn during the period of heating above the growth temperature; during cooling the ilmenite acts as a source for Mn, expelling it into the garnet. The ability of ilmenite to act as a diffusional sink on the heating path is greater than its ability to act as a source on the cooling path because as temperature decreases the systems potential for diffusion rapidly drops. This process produces diffusional features that vary in length and a bimodal diffusion profile is created. According to these theoretical considerations the Mn diffusion profile should have a sharp increase in concentration adjacent to the ilmenite inclusion then a Mn moat surrounding the ilmenite inclusion. The diffusion profile for Fe theoretically mirrors this behaviour. This profile has been observed in electron microprobe transects across ilmenite inclusions in garnet.

Pownceby, M. I., Wall, V. J., O'Neill, H. St.C. (1987). Fe-Mn partitioning between garnet and ilmenite: experimental calibration and applications. *Contributions to mineralogy and Petrology* **97** 116-126.

Gravity drives Great Earthquakes

Gordon Lister[1, 2] and Marnie Forster[1, 2]

[1] Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia
[2] ANU Centre for Natural Hazards

It is evident that the most violent of Great Earthquakes are driven by ruptures on giant megathrusts. Current theory suggests that the rupture harvests (and thus releases) elastic energy that has been previously stored in locked segments of the megathrust, and that this energy is stored as the result of relative motion of the adjacent stiff elastic tectonic plates. However it is clear that this mechanism fails to explain many first order aspects of large earthquakes. The energy source for strain accumulation can also be found in gravitational collapse of orogenic crust and/or in the foundering (or roll-back) of an adjacent subducting lithospheric slab.

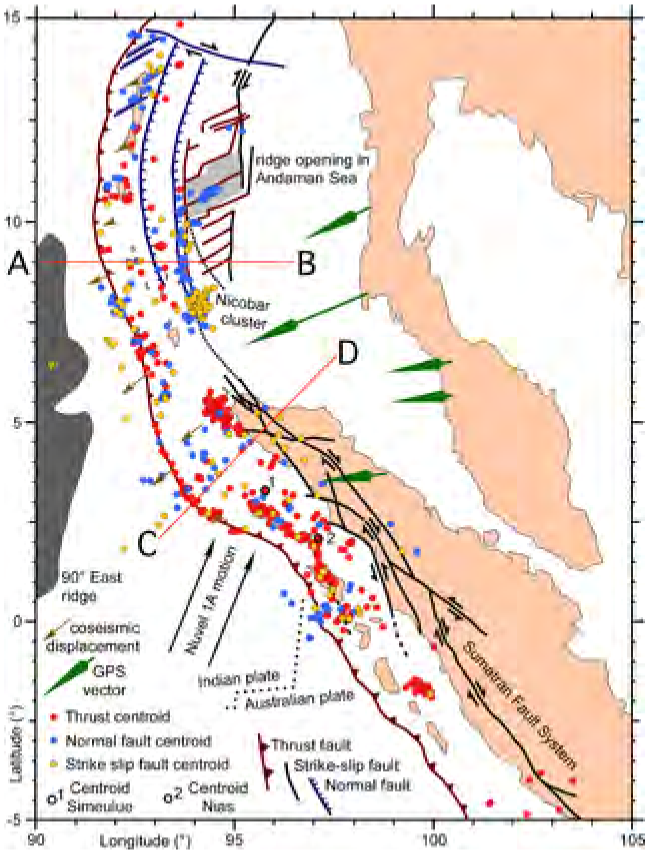


Figure 1. Map of the area afflicted by the aftershocks from the 2004 Great Sumatran Earthquake. The earthquakes shown are those for which centroid moment tensor solutions exist, and are derived from the Global CMT project database.

Analysis of the geomery of aftershocks allows distinction of two types of failure. The classic view is that megathrusts fail in compression, with motion analogous to that expected if accretion takes place against a rigid (or elastic) backstop. This type of megathrust behaviour may well have applied to the southern segment of the Sumatran megathrust, from whence emanated the rupture that drove the 2004 Great Earthquake. The northern segment (beneath the Andaman Sea) admits to no such explanation. The geometry of aftershocks suggest that the crust above the initial rupture failed in an extensional mode.

Therefore westward roll-back of the subducting Indian plate, and the consequent gravity-driven movement of the over-riding crust and mantle can be implicated in the origin of the tsunamigenic Great Sumatran Earthquake of 2004. The edge of the Indian plate is foundering, with slab-hinge roll-back in a direction orthogonal to its motion vector. Aftershocks show that this motion may have driven afterslip in the Andaman segment of this giant megathrust-related earthquake.

The crust and mantle above major subduction zones is mechanically weakened by the flux of heat and water associated with subduction zone processes. In consequence the lithosphere of the over-riding orogens can act more like a fluid than a rigid plate. Such fluid-like behaviour has been noted for the Himalaya and for the crust of the uplifted adjacent Tibetan Plateau, which appear to be collapsing. Similar conclusions as to the fluid-like behaviour of an orogen can also be reached for the crust and mantle of Myanmar and Indonesia, since here again, there is evidence for arc-normal motion adjacent to rolling-back subduction zones.

Earth Physics

Introduction

The Research School of Earth Sciences includes substantial activities in geophysics. The main research themes are Geodynamics, Geodesy, Geophysical Fluid Dynamics, Mathematical Geophysics and Seismology. These span observational, theoretical, laboratory, computational and data oriented studies, all directed towards understanding the structure and physical processes in the earth's interior, the crust or the earth's fluid envelope.

In 2009 Professor M. Sambridge was awarded the 2009 Price medal from the Royal astronomical Society of London for achievements in Earth Science. Dr M. Roderick was awarded the Australasian Science Prize by the journal Australasian Science for his work on the Earth's hydrologic cycle and showing how pan evaporation rates in Australia have decreased over time with global warming. Professor R. Griffiths joined the Australian Research Council College of Experts (Physics, Chemistry, Earth Science panel).

RSES continues to take a major role in the National Cooperative Research Infrastructure Strategy (NCRIS): "Structure and Evolution of the Australian Continent", which is managed through 'AuScope'. RSES hosts activities in Earth Imaging through support of portable instrumentation and transects, Geospatial through gravity measurements and testing of portable equipment for satellite laser ranging, and Simulation & Modelling through 'pPlates' software for tectonic reconstruction. As a linked activity between three AuScope components (Imaging, Geospatial and Access and Interoperability), the Terrawulf II cluster computer at RSES (Centre for Advanced Data Inference) provides capability in geophysical inversion and the computation reduction of observational data. RSES also continues the management of the Warramunga Seismic and Infrasonic Research Station near Tennant Creek in the Northern Territory, as a primary station in the International Monitoring System for the Comprehensive Nuclear-Test-Ban Treaty Organisation.

Research in **geodynamics** and **geodesy** has focused on measuring deformation of the Earth from both terrestrial and space-based observations. Estimates of total water storage from the GRACE space gravity mission were compared to terrestrial estimates of surface, soil and ground water in a study of the multi-year drought in the Murray-Darling Basin. The finding that a significant component of water loss had come from groundwater reserves generated considerable media interest. Other results were a demonstration of the non-stationary nature of geophysical signals observed by GRACE, that positive gravity anomalies in Enderby Land (Antarctica) are not related to glacial isostatic adjustment, and improvements in GPS analysis strategies that lead to a better agreement between GPS- and GRACE-based surface deformations than reported in previous studies. Terrestrial gravity measurements have been made using an absolute gravimeter and tidal meters in order to quantify the surface deformations caused by ocean tide loading.

In **geophysical fluid dynamics**, laboratory experiments have been used to examine the three-dimensional flow in mantle subduction zones, and the interaction of ascending mantle plumes with subduction zones, with a view to explaining the history of volcanism in the Columbia River Basalts, the Lava High Plains and Yellowstone hotspot of the northwest USA. Modelling of the combined chemical and thermal evolution of the Earth's mantle has been extended to Venus' mantle to test ideas about the operation of plate tectonics on Venus and whether the 'basalt barrier' mechanism can explain the outburst of volcanism that completely resurfaced Venus about 500 Myr ago. Another highlight is an explanation of the energetics of the global meridional overturning circulation of the oceans, which shows that energy supplied to irreversible turbulent mixing from the winds and tides (or other sources) must be in balance with the available potential energy supplied by the surface buoyancy fluxes. Hence the energetics indicate that the rate of overturning is governed by both the buoyancy fluxes and the mixing rate, as previously argued on the basis of dynamical considerations. Numerical solutions from a general circulation model were also found to be different depending on whether it was run in the usual hydrostatic and low-resolution mode, or in non- hydrostatic mode with an extremely high resolution resolving the vertical convective motions. In closely related work aimed at understanding both turbulent mixing and the global circulation, new experiments were carried out to obtain additional information about the nature of mixing in exchange flows over topographic sills. The results indicate that the proportion of energy input that goes into raising the potential energy by mixing is in the range 5-10%, efficiencies much smaller than the 20% often assumed in analyses of global ocean energy balances. Work also continues in high-resolution modelling of flow in the Southern Ocean, designed to determine the dynamics driving the circulation in this region. The latest results give a clearer indication of the likely response of the Southern Ocean to climate change.

In parallel with the gravity satellite research, and the ocean studies, we conduct detailed studies on the hydrologic cycle. Of principal interest here is the development of a theoretical framework that can provide physical understanding of the possible changes in the hydrologic cycle with global warming, at both global and local scales. One highlight this year was the publication of "The Global Water Atlas" (by ANU ePress), which documents model predictions contributed by international climate modelling groups to the 2007 4th Assessment Report of the Intergovernmental Panel on Climate Change.
Activities in **seismology** in 2009 included extensive field-based deployments of seismic instrument arrays, data analysis and theoretical development, for studies of Earth structure from the crust to the core. Much of the activity centred on the WOMBAT experiment, a rolling-array deployment that has been in operation since 1998 and is currently focused on achieving

high resolution imaging of the crust and upper mantle beneath south-eastern Australia, including the Flinders ranges and the Murray Basin. The results show little evidence for the Palaeozoic building blocks of the southeast Australian continent that had been inferred from geological mapping. By utilizing differential PcP-P times from WOMBAT, high resolution imaging of the core-mantle boundary is also possible and current efforts are directed at mapping variations in core-mantle boundary geometry and D" velocity. New global observations of waves reflected from the Earth's inner and outer core (PKiKP and PcP waves), originating from earthquakes and nuclear explosions, were used to place bounds on density ratio between the inner and outer cores. Other arrays were deployed in the region around Mt Isa in Queensland and between the Eyre Peninsula in southern Australia and Tennant Creek in northern Australia, in order to examine the transition between the northern and southern Australian cratons. The new Seismic Data Centre (SDC) now provides easy access to all current and past seismic data collected by RSES in a variety of user-friendly formats. Model structures for the inner core were re-examined using our Antarctic permanent stations as well as the temporary SSCUA deployment operated by the RSES during 2002-2005, and provide evidence against a proposed cylindrical structure in the outer core tangent to the inner core in the southern hemisphere.

A portrait of the Bárdarbunga volcano, Iceland, earthquake and insights into the kinematics of the caldera drop

Hrvoje Tkalčić[1], Andreas Fichtner[2], Douglas S. Dreger[3], Gillian R. Foulger[4] and Bruce R. Julian[5]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Department of Earth Sciences, Utrecht University, 3508 TA Utrecht, Netherlands
[3] Berkeley Seismological Laboratory, University of California at Berkeley, Berkeley, CA 94720, US
[4] Department of Earth Sciences, Durham University, Durham DH13LE, UK
[5] United States Geological Survey, Menlo Park, CA 94025, USA

The Bárdarbunga volcano lies beneath the 500-m-thick Vatnajokull icecap, the largest glacier in Europe. An earthquake with Mw=5.6 occurred beneath the caldera on 29 September, 1996 and produced an unusual radiation that cannot be explained by a shear slip on a planar fault. A peculiarity of this earthquake was that it was the first in a sequence of seismic and magmatic events and that it was followed, not preceded or accompanied, by a major eruption, which ultimately led to a breakout flood from the subglacial caldera lake. It was hypothesized that the observed source mechanisms results from slip on an outward-dipping cone-shaped ring fault beneath the caldera, as a result of a change in pressure in the volcano's shallow magma chamber. The earthquake was recorded well by the Iceland Hotspot Project seismic experiment.

The absence of a volumetric component in the source mechanism is surprising, however a possible mechanism that can produce an earthquake without a volumetric component involves two offset sources with similar but opposite volume changes. We show that although such a model cannot be ruled out, it is unlikely. We simulated different caldera geometries and rupture scenarios on the walls of a conical surface. These experiments support a super-shear rupture extending unilaterally accross one-half perimeter of the caldera or a bilateral rupture extending accross full perimeter of the caldera as likely scenarios for the Bárdarbunga earthquake.

If studied in different frequency bands, synthetic seismograms based on a point source approximation fail to simultaneously explain the observed data, and this indicates the presence of finite-source effects. Using a 3D model of the Icelandic crust and upper mantle, we perform a probabilistic finite source inversion. One of the most robust outcomes of this is a well-constrained source duration with approximately equal amount of energy radiated by individual segments. This indicates that the caldera dropped coherently as a single block. We also hypothesise that a smaller subglacial eruption that triggered the caldera collapse occurred and went unnoticed. The caldera drop could have increased the pressure in the magma chamber thus inducing the principal eruption. The major eruption after the earthquake is consistent with the classical model where the ring fault is located above the magma chamber.

Figure 1. Bardarbunga volcano, Iceland

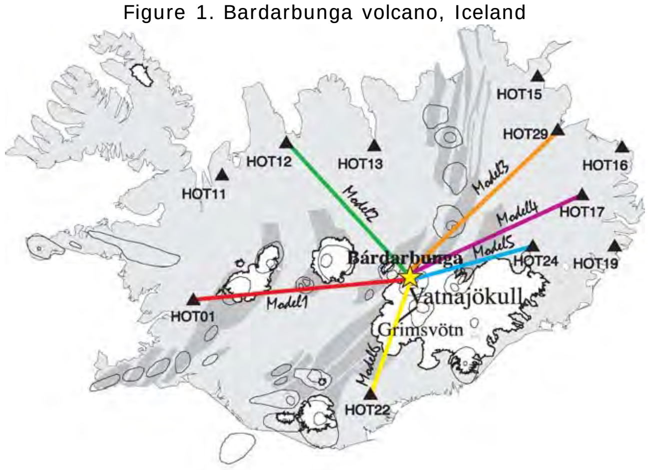


Figure 2. Map of Iceland showing the Hotspot seismic stations used in the study. The locations of Bardarbunga and Grimsvotn volcanos are also displayed.

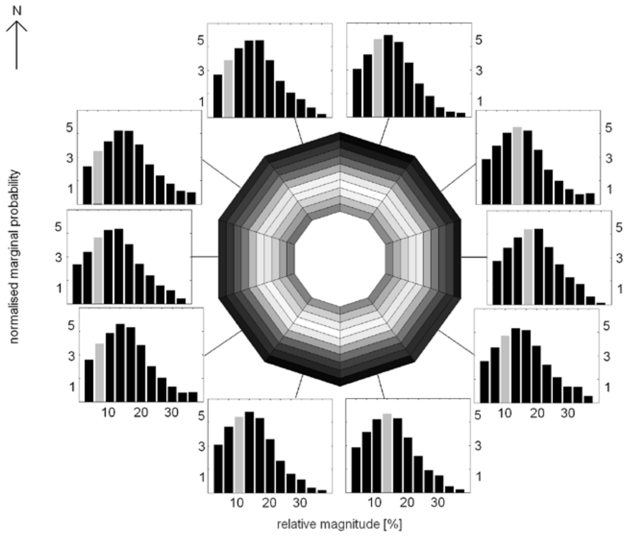


Figure 3. Marginal probability distributions for the rupture time on the individual fault segments. The hight of a bar in the histograms indicates the probability that the magnitude on a given segment falls into the interval covered by the width of that bar. The circular image in the centre shows the marginal probability densities as gray scale distributions. Each of the 10 subfaults released about 10% of the total elastic energy. The relative magnitudes for the most probable finite source model are shown as gray columns.

Link to the online article:
http://www.bssaonline.org/cgi/content/abstract/99/5/3077

South Australian Seismic Arrays

Michelle Salmon and Brian Kennett

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

As part of a wider AUSCOPE project 67 short-period seismometers were deployed across the Gawler and Curnamona Cratons in South Australia. Station spacing was approximately 60 km and covers the area from the Streaky Bay in the east to the New South Wales border in the west. The north-south extent of the array runs from Cameron Corner to Port Lincoln. Stations recorded continuous three component data for a period of 6-8 months. The instruments are capable of recording data from both local and distant earthquakes.

The primary aim of these arrays is to increase data coverage in this part of Australia for seismic imaging. There are few permanent seismographs in the region covered by this array. The area covered is currently of particular interest for the supply of geothermal energy and there are many ongoing industry projects in the area. This area of South Australia is also seismically active and local earthquake data recorded on this array will help improve our ability to locate and characterize these events.

Currently the data are being used for receiver function analysis to locate seismic discontinuities such as the crust-mantle boundary (Moho). This is contributing the the ongoing AusMoho project mapping the Moho beneath the Australian continent (figure 1).

Curnamona Craton seismic stations

http://maps.google.com.au/maps/ms?hl=en&ie=UTF8&msa=0&msid=103343213149735877786.00046a786a658a692886c&ll=-31.672083,137.329102&spn=8.504599,17.072754&z=6

Gawler Craton seismic stations

http://maps.google.com.au/maps/ms?hl=en&ie=UTF8&msa=0&msid=103343213149735877786.000458b85f5e764738e6c&ll=-32.861132,136.494141&spn=7.932711,17.072754&z=6

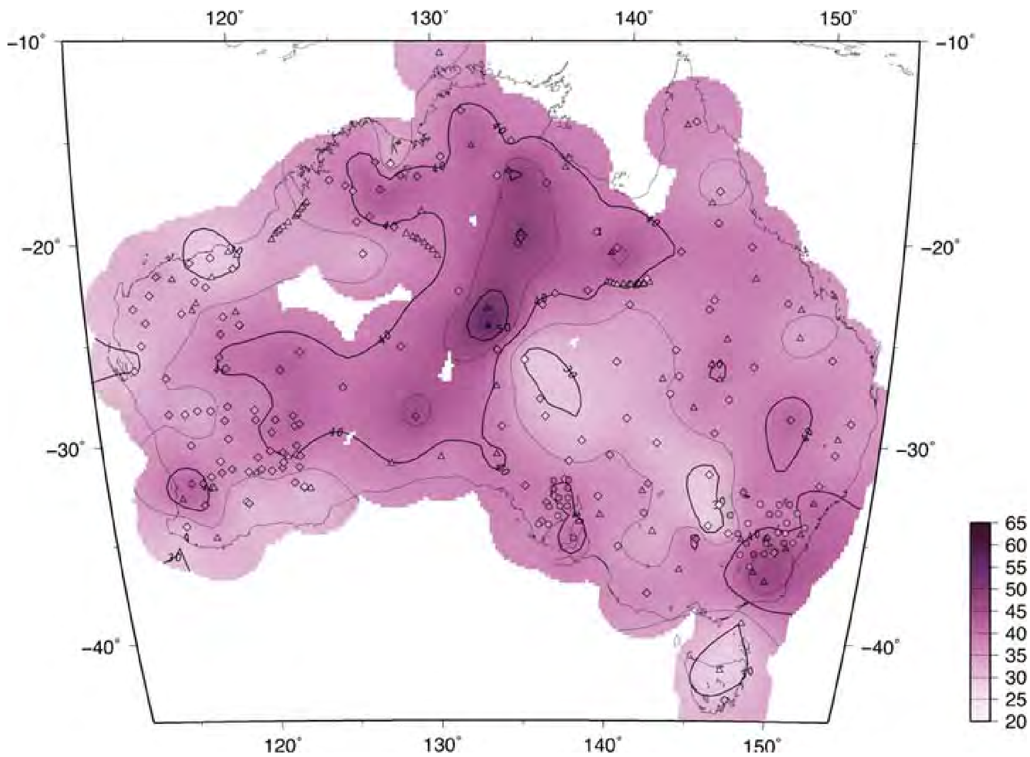


Figure 1. Current AusMoho map. Contours show the deoth to the crust-mantle boundary in kilometers. Data points from short-period receiver functions are shown as circles, data points from broadband receiver functions are shown as diamonds and refleaction/refraction line data are shown as triangles.

High Resolution Imaging of the Core Mantle Boundary with PcP-P Differential Travel Time Residuals

Sara H Pozgay[1], Hrvoje Tkalcic[1], Nick Rawlinson[1], C Haberland[2], T Ryberg[2] and F Tilmann[3]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] GFZ, Potsdam, Germany
[3] Cambridge University, England

Southeastern Australia is favorably positioned relative to much of the Pacific Rim and SE Asian subduction systems for detection of PcP phases from subduction zone earthquakes, which are best recorded between approximately 25-75°. The subduction zones of Indonesia, Papua New Guinea, Tonga/Kermadec, Philippine, Izu-Bonin-Mariana, and Japan are all within 25-75° of SE Australia. As such, any seismic stations deployed in this area have potential for detailed PcP-P travel time studies. Using data from a large rolling seismic array in southeast Australia, we obtain unprecedented high-resolution coverage of the core-mantle boundary in this region.

Surface projections of PcP bounce points are clustered directly beneath the large region spanning central and northern Australia, the Arafura Sea, north of Papua New Guinea, and the Tasman Sea. There is an overall predominance of negative residuals throughout the region, particularly near Sulawesi, western Indonesia, central Australia, and west of New Zealand. In particular, results under the Tasman Sea show a transition from large and negative residuals to moderate and positive residuals, which could be suggestive of remnant subduction signals at the CMB from in the Tonga/Kermadec region.

With the remaining analysis using the rest of the >500 short-period stations in SE Australia and >100 stations in Sumatra, we aim to produce high-resolution images of the lower mantle and core-mantle boundary. We will focus on the regions of central Australia and the Timor and Tasman Seas in particular as they have the densest raypath coverage. Using traveltime tomography, waveform coherence, any precursory phase analysis, and amplitude information, we will investigate the trade-off between velocity structure and interface depth at the core-mantle boundary

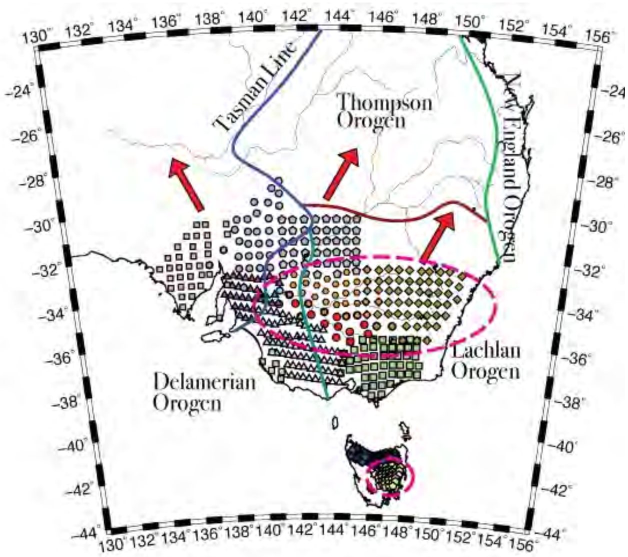


Figure 1. The WOMBAT array of short-period seismic stations marching across southeast Australia at 40-50 km spacing (15 km spacing in Tasmania). The earliest deployment was in 2001 (light green squares), the gray pentagons are currently recording, and the gray circles were just pulled out for imminent redeployment to the east of the current configuration. Stations used in the current study are encircled with pink dashed line.

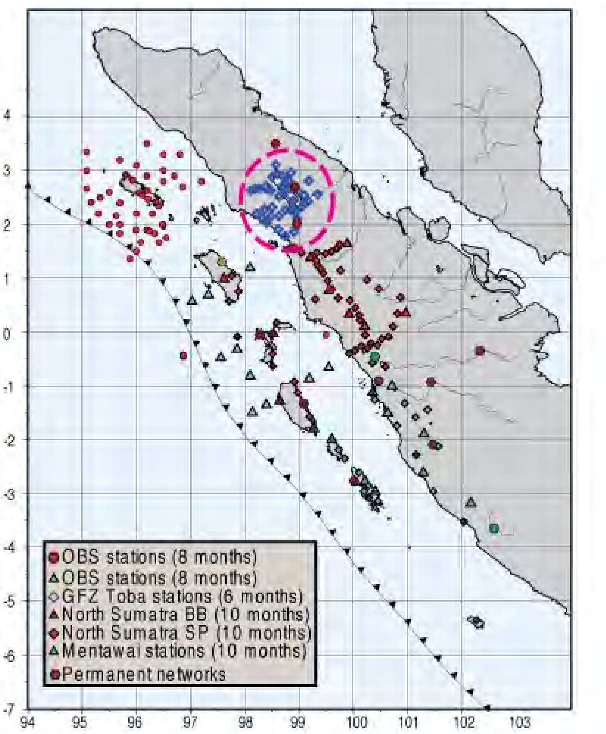


Figure 2. Short-period and broadband seismic stations in Sumatra, Indonesia for much of 2008. GFZ Lake Toba stations (hollow blue diamonds encircled with pink dashed line) are the only stations used in the current study. Future work will include data from all other stations as shown.

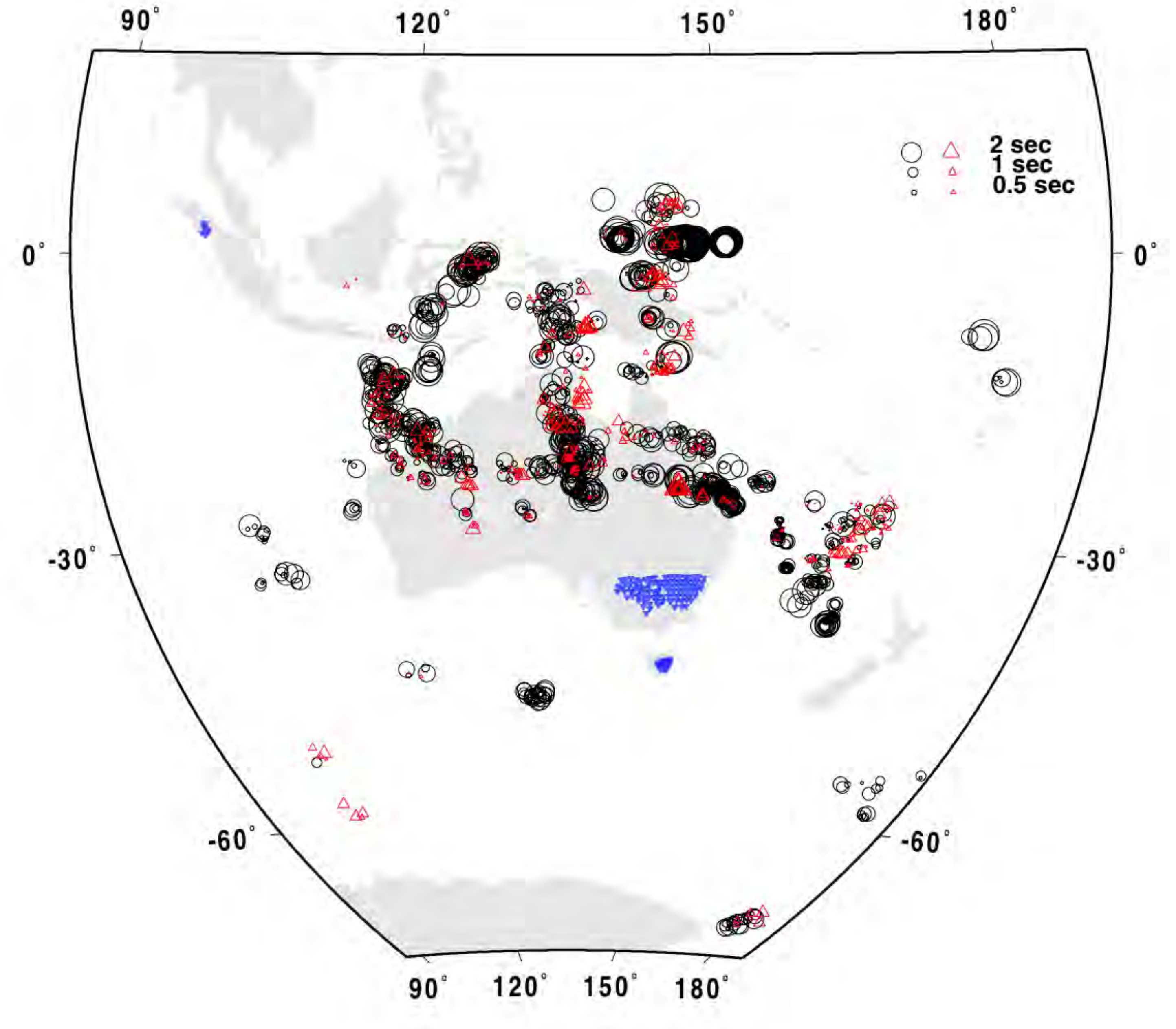


Figure 3. Surface projections of PcP-P bounce points. Points are scaled by PcP-P residual, black circles are negative, red triangles are positive. Inverted blue triangles are stations used in the study.

Ambient noise tomography of southeast Australia using WOMBAT seismic data

N. Rawlinson, P. Arroucau and M. Sambridge

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

Detailed images of Rayleigh wave group velocity are derived from ambient seismic noise recorded by WOMBAT, a large rolling seismic array project in southeast Australia (see Figure 1). Data from 282 stations deployed as part of seven separate array movements are used, with a maximum of 57 stations recording at any one time. Group velocity maps sensitive to shallow crustal structure (Figure 2) reveal the presence of low velocity regions associated with sedimentary basins and the Newer Volcanic Provinces of western Victoria, and high velocities associated with regions of outcropping metamorphic and igneous rocks in the Great Dividing Range. Distinct and well-constrained patches of low velocity within the Murray Basin, a large Tertiary intra-cratonic basin, point to the presence of infra-basins, the existence of which have been confirmed by drilling, but whose spatial extent is poorly understood. In a broader tectonic context, our results show little evidence for the Palaeozoic building blocks of the southeast Australian continent that have been inferred from geological mapping and potential field data. For example, the transition from the Delamerian to the Lachlan Fold Belt is not marked by a change in group velocity, nor is the so-called Tasman Line, which supposedly separates Precambrian western Australia from Phanerozoic eastern Australia. In the latter case, the new results support the contention that the change from an accretionary orogenic terrane in the east to a much older cratonic terrane in the west is likely to be gradual rather than distinct.

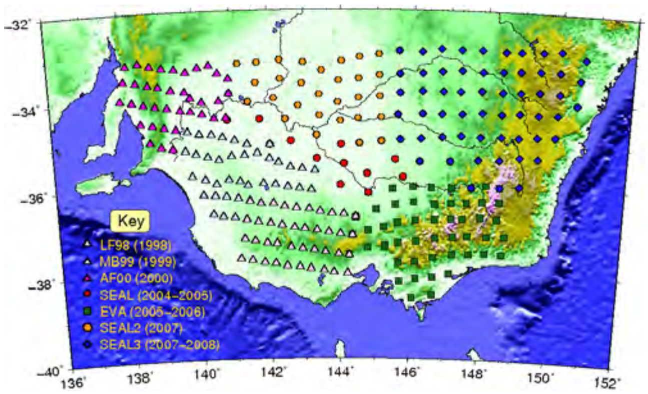


Figure 1. Location of WOMBAT stations in southeast Australia that recorded ambient seismic noise used in this study.

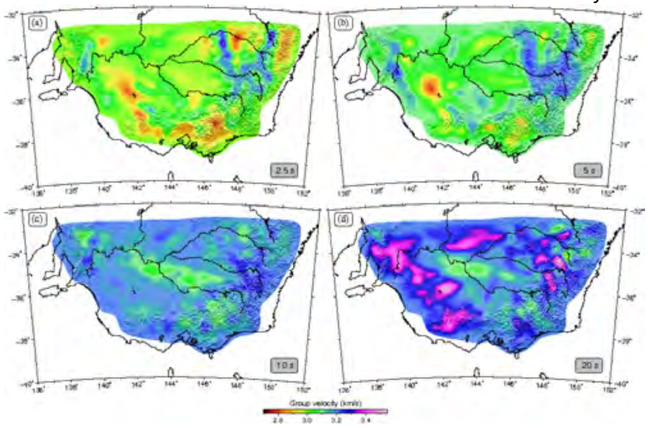


Figure 2. Rayleigh wave group velocity maps for four different periods derived from ambient noise seismic tomography.

High Frequency Po/So and the nature of the oceanic lithosphere

B.L.N. Kennett[1], Y. Zhao[1] and T. Furumura[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] CIDIR & Earthquake Research Institute, University of Tokyo, Japan

It has long been recognised that high frequency seismic body waves can travel for substantial distances through the oceanic lithosphere. In the western Pacific such Po and So phases are very common from shallow events in the various subduction zones, and have been recorded at more than 3000 km from their earthquake source. Usually So is stronger and longer duration than Po when recorder on seismometers, but weaker when a hydrophone is used as the sensor. A combination of multiple propagation legs within the lithosphere reinforced by more rapid reflection processes in the water and sediments helps to carry such Po and So energy to long distances. The complex observed waveforms with long tails can be well simulated by numerical models that include heterogeneity in the lithosphere with much large horizontal than vertical extent.

Despite the generally good propagation to stations in the western Pacific where poor propagation is inked to source location in the back arc region, the situation is more complex in the east. The underwater observatory H2O on an old telephone cable between Hawaii and the Mainland USA only records So from events on Hawaii, and even these arrivals are relatively weak compared with Po. A survey of Po/So properties across the Pacific (Fig 1) highlights the differences in propagation characteristics. It appears that the poor transmission of Po and So may be related to the presence of the major transform fault systems in the eastern Pacific that are likely to be linked to changes in lithospheric thickness. These effects are being investigated through detailed analysis of the signals and numerical modelling of the high frequency wavetrains. Oblique incidence on a major step in lithosphere thickness is likely to have a significant effect on the complex wave packets.

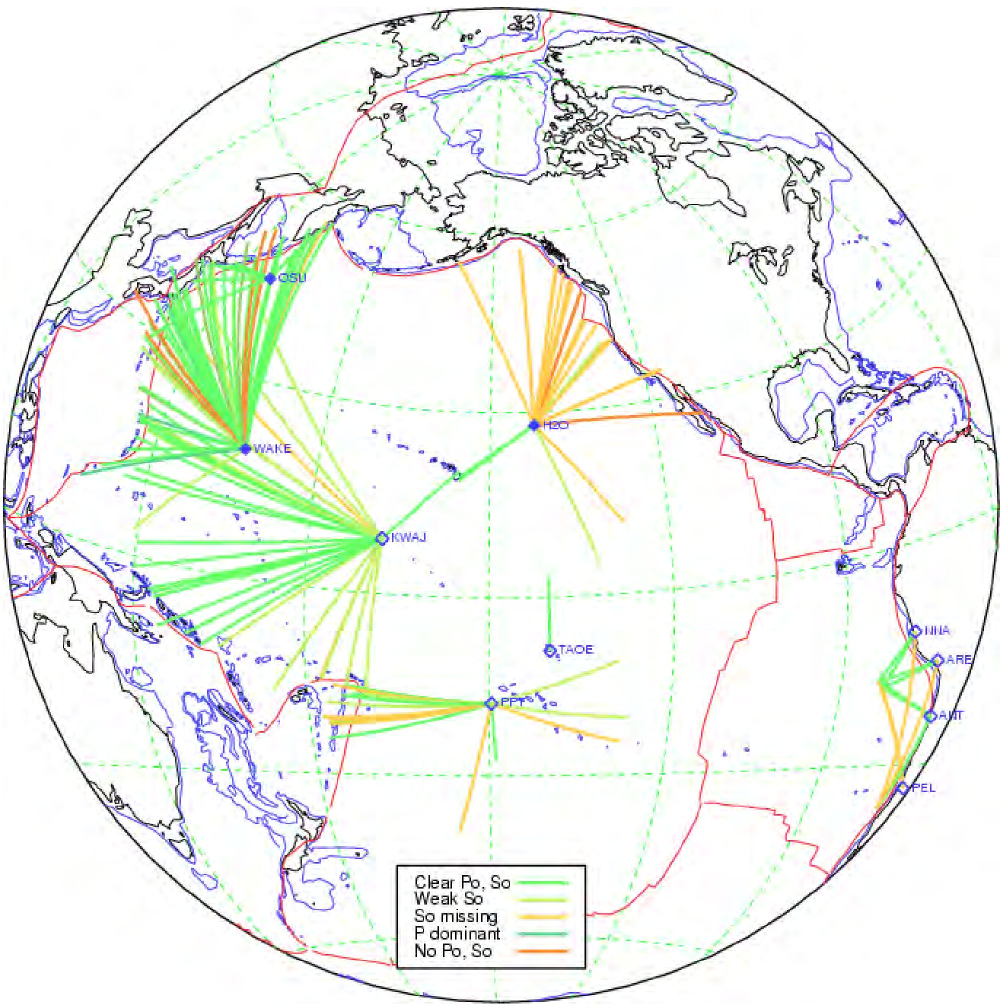


Figure 1. Compilation of Po and So propagation characteristics in the Pacific showing the clear propagation of Po and So in the western pacific and the relatively poor propagtion in the east where paths traverse major transform faults systems.

Eddy response of the Southern Ocean to climate mode forcing

Marshall L. Ward[1], Andrew McC. Hogg[1], R. Morrow[2] and S. Pasquet[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] LEGOS/CNRS, 18 avenue Edouard Belin, 31401 Toulouse, France

The Southern Ocean consists of some of the most dynamically complex ocean currents in the world. Not only does it include the Antarctic Circumpolar Current (ACC), which is among the world's strongest in terms of transport, but also contains a network of vigorous small-scale eddies. As a transit point for the exchange of water masses between the other major oceans, the Southern Ocean plays a crucial role in the climate of our planet, and these currents can have a significant impact on the state of world oceans.

The consequences of this active eddy field have yet to be fully understood. For example, the ACC transport has been shown to be largely insensitive to wind forcing in high resolution models. Rather, such forcing tends to produce a more vigorous and spatially inhomogeneous eddy field. Modeling work of the GFD group at ANU has shown that this eddy field is sensitive to standard modes of climate variability, specifically the Southern Annular Mode (SAM) and ENSO. In particular, ENSO can have a modulational effect on SAM, either amplifying or suppressing the eddy response in specific regions across the Southern Ocean (Figure 1). Such an inhomogeneous and time-dependent eddy field directly impacts the mixing and large-scale transport of water throughout the Southern Ocean, and can lead to long-term impacts on the world's oceans.

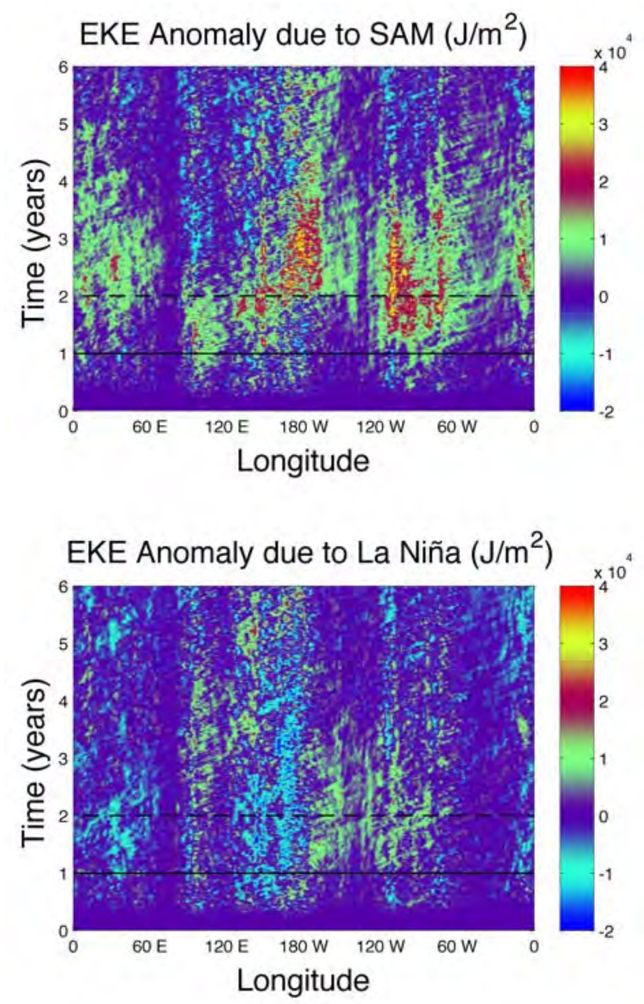


Figure 1. Wind forcings based on the Southern Annular Mode (SAM) and La Niña are applied over a two year period (below dashed line), producing eddy kinetic energy (EKE) responses with dramatic spatial and temporal variability. Despite a dominant SAM mode, La Niña can enhance (90W, Pacific) or suppress (30E, Atlantic) the SAM response.

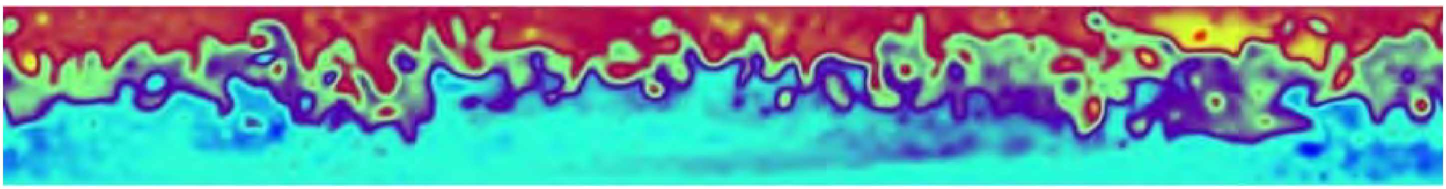


Figure 2. This snapshot of the pressure field from numerical modeling reveals an active eddy-rich flow along the fronts of the Antarctic Circumpolar Current. Variations in wind forcing are transferred predominantly to these small-scale structures.

Mixing in flows between ocean basins

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

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

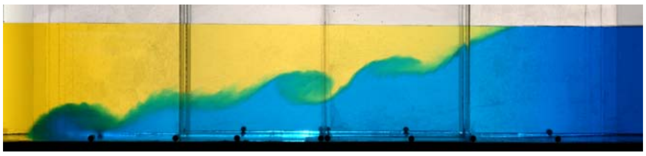


Figure 1.

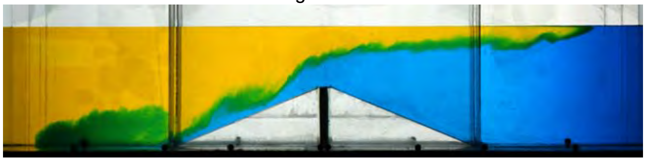


Figure 2.

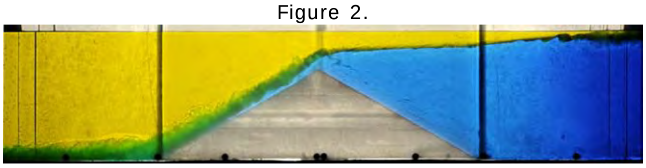


Figure 3. Dye visualizations of exchange flow experiments. Fresh water (yellow) flows from left to right and salt water solution (blue) from right to left. Exchange takes place through a pure lateral constriction (situated between the two bands of vertical lines) in the first case, and across a bottom sill located in the constriction in the second case. The third case shown has a higher topographic sill and a larger Reynolds number. Strong interfacial disturbances lead to turbulence and mixing.

Underwater cascades carrying huge volumes of water are common in the oceans. They occur where water overflows from sea and ocean basins into neighbouring basins over bottom ridges, or through channels and straits. When the overflow water is dense enough, it falls down the slopes to the bottom of the ocean as a turbulent current. The extent to which the cascading water mixes with its new surroundings influences the density stratification in the oceans, and we have previously argued that this mixing also influences the global rate of overturning of the oceans, hence the poleward heat transport.

Overflows, or hydraulically-controlled density-driven exchange flows, have been set up in the Geophysical Fluid Dynamics Laboratory at ANU. The amount of mixing was measured to see whether it depends on sill height, bottom slope, or density difference (figures 1-3). These experiments also serve as a case study of the fundamental nature of turbulent mixing more generally, and may help to improve climate models by allowing us to develop a better description of mixing in the oceans.

The global ocean overturning: what pushes must pull

Ross W. Griffiths, Graham O. Hughes, Andrew McC. Hogg and Kial D. Stewart

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

What governs the rate at which cold water from the ocean surface sinks at high latitudes, passes through the deep ocean, is reheated and returns to the surface? This is an important question because the overturning circulation redistributes heat and helps to regulate the Earth's climate.

Oceanographers argue about the relative importance of heat fluxes through the sea surface (heating of the upper ocean at low latitudes and cooling it at high latitudes) and mixing within the ocean. Some ask whether the dominant factor is the "push" from the buoyancy of the dense sinking water at high latitude or the "pull" associated with the downward mixing of heat and buoyancy over much of the area of the oceans.

In a paper in the Journal of Physical Oceanography we have shown how surface buoyancy fluxes generate available potential energy (figure 1). The density of the ocean water can be altered only by irreversible mixing and surface buoyancy fluxes. Hence the energy transports associated with these two processes must balance (in a steady circulation). In other words, both the surface heat fluxes and sources of kinetic energy for turbulent mixing - commonly associated with winds and tides - are simultaneously necessary to maintain the observed ocean overturning circulation. The analysis of energy transformations shows that "pushing" and "pulling" cannot be separated, a point we have previously argued based on models of the forces and momentum balance of the circulation.

As a corollary, aspects of the ocean overturning circulation predicted by general circulation models are strongly influenced by the nature of the model computation. In particular, the circulation (figure 2) is influenced by whether vertical convective motion is parameterized, or whether these motions are fully resolved by using extremely high-resolution computations. Parameterisation of convection and an assumption of hydrostatic flow are commonplace in climate models, but do not correctly describe the energy changes.

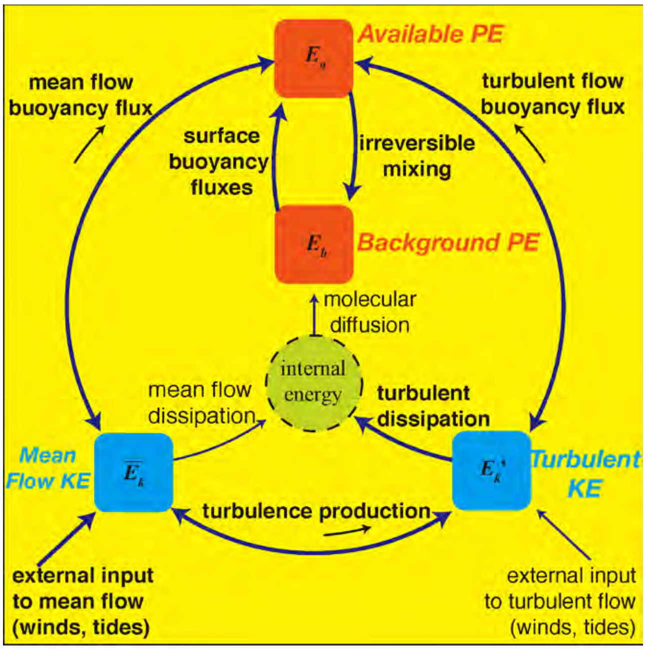


Figure 1. Energy pathway diagram for the ocean, depicting reservoirs of potential energy (PE, in red) and kinetic energy (KE, in blue). Available potential energy is seen to be the crucial link in facilitating the conversion of energy between that stored in the density field (as PE) and responsible for motion (mean flow and turbulent KE). Heating and cooling at the surface of the oceans and external inputs of mechanical energy from the winds and tides are both essential for the maintenance of the overturning circulation in the oceans.

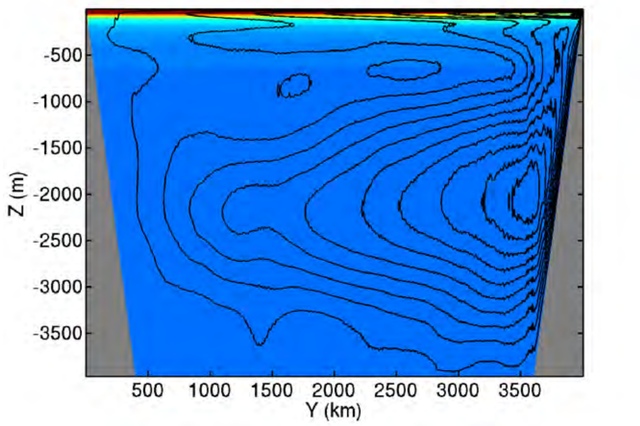


Figure 2. The time-averaged overturning circulation obtained in 2-D numerical simulations of a model ocean basin forced by surface heating and cooling (varying smoothly from 200 W/m^2 at the left end to –200 W/m^2 at the right end, with no net heat input to the basin). The simulation was non-hydrostatic, was conducted at high resolution (10–75 m vertical resolution and 0.75 –7.5 km horizontal resolution), and was run with a vertical diffusion coefficient of 10^{-4} m^2/s (simulating external energy input to mixing). The coldest water is blue and warmest water is red. The maximum overturning streamfunction is 28 x 10^3 kg/s per unit width.

These concepts are being further examined in laboratory experiments with overturning forced by salt and freshwater fluxes at the surface. In the experiments turbulent mixing is generated by horizontal bars, which are traversed up and down through the depth of the water, and the flow is allowed to reach an equilibrium state before the density stratification and circulation flow velocities are measured. The results, particularly the dependence on vertical diffusivity owing to mixing, will be compared with theoretical solutions and with the behaviour of ocean general circulation models.

Internal gravity waves and convection

Graham O. Hughes, Ross W. Griffiths and Melissa Coman

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

Coherent propagating waves have been discovered to be a ubiquitous feature in numerical simulations of convection that have been undertaken in RSES to investigate the dynamics of global ocean overturning circulation. These waves have been identified as internal gravity waves, and are normally absent in convective flows because the convection tends to keep the fluid well mixed. In contrast, when the ocean surface is heated at low latitudes and cooled at high latitudes, the associated buoyancy forces drive a circulation that maintains both gravitationally stable density stratification and overturning throughout the flow. This form of circulation is known as “horizontal convection”. Our simulations, supported by evidence from laboratory experiments, show that the sinking leg of the circulation, a turbulent plume, excites a spectrum of internal gravity wave modes, and that these are a source of strong variability throughout the domain (figure 1). Further work is required to assess the importance of this phenomenon in the ocean overturning circulation.

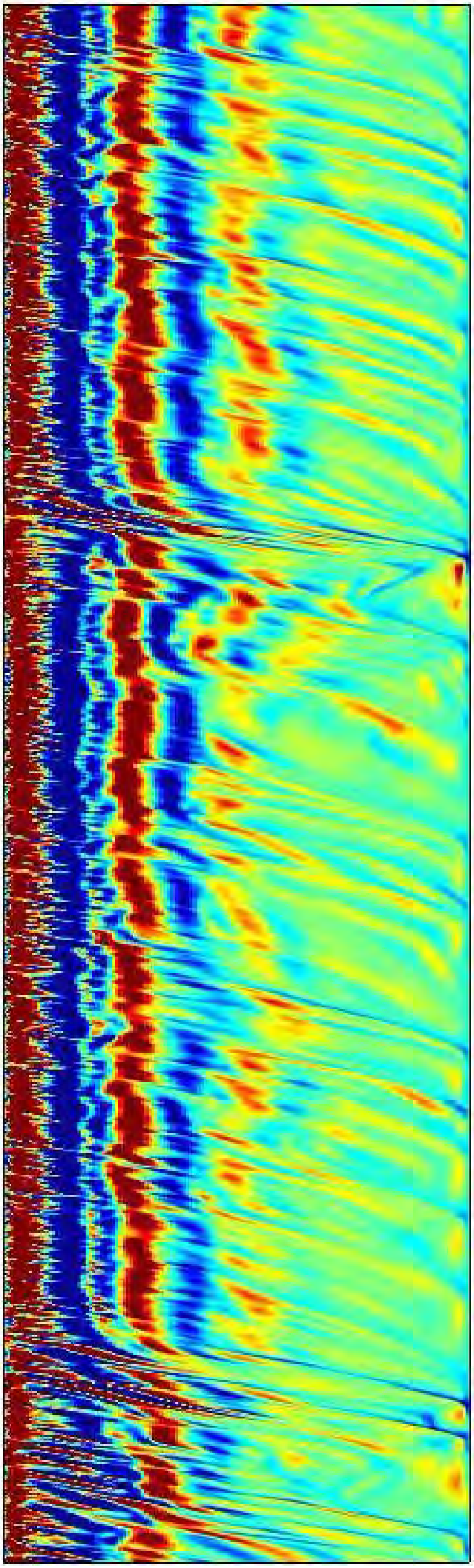


Figure 1. Hovmöller plot of the vertical velocity along a horizontal section towards the bottom of the box in a 2-D numerical simulation of horizontal convection. Time increases downwards; blue represents upwelling motion, green approximately no motion, and red downwelling motion. The region of high latitude sinking is located at the left hand end of the horizontal section, and excites strong wave modes that propagate towards the right hand end of the section (‘low latitudes’). The waves appear to be responsible for much of the variability in this flow.

Wind forcing of the Southern Ocean

Do small scales alter wind power input?

David K. Hutchinson[1], Andrew McC. Hogg[1] and Jeffrey R. Blundell[2]

[1] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia*
[2] *National Oceanography Centre, Southampton, United Kingdom*

Circulation in the Southern Ocean is driven by strong winds which help to force the world's strongest ocean current, the Antarctic Circumpolar Current (ACC). Recent satellite measurements have indicated small-scale structure to the wind stress field (see Fig. 1). In this study, we investigated the effect of small-scales in the forcing field upon the large-scale circulation.

We use a high-resolution ocean model of the Southern Ocean region, coupled to a dynamic atmospheric mixed layer to evaluate the performance of two different wind stress parameterisation schemes. The first is the standard quadratic drag law used by most climate models, while the second (more exact) formulation is based on the difference between ocean and atmosphere velocities. The two different schemes give very similar magnitudes of stress, but, somewhat curiously, the latter scheme contributes substantially less energy to the ocean circulation. The differences occur because small scale (10-50 km) turbulent eddies act to reduce energy input.

These results have significant implications for the Antarctic Circumpolar Current. In particular, despite the lower power input to the ocean, the relative velocity scheme has a stronger ACC, because there are less turbulent eddies to dissipate the flow.

Pre-print of Hutchinson et al. (2009; In Press)
http://rses.anu.edu.au/people/hogg_a/files/veldiff-preprint.pdf

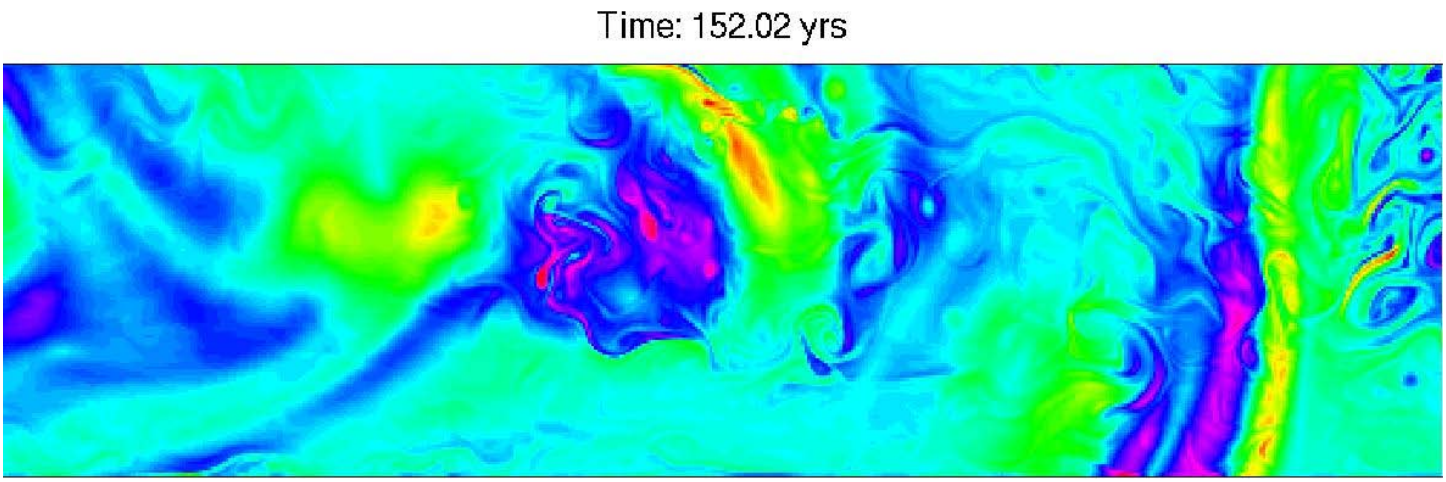


Figure 1. An image showing the distribution of wind stress over the Southern Ocean. The large spatial scales show stress due to atmospheric motion (e.g. high and low pressure cells, storms) while the smaller scales show the effects due to oceanic eddies.

Thermal erosion of felsic ground by the laminar flow of a basaltic lava

Ross Kerr

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

Thermal erosion of basaltic ground during the laminar flow of a basaltic lava has been observed on the Big Island of Hawaii, where flows about 1 m deep have been observed to erode 5-15 m into the underlying solidified basalt over several months to create deep lava tubes (Figure 1). These observations were first explained fluid dynamically by Kerr (2001).

In Kerr (2001), the lava was assumed to be identical to the ground it was flowing over. However, in many geological situations, the lava will have a composition that is different to that of the underlying ground. For example, in the Cave Basalt on Mt. St. Helens (Figure 2), the basaltic lava flowed over and eroded a dacitic pyroclastic flow, which led to contamination of the basaltic lava. This geophysically and geochemically interesting problem has been recently investigated by Kerr (2009). My analysis predicts that initially a chill layer is grown and then remelted at the base of the lava flow. A steady thermal erosion velocity is then established, which is limited by the buoyant instability of the melted ground or by the effective freezing temperature of the basaltic lava. When my analysis is applied to the longest lava tube system of the Cave Basalt on Mount St. Helens, it is found that about 100 days of flow is sufficient to produce the observed ground erosion.

Kerr RC (2001) Thermal erosion by laminar lava flows. *Journal of Geophysical Research* **106**: 26453-46465

Kerr RC (2009) Thermal erosion of felsic ground by the laminar flow of a basaltic lava, with application to the Cave Basalt, Mount St. Helens, Washington. *Journal of Geophysical Research* **114**: B09204, doi:10.1029/2009JB0064230

Figure 1. **A roofed lava tube in Hawaii Volcanoes National Park (photo courtesy of the USGS).**

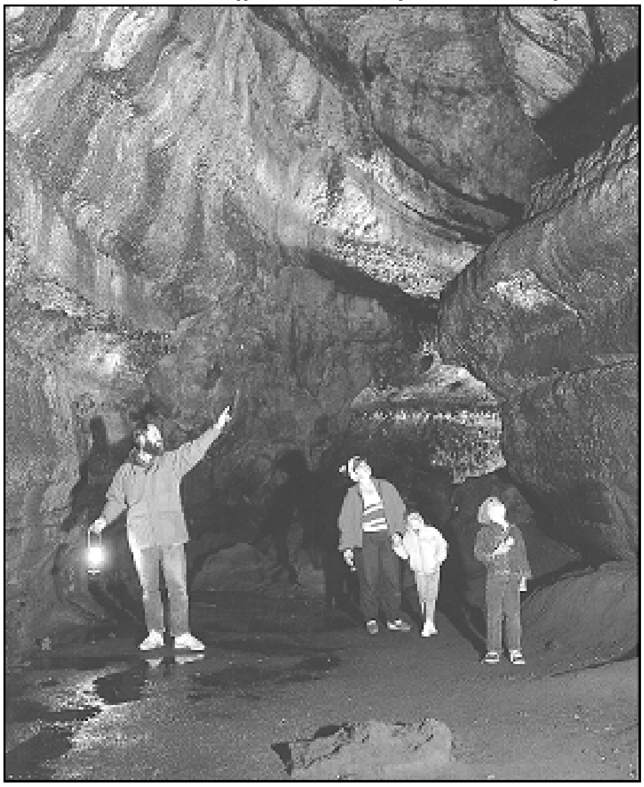


Figure 2. **Ape Cave in Mount St. Helens National Volcanic Monument. It is one of the longest lava tubes in the continental United States, with a length of about 4 km.**

Model dimension and data uncertainty in non linear inversion : An expanded Bayesian formulation.

σ

Thomas Bodin[1], Malcolm Sambridge[1] and Kerry Gallagher[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Geoscience Rennes, Universite de Rennes1, Rennes 35042, France

In an inverse problem, it is well known that the data fit is improved as more unknowns are added into the problem. If too many unknowns are introduced the data may become over fit and artifacts introduced into the model.
In contrast to optimization based approaches to inversion (e.g. a least square minimization), the transdimensional approach uses a sampling based (Bayesian) framework and is able to directly adjust the model dimension in order to fit the data to the dregree required by the noise. In this case, the both the degree of freedom in the model and the level to which the data is fit is driven by the data itself rather than imposed subjectively. This property is illustrated when applying the reversible jump scheme to a simple 1D non-linear regression problem. Figure 1 shows solution curves obtained with the same data assuming differrent values of data noise, σ_{est}. The true value of the noise is σ_{est}=10. When assumed too small (σ_{est}=4) we see the classic feature of over fitting the data. The estimated curve green departs from the true curve (gray) as it tries to fit the data to the required accuracy. When it is too large (σ_{est}=30) the data are under fit and the model is too smooth.
Only when it is correct (σ_{est}=10) is the recovered model close to the true solution. This shows the importance of knowing the noise in the data in a Bayesian framework. The trans-dimensional inversion approach is the same in all three cases and we see how it has only introduced the number of unknowns (cells) necessary to fit the data adequately. This is an advance over the alternative which is to impose the number of unknowns beforehand. In absence of information about data noise, it would be impossible to give a preference to any of the three solutions in Figure 1.

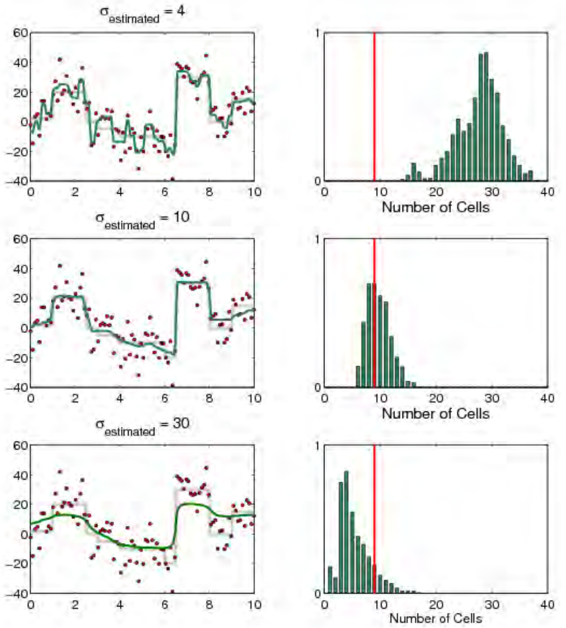


Figure 1. Non linear regression with the reversible jump algorithm.The synthetic data (60 red circles) are defined by a true synthetic model (thick grey line) plus a random Gaussian noise with a standard deviation of 10. Left panels show solution models (green lines) obtained with differrent estimated values for the data noise σ_{est}. Right panels show the posterior distribution for the model complexity (i.e. number of parameters in the estimated model). The dimension of the true synthetic model is show in red. The number of model parameter used, and therefore the complexity of the average solution, clearly depends on the estimated data noise. Note that when the correct value of data noise is used (middle panels), the posterior distribution on the model complexity is maximum at 9 which is the number of cells in the true model.

An expanded Bayesian formulation can take into account the lack of knowledge we have about data errors. Instead of being fixed, the variance of the measurement errors can become an unknown in the problem also and be determined by the data. This methodology is called ``Hierarchical Bayes'' and results are shown in Figure 2. Without knowledge about the data noise and the complexity of the true model, the algorithm is able to provide a solution model (top panel in Figure 2) with the correct complexity, and that fits the data to the required level. Furthermore, the expected posterior value for the data noise (bottom panel in Figure 2) is close to the true data noise.
Current applications of this approach are to seismic inversion of receiver functions for 1-D earth models and also to palaeoclimate time series data where little is known about data errors. The hierarchical Bayes formulation gives also promising results when used for seismic tomographic imaging.

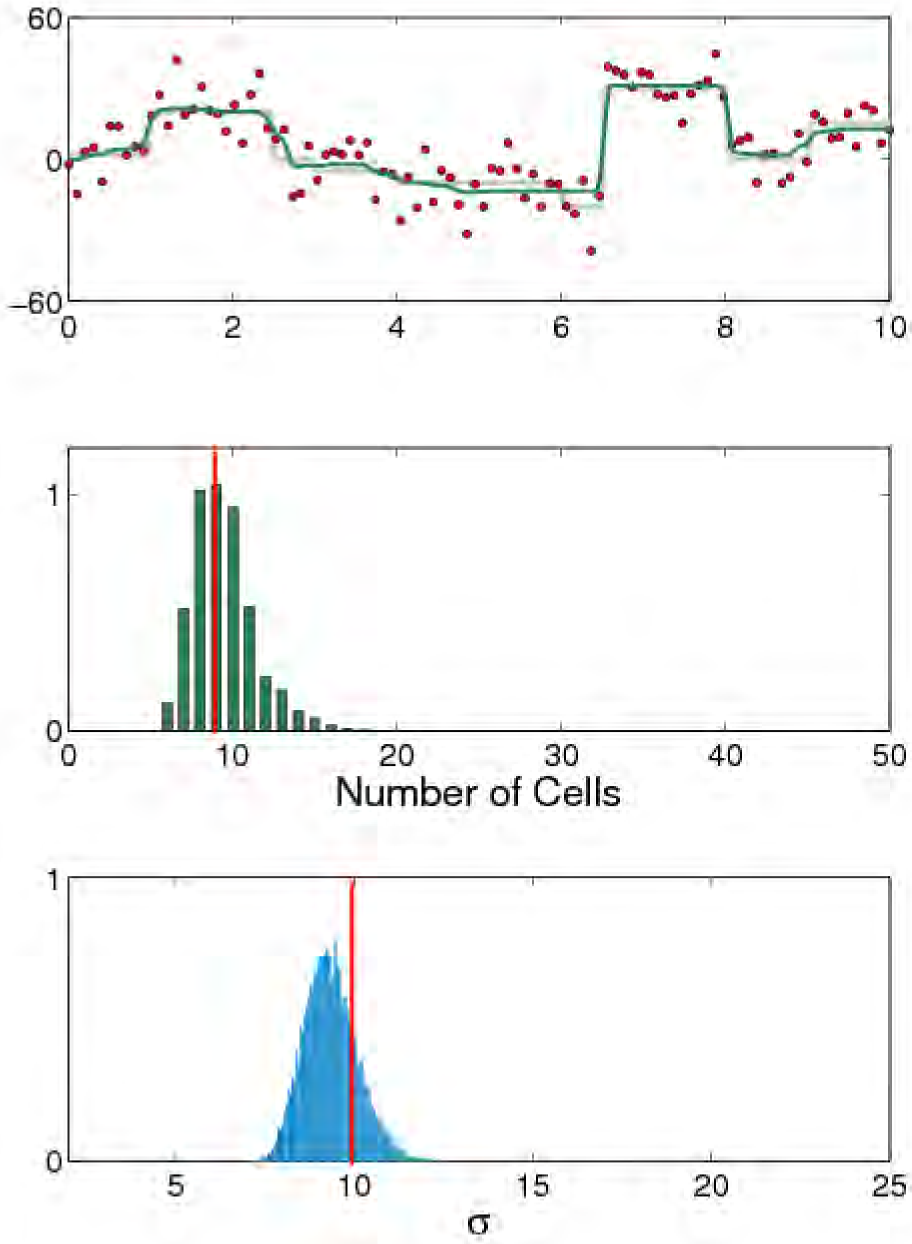


Figure 2. Results with hierarchical Bayes. Here, the estimated data noise is not a number to be given by the user but a unknown parameter whose posterior probability distribution is to be determined by the Bayesian inversion. Top : solution model. Middle : Posterior probability distribution on the model complexity (the value of the true synthetic model is 9). Bottom : Posterior probability distribution for data noise (the true value of data error is 10)

TerraWulf II: Many hands make light work of data analysis

M. Sambridge[1], T. Bodin[1], H. McQueen[1], P. Tregoning[1], S. Bonnefoy[1] and C. Watson[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] School of Geography & Environmental studies, Univ. of Tasmania, Hobart, Australia.

In 2008, RSES launched TerraWulf II the latest in a long line of high powered computing facilities, stretching back more than 30 years. As the name suggests, this is the second of its particular species. The first, built in 2003, capitalised on a worldwide trend of combining off the shelf PC computers to form a highly cost effective (BeoWulf) supercomputer. The second, TerraWulf II (or TII as it is known to users) has 10 times the compute power of TI (~1.5 Teraflops) and occupies one quarter of the room space. Its construction was a joint venture between ANU (through RSES) and AuScope Ltd (The Earth Science infrastructure initiative funded through the Federal Government's National Collaborative Research Infrastructure Strategy program). TII was designed primarily for use in earth imaging and geospatial applications however scientists are constantly finding new and innovative ways to exploit its power and convenience.

A key difference between modern computational clusters like TII and the 1980s machines at RSES is the focus on parallelism. The increase in processing power of each generation of micro-processors has begun to slow down, however computational gains can still be made by combining multiple processors together to perform complex calculations. Hence the rise of parallel based clusters like TI and TII. The initial uses of parallel computers (more than 10 years ago) were largely in areas involving highly advanced simulations of physical phenomena, e.g. weather prediction, ocean modelling, mantle convection and seismic wavefield simulation through complex media. As a consequence, parallel computing facilities gained a reputation for being highly exotic and only for the specialised user. In recent times, this situation has begun to change, as the power of parallel computing has become accessible to a broader range of scientists, even those without the interest in or need for advanced computational methods. A prime driver is the need to analyse data from large spatial arrays of instruments being used to build earth observing datasets, a task which is often particularly suited to parallelism. TII is increasingly being used for this type of 'loosely coupled' calculation.

An example is the geospatial scientist who has to perform the same processing tasks on many separate subsets of data independently (e.g. one analysis for each day of recorded observations). With a cluster of computers, each independent job is performed simultaneously in parallel meaning that the whole task can be achieved in a fraction of the time that it would normally take with single processor workstations. Another example is in the use of Monte Carlo based data inference (inversion) methods where many independent potential solutions to a problem need to be tested against the data, e.g. seismic models of the Earth interior fitting observed travel times or waveforms. TII has been used for both types of calculation, as well as the more traditional simulation of geophysical phenomena using advanced computational techniques. In its short life it has already racked up over seven hundred thousand cpu-core hours of use across applications ranging from earth imaging, geospatial analysis as well as simulation of geophysical processes from the Earth's surface to its core. In addition it has been used as a test bed to develop a new generation of data inference tools.

These examples show how cluster-computing facilities like TerraWulf II are becoming an invaluable tool to the geophysicist. Clusters have been proliferating in research institutions, business and industry in recent years and as more applications evolve we can expect demand for such facilities to increase in the future.

http://rses.anu.edu.au/terrawulf/

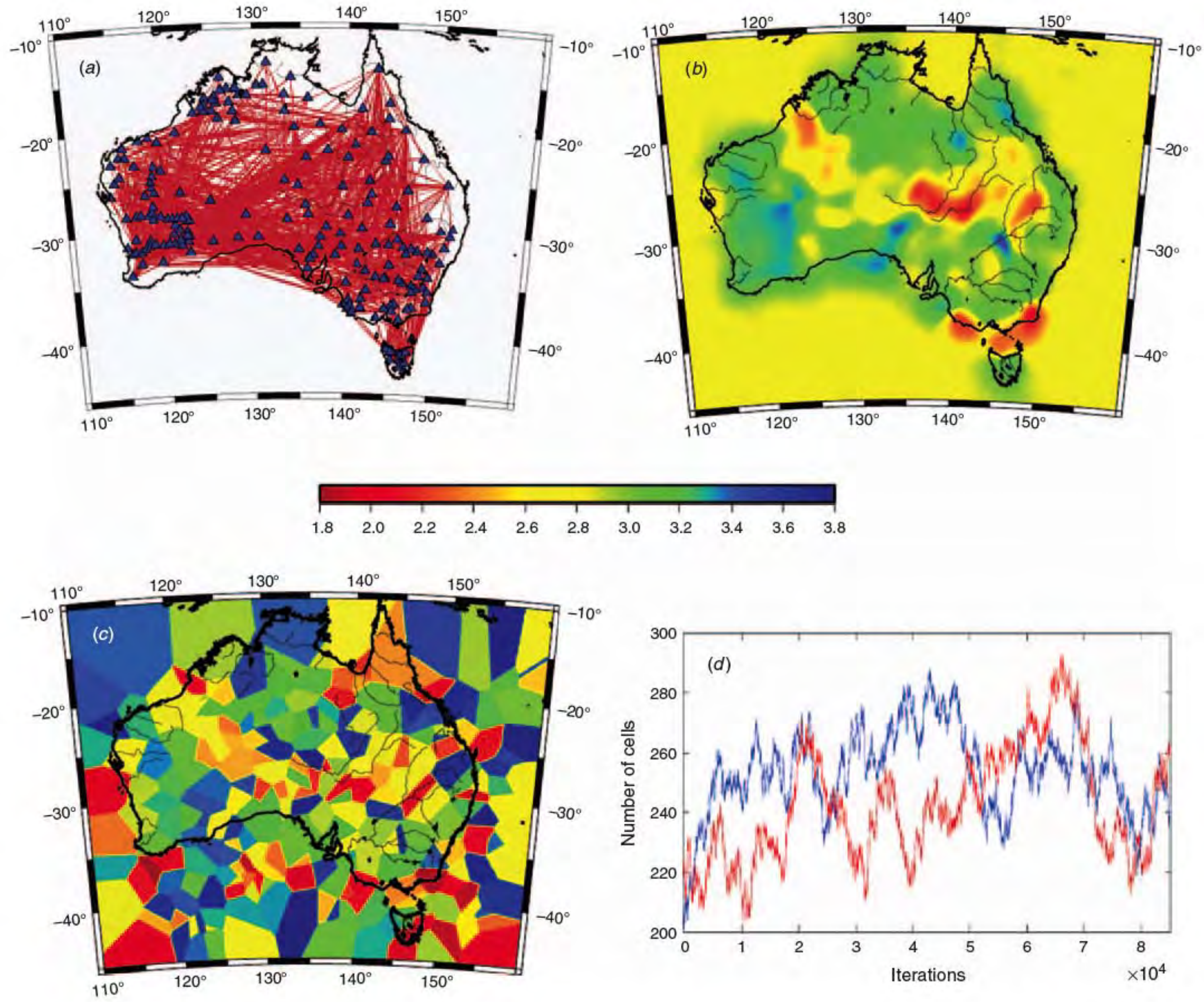


Figure 1. *A Monte Carlo style inversion performed on TII for seismic structure in Australia using ambient noise. (a) Ray path density for 1158 rays in ambient noise dataset of Saygin and Kennett (2009). (b) Shear wave speed model produced by averaging 8000 models generated by the Bayesian Monte Carlo procedure on Terrawulf II, (c) best fit model obtained, (d) number of cells in the model as a function of iteration. Red and blue lines represent results from two of the 200 independent random walks through the model space.*

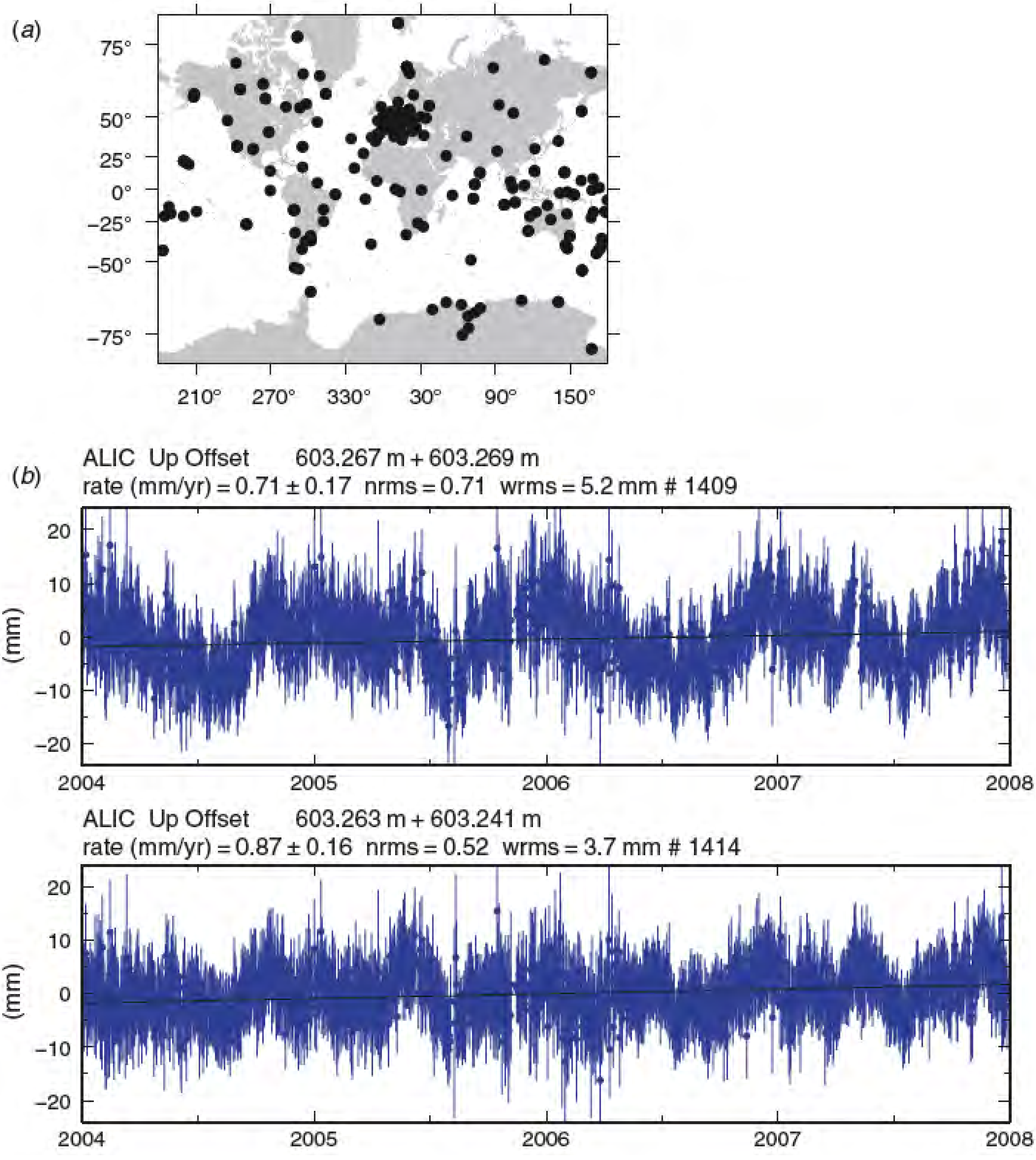


Figure 2. *GPS data re-processing of eight years of data performed on TII. On a single CPU it is estimated that this analysis would taken approximately 23 years to complete. (a) Map of GPS site locations used in the analysis. The time series of the height estimate of the site at Alice Springs, NT, (b) from the original analysis (upper right) and (c) the refined analysis (lower right). The weighted root-mean-square of the daily height estimates has been reduced from 5.2 to 3.7 mm.*

IDOP

Introduction

The Integrated Ocean Drilling Program (IODP) is the world's largest geoscience research program. It aims to solve global scientific problems by taking continuous core of rocks and sediments at a great variety of sites in the world's oceans. IODP carries out deep scientific coring in all the world's oceans using a variety of platforms, and provides 'ground truthing' of scientific theories that are based largely on remote sensing techniques. IODP's key research areas are:

- Deep biosphere and ocean floor
- Environmental changes, processes and effects
- Solid earth cycles and geodynamics

The Australian IODP Office (AIO) was established at RSES in 2008, and also serves as the Australian and New Zealand IODP Consortium (ANZIC) headquarters (www.iodp.org.au). Australian funding is provided for Australian IODP membership, for running AIO, and for travel for scientists from around Australia involved in IODP activities. Fourteen universities, CSIRO and AIMS all support Australian membership and are involved in scientific activities. New Zealand's membership is supported by GNS Science in Wellington and three universities.

Neville Exon is Program Scientist with the Australian IODP Office under a part time professorial contract. His administrative assistant, Sarah Howgego, was appointed early in the year. The program has a Governing Council and a Science Committee, which meet in person and by video or phone link during the year.

We have representatives on a number of IODP panels which meet around the world, and one panel meeting was held in Melbourne in November. Seven Australian and New Zealand scientists have been placed on six IODP expeditions in ANZIC positions this year. Next year four ANZIC positions have been allocated thus far, with Jody Webster of Sydney University a co-Chief Scientist on the Great Barrier Reef environmental expedition starting in January.

The INVEST Conference was held in Bremen in September, to help design to IODP's Phase 2, beginning in 2013, and was attended by more than 500 scientists from around the world. An ANZIC white paper was developed and submitted by Stephen Gallagher and others, and is now on www.iodp.org.au (front page link). AIO sent Brian Kennett, Jody Webster, Stephen Gallagher, Richard Arculus and Chris Yeats to INVEST; Chris Hollis was funded by GNS Science NZ; Australian younger scientists Helen McGregor and Liz Abbey attended at IODP-MI expense. A committee of fourteen has been appointed to draft the new science plan, and this includes Richard Arculus of ANU and Peter Barrett of Victoria University, Wellington.

There are two important but smaller IODP review committees in action at present. One includes Chris Yeats of CSIRO, and the other Geoff Garrett, the former head of CSIRO. It is very apparent that ANZIC, a small member of IODP, is highly regarded for its scientific and organisational expertise. It also tends to represent Southern Hemisphere science in a broad sense.

A major Australian IODP Office activity this year was putting together a bid for additional ARC LIEF funding, which succeeded. Twelve partners each agreed to put in an additional $5000 p.a. for 2009-2012. In the end ARC decided to make a simple variation of the existing Arculus LIEF grant, increasing their funding to $1,550,000 p.a. This puts us on a much firmer financial footing in paying $US1,400,000 p.a. as the Australian IODP membership fee. The total annual budget is now $2,180,000 through to 2012, $410,000 p.a. more than it was previously. We can also spend up to $20,000 per head on post-cruise funding for 5 university scientists, a total of $100,000 p.a. This latter development is invaluable in enabling those with access to no other source of funding in the immediate post-cruise period to make a start on their work.

PRISE

Introduction

PRISE continued to operate as an externally funded research group within the Research School of Earth Sciences, providing access to the Research School's specialised equipment and expertise in areas of geochronology, geochemistry and petrology. PRISE scientists also undertake their own research projects as supported by competitive grant applications. They supervise postgraduate students, both within the Research School and internationally.

During 2009, Dr Greg Yaxley was awarded an ARC Future Fellowship. Drs Richard Armstrong and Marc Norman have been succesful in ARC Discovery Projects and as part of a LIEF grant to purchase a new thermal ionisation mass spectrometer.

All PRISE staff members are actively involved in wide-ranging collaborative research projects with academic colleagues throughout the world, as well as providing research and analytical skills to industry and Government agencies on a commercial basis. During 2009 PRISE hosted twenty-nine local and international visitors, most of whom undertook collaborative projects using the SHRIMP, Laser ablation- and solution ICPMS, electron microprobe and TIMS analytical facilities. PRISE staff also participated in a number of field-orientated studies in Australia, Africa, North and South America and Europe.

Some areas of current research include:

- Investigations of the origins of pyroxenite bodies in peridotite massifs of the Western Gneiss Region, Norway (PhD student A. Rosenthal)
- High pressure experimental investigations of kimberlite and carbonatite petrogenesis (PhD student K. Kiseeva)
- Impactor fluxes in the inner solar system from the ages and compositions of lunar glasses (PhD student S. Hui)
- Bioarchaeology in early Cambodian populations and in situ oxygen and strontium analysis of human teeth
- Multi-isotopic and trace element zircon studies to constrain magmatic evolution of plate margins and continental reconstructions; combined U-Th-Pb, Lu-Hf, Ti geothermometry, trace and REE chemistry, and oxygen isotope studies.
- Development of in situ sulphur isotope analytical protocols for the SHRIMP
- Use of sulphur isotopes to aid in understanding the origin and conditions of formation of metal sulphides
- Chronology of the Archaean-Proterozoic transition and the rise of oxygen in the atmosphere
- Geological Connection between West Antarctica and Patagonia since the late Paleozoic: Tectonism, Paleogeography, Biogeography and Paleoclimate
- Placing realistic constraints on the timing of world-wide Neoproterozoic glacial events: a critical examination of the "Snowball Earth" hypothesis
- Ages of granites and related mineralisation in NSW
- Origin and evolution of plume magmas and Hawaiian volcanoes
- Hydrochemistry of groundwater resources in the Sydney basin and Murrumbidgee Irrigation area of NSW

Imbrium Provenance for the Apollo 16 Descartes Terrain: Argon Ages and Geochemistry of Lunar Breccias

Marc Norman[1], Robert Duncan[2] and John 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 97331-5503, USA

The primary geological objective of the Apollo 16 mission to the Moon was to investigate and sample two physiographic units identified by pre-mission planning: the "Descartes Mountains" and the "Cayley Plains". Both units were found to be impact-related deposits, distinguished by differences in lithology and bulk composition as well as morphology, but the provenance and genetic relationship of these units to specific basins or craters is not well established. The Descartes breccias are of particular interest because they are often considered to be primary ejecta from the Nectaris basin. Existing constraints on the source of the Descartes breccias are, however, permissive and subject to interpretation. Arguments for an origin as Nectaris ejecta are based mainly on analogues with the Orientale basin, the youngest and best-preserved multi-ring basin on the Moon, and predictions from cratering models. Alternatively, geological relationships observed from lunar orbit suggest that the Descartes and Cayley units both could be distal ejecta from the Imbrium basin.

As Nectaris ejecta, the emplacement age of these breccias would have significant implications for lunar stratigraphy and the hypothesis that the Moon experienced a late heavy bombardment of impacting planetesimals at about 4 Ga. Nectaris is the one of oldest nearside basins and together with Imbrium stratigraphically brackets 12 other lunar basins. The often-quoted ages of 3.92 Ga for Nectaris and 3.85 Ga for Imbrium tend to favor a late heavy bombardment, whereas an older age of Nectaris would weaken the case for a late cataclysm. Geochemical characteristics of the Descartes breccias are similar to those of the Feldspathic Highlands Terrane, so a better understanding of these breccias may provide insights into the origin and evolution of major crustal provinces on the Moon as well as the early impact history of the inner solar system.

The goal of this study was to improve constraints on the provenance and emplacement age of the Descartes breccias based on ^{40}Ar-^{39}Ar incremental heating ages, major element, and trace element compositions of clasts extracted from two feldspathic fragmental breccias that represent the Descartes terrain (67016, 67455). Anorthositic clasts with well-behaved ^{40}Ar-^{39}Ar spectra define ages that are identical with the currently accepted age of the Imbrium basin, and trace element compositions suggest a provenance in the Procellarum-KREEP Terrane. We conclude that these characteristics points toward emplacement of the Descartes breccias as Imbrium ejecta, rather than from Nectaris.

This conclusion pulls the pin on the Late Cataclysm hypothesis. Mass flux curves showing a late cataclysm depend critically on an assumed age of ~3.9 Ga for Nectaris to create a sharp rise in the accretion rate at this time. In addition, crater density populations on the large lunar basin deposits and dynamical evolution models tend to favor a late increase in mass flux if Nectaris is ≤4 Ga, but provide little support for a late cataclysm if Nectaris is as old as ~4.1-4.2 Ga. However, the age of Nectaris now appears to be unconstrained by the lunar sample data, in contrast to previous conclusions. A robust test of the late cataclysm hypothesis will require an accurate absolute age for one or more of the older lunar basins. Obtaining these ages will be a high priority goal in the next phase of lunar exploration.

This research was published as:

Norman MD, Duncan RA and Huard JJ (2010) Imbrium Provenance for the Apollo 16 Descartes terrain: argon ages and geochemistry of lunar breccias 67016 and 67455. Geochimica et Cosmochimica Acta 74, 763-783.

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V66-4XH5MNN-4&_user=10&_coverDate=01%2F15%2F2010&_rdoc=24&_fmt=high&_orig=browse&_srch=doc-info(%23toc%235806%232010%23999259997%231573278%23FLA%23display%23Volume)&_cdi=5806&_sort=d&_docanchor=&_ct=26&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=867b6eb8ccce33aef33ad095cc8d187a

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V66-4XH5MNN-4&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=f1ffd4579dd096c42a68b2f5ed99f268

Experimental phase and melting relations of metapelite in the upper mantle – implications for the petrogenesis of intraplate magmas

Carl Spandler[1], Greg Yaxley[2], David H. Green[3] and Dean Scott[2]

[1] School of Earth and Environmental Sciences, James Cook University, Townsville, Australia
[2] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[3] CODES, University of Tasmania, Hobart, Tasmania, Australia

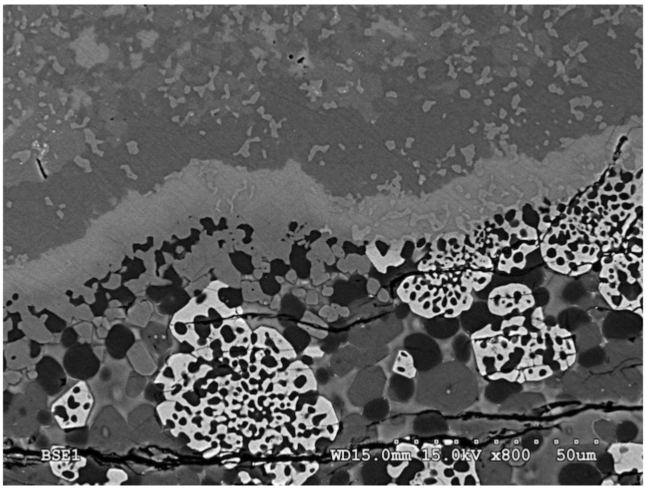


Figure 1. Back-scattered electron image of a high-pressure experimental run product (3.0 GPa, 1300°C) in which an (upper) layer of peridotite was run adjacent to a (lower) layer of pelite. The peridotite has crystallised as olivine, orthopyroxene, clinopyroxene and garnet, whereas the pelite has crystallised as clinopyroxene, garnet, coesite with interstitial melt now quenched to glass. The mid-tone gray band running approximately across the centre of the image is a pyroxene and garnet rich layer which formed as a result of reactions between silica-rich partial melts of the pelite and chiefly olivine in the peridotite.

The return of extensive volumes of crustal material to the mantle is an inevitable consequence of long-lived plate tectonics on Earth. Accordingly, previously subducted materials may collectively represent a significant proportion of the mantle and may strongly influence its geochemical inventory and the production of mantle-derived magmas. Some distinctive enriched components detected in primitive oceanic basalts have been attributed to the presence in the basalts' upper mantle source of recycled pelitic sedimentary material, recycled back into the convecting upper mantle via subduction zones.

To examine the melting behaviour and phase relations of sedimentary rocks at upper mantle conditions, we performed a series of piston-cylinder experiments on a synthetic pelite starting material over a pressure and temperature range of 3.0 to 5.0 GPa and 1100 to 1600 ºC. The anhydrous pelite solidus is between 1150 and 1200 ºC at 3.0 GPa and close to 1250 ºC at 5.0 GPa, whereas the liquidus is likely to be at 1600 ºC or higher at all investigated pressures, giving a large melting interval of over 400 ºC. The subsolidus paragenesis consists of quartz/coesite, feldspar, garnet, kyanite, rutile, ±clinopyroxene ±apatite. Feldspar, rutile and apatite are rapidly melted out above the solidus, whereas garnet and kyanite are stable to high melt fractions (>70%).

Our results indicate that sedimentary protoliths entrained in upwelling heterogeneous mantle domains may undergo melting at greater depths than mafic lithologies to produce ultrapotassic dacitic melts. Such melts are expected to react with, and metasomatise, the surrounding peridotite, which may subsequently undergo melting at shallower levels to produce compositionally distinct magma types. This scenario may account for many of the distinctive geochemical characteristics of EM–type ocean island magma suites.

Tracking Formation and Transport of Apollo 16 Lunar Impact Glasses through Chemistry and Dating

Simeon S. M. Hui[1], Marc D. Norman[1] and Fred Jourdan[2]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia
[2] Western Australia Argon Isotope Facility, Curtin University of Technology, GPO Box U1987, Perth, Western Australia, 6845, Australia

Lunar impact spherules are micron to centimetre sized glass particles formed during impact events where shock induced melting of the lunar regolith and impactor produce melt splashes that can be deposited locally or be ejected far beyond the point of impact. These particles can be found within the lunar soil and in microbreccias and are a medium from which we can study lunar chemistry and impact history.

We have separated over 900 lunar spherules from the Apollo 16 fines, 66031. Using new mounting and analysis techniques we have obtained major and trace element compositions while preserving the maximum volume of sample for $^{39}Ar/^{40}Ar$ dating on single particles. Petrographic descriptions and dimensions were obtained for 272 lunar glasses greater than 75µm in diameter along with major element compositions. Trace element compositions were obtained for a total of 164 lunar impact spherules. Thirty of these spherules were further selected for radioisotopic dating using the $^{40}Ar/^{39}Ar$ method. Twenty-two of the dated spherules gave statistically acceptable $^{40}Ar/^{39}Ar$ isochrons and plateaus, allowing us to develop the first impact flux for local impact spherules at the Apollo 16 site (See Figure 1.) complementing previous work at Apollo 12 (Levine et al., 2005) and 14 (Culler et al., 2000). This is the first time such an integrated dataset has been collected for lunar impact spherules. This additional resolution allows us to determine contributions to the impact flux from local and exotic events and identify groups of impact spherules that may have been formed from a single impact. Our results show that 13-17 unique impact events may have produced the twenty-two spherules that were dated at our site, depending on how the groups are identified. Our approach has shown that there is potential to suppress apparent peaks on the impact age distribution, as seen by lunar impact spherules, and increase the apparent contribution of spherules from exotic sites.

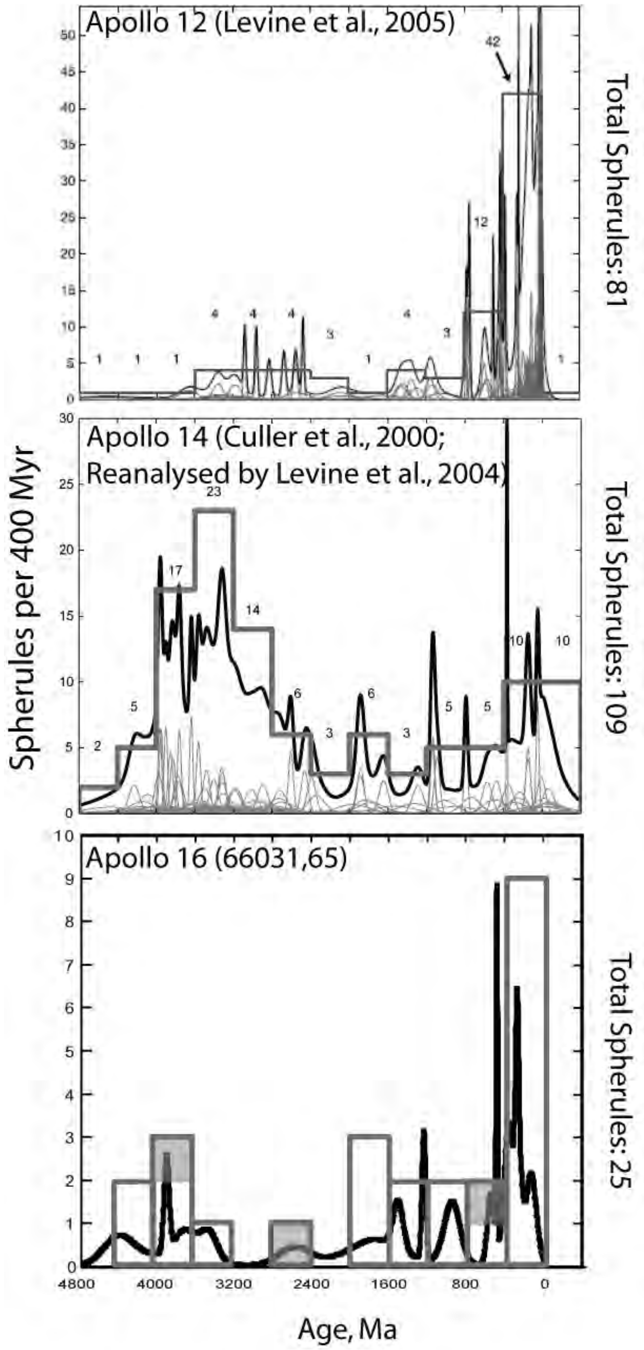


Figure 1. **Fig 1.** Bombardment history as shown by ideograms created using the lunar impact spherule flux from Apollo 12 (Levine et al., 2005), Apollo 14 (Culler et al., 2000) and Apollo 16 (this study). The shaded regions in the Apollo 16 histogram indicate the presence of exotic impact spherules.

Results of this study were presented at the 9th Australian Space Science Conference, Sydney, Australia, 28th September – 30th September 2009.

Culler T. S., Becker T. A., Muller R. A. and Renne P. R. (2000) Lunar Impact History from 40Ar/39Ar Dating of Glass Spherules. *Science* **287**(5459), 1785-1788.

Levine J. (2004) Lunar glass spherules as probes of the meteoroid impact history of the Moon. Ph.D. thesis. University of California, Berkeley.

Levine J., Becker T. A., Muller R. A. and Renne P. R. (2005) 40Ar/39Ar dating of Apollo 12 impact spherules *Geophysical Research Letters* **32**(15), L15201.

Geological exploration of Australia in the early 19th century

An account of the Baudin expedition

Wolf Mayer

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

Following the establishment of the first European settlement in New South Wales, geological investigations were carried out by interested amateurs including naval officers and educated citizens. The first university trained geologists to visit Australia were members of the French expedition commanded by Nicolas Baudin in 1801-1803. My research into the scientific work of this expedition has involved the study of manuscripts and early publications in archives, museums and libraries in both Australia and France and visits to the localities around Australia's coastline where the French naturalists carried out their investigations.

The Baudin expedition's scientific investigations in Australia provided the first insights into the geological constitution of this hitherto unexplored landmass and contributed to a better understanding and appreciation, among European scientists, of the global extent of some geological processes and the formation of major rock formations.

The science of geology was, at that time, still in its infancy. The identification of minerals was imprecise and the classification of rocks was disputed. The expedition's geologist, Louis Depuch and Charles Bailly, followed a four-fold scheme of rock classification taught by the famous French geologist Déodat de Dolomieu. This recognised primary rocks, such as granite; secondary rocks, such as stratified sandstone and limestone; alluvium; and volcanic rocks, such as basalts. The French geologists' recording of these four categories of rocks in Australia confirmed their world-wide distribution. Together with the zoologist François Péron, who also carried out geological investigations, the French travellers were the first to establish the presence of a chain of highlands along the eastern coast of the Australian continent, they noted evidence of past sea level changes and the presence of living molluscs, long extinct in Europe. While many of their discoveries in Australia confirmed that the explanation and interpretation of geological features in Europe could be applied on a global scale, their findings suggested that some long-held European views about the universality of geological processes might need to be changed.

Planetary Crusts: Their Composition, Origin and and Evolution

Stuart Ross Taylor[1] and Scott M. McLennan[1]

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

[2] *Department of Geosciences, State University of New York, Stiny Brook, NY USA*

Planetary Crusts is the first book to explain how and why planets and satellites develop crusts. It presents a geochemical and geological survey of the crusts of the Moon, Mercury, Venus, the Earth and Mars as well as the distinct crusts of the asteroid Vesta and the major satellites of the giant planets. Spanning a much wider compass than mere description of the diverse crusts encountered in the solar system, the book begins with a discussion of the nature of solar system bodies and their formation. The authors then adopt a comparative approach to investigate the many controversies surrounding the development and evolution of planetary crusts. . The authors conclude that stochastic processes dominate crustal development and the book ends with a discussion of the likelihood of Earth-like planets and plate tectonics existing elsewhere in the cosmos The following comments are from a review by W. Bruce Banerdt (Jet Propision Laboratory) in Nature Geoscience Vol 2, 237 April 2009 "The authors ultimate conclusion is a cautionary tale for advocates of comparative planetology. They argue that planetary formation and evolution is governed by essentially random processes.The implications of the book’s conclusions for the search for ‘Earth-like’ planets are profound. It is not enough for a planet to be of the correct size and to orbit a star at the right distance. Even a composition similar to Earth’s will not guarantee an Earth-like environment. We now know that the details of crustal formation are a key to many of the attributes of our planet that make it so agreeable, and if Taylor and McLennan are correct, the evolutionary preconditions for the environment that exists on the Earth’s surface appear to be absurdly improbable. When it comes to forming planets and their crusts, it seems that God does indeed play dice."

RESEARCH SUPPORT

Electronics Group

Andrew Latimore, Tristan Redman, Norm Schram, Derek Corrigan, Daniel Cummins, David Cassar, Hideo Sasaki
Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

Introduction

The Electronics Group provides technical support, research and development facilities and advanced electronics maintenance to all areas of RSES academic research.

During 2009 the Electronics Group undertook numerous engineering projects indicated by the proportion of labour distributed to Research and Development tasks, see table1. We have experienced a high demand for electronic maintenance this period, our group endeavours to promptly attend to any problem and pride ourselves on maintaining legacy equipment. This year has proven extremely productive with several major projects coming to fruition. The highlights of 2009 were the completion of electronic systems for Earth Chemistry's SHRIMP SI mass spectrometer project and Jaeger 1 Process Cooling System, a major infrastructure project involving an intelligent and environmentally sound method to cool high pressure apparatuses.

Table 1
RSES Electronics Group Resource Distribution 2009

Labour totals	hours	%
Administration total	1307	15
Maintenance total	1355	16
R&D Total	5822	69
Total	8483	100
Administration		
Electronics Group overheads	717	55
Study leave + other	590	35
Total	1307	100
Maintenance		
Earth Chemistry	828	61
Earth Environment	139	10
Earth Materials & Processes	212	16
Earth Physics	52	4
Mechanical workshop	35	3
External clients+ other	15	5
Electronics workshop	26	2
Total	1355	100
Research and Development		
Earth Chemistry	3615	62
Earth Environment	947	16
Earth Materials & Processes	1078	19
Earth Physics	3	0
Mechanical workshop	31	1
External clients + other	149	3
Total	5822	100

Electronic Engineering Highlights

Shrimp SI

Several electronic engineering projects for the development of SHRIMP SI have been completed this year, each deserves commendation with significant design and fabrication required achievable only through years of experience and improvement to existing designs. The highlights include;

- Commissioning the new Iflex electrometers, (Schram)
- Sample stage mechanical design, (Corrigan)
- High voltage control, (Schram, Redman, Sasaki)
- Vacuum Management system, (Cassar, Latimore, Sasaki)
- Motor control system, (Redman)

- Field control system, (Latimore)
- Magnet safety system, (Sasaki, Redman)
- Data acquisition system, (Cummins,, Latimore)
- Beam monitors, (Cummins, Redman)
- Microprocessor (Latimore)

These systems are unique to SHRIMP SI involving hours of design, programming, construction and testing. The team has worked professionally to successfully produce all systems in view of an end of year completion schedule.

Jaeger 1 Process Cooling
During 2009 the Research School of Earth Sciences committed to designing a potable water saving plant to service all high pressure apparatuses utilised and situated in Earth Materials & Processes. The system has intelligence to cycle cooling water from a refrigerated unit to dry air cooler to maximise efficiency, minimising power consumption. The system provides chilled water to 20 experiments and will safely cut power and supply of water in the event of any detectable leakage, saving the school substantial water costs and reducing the schools environmental impacted. The project was a major initiative supported by ANU Green and was developed in conjunction with ANU F&S. All electronic controls were design and implemented by RSES Electronics Group. The project has proven to be a prominent illustration of water management and example for future conservation projects.

Laser Ablation Cell
During 2009 our mechanical engineering efforts have been partially focused on design and construction of a new gas distribution and control system for the ICP-MS Laser Ablation Cell device. Engineering drawings of the ablation cell were produced and construction of several cells has commenced. The Electronics Group has begun a new design for producing a more efficient and improved cell based on previous technologies.

Our team has new projects insight for 2010 including the development of digital data recorders for Seismology and Graphitisation furnace system automation. These projects will allow the group to investigate new areas of electronics and mechanical design. The Electronics Group will endeavour to provide timely professional service to support RSES research.

Engineering Group

Andrew Wilson[1], David Thomson[1], Carl Were[1], Geoff Woodward[1], Brent Butler[1], Link Williams[2], Ben Tranter[2] and Hayden Miller[3]

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

[2] College of Science Apprentice on six to nine month rotation

[3]Trainee Technical Officer 50/50 Earth Materials/Workshop

Completion of SHRIMP SI was the priority for the Engineering Workshop for 2009. Progress was very good with all internals completed during the year. Some work remains on the sample manipulator and various fitting and assembly details as required in early 2010. All workshop staff contributed well to the SHRIMP SI. Mr Geoff Woodward and Mr David Thomson in particular have made major contributions.
The usual demand from other areas of the school remained throughout the year so very little external work was undertaken.

An important project for 2010 will be the construction of a high temperature furnace for Dr Masahiko Honda's new Mass Spectrometer. Considerable design work has been devoted to this project over the last few months by Mr Brent Butler and Mr Ben Tranter.

Workshop staff logged a total of 7469 hours to the month of December. 77% of total hours were devoted to RSES internal work. External clients accounted for 2% of our time. 21% of our time was uncharged. 26% of our charged/internal time was spent on jobs which took less than 50 hours to complete.

Internally the main commitments were:

SHRIMP SI- Internal mechanical components. (Geoff Woodward, David Thomson, Brent Butler, Link Williams, Ben Tranter, Hayden Miller and Andrew Wilson)
Safety Shields for 200T presses for Prof Hugh O'Neill (Hayden Miller, David Thomson)
Rotatable ICPMS slit mechanism for Prof Hugh O'Neill. (Carl Were)
Completion of ten new half inch bore pressure vessels for Prof Hugh O'Neill. (Carl Were, David Thomson)

General SHRIMP Maintenance (Carl Were, David Thomson and Geoff Woodward)
Laboratory acid column racks for Dr Oliver Nebel (Brent Butler, Ben Tranter and Carl Were)
Beam alignment posts and special vacuum fittings for Dr Stewart Fallon. (Andrew Wilson, Carl Were, Geoff Woodward)

Rock Mechanics Furnace Core-
Showing fine helical grooving in Aluminum
Oxide for heater windings

Porewater samplers for Dr Stephen Eggins (Brent Butler)
Support was also provided for Professor Ian Jacksons Rock Mechanics Laboratory including new furnace cores, high temperature/pressure apparatus modifications and the usual sample preparation. (Geoff Woodward, Ben Tranter, Andrew Wilson, Carl Were, Hayden Miller and Brent Butler)

1582 hours of uncharged time was accounted for as follows:

22% Staff Training

35% Workshop Administration

20% Workshop Infrastructure. This includes the time taken for improvements and modifications to tooling, machines, workshop layout, workshop storage and assistance with workshop building maintenance.

11% Machine Maintenance

12% of uncharged hours were spent at meetings, seminars, conferences and exhibitions as well as on some uncharged jobs.

Other Developments

A new CNC Machining Center is due to arrive early in 2010. This machine will add physically larger CNC milling capacity, the ability to do heavy cutting and advantages of a modern interface. The machine, an Okuma MB-56 Machining Center, was purchased using workshop funds made possible by the internal charge back arrangement which has been in place for several years.

During the year, Brent Butler coached the Australian national team to the silver medal in the 'Worldskills' teams manufacturing category in Calgary.

Good progress has been made this year documenting unusual tasks and jobs which are repeated regularly. Improved knowledge management is vital for retaining techniques and methods into the future.

2009 Publications by Author
(Listed alphabetically within research areas)

Earth Chemistry

Amelin, Y. (2009) U-Pb and Sm-Nd in single titanite grains. Chemical Geology vol.261, 52–60.

Amelin, Y., Connelly, J., Zartman, R.E., Chen, J.H., Göpel, C. and Neymark, L.A. 2009. (2009) Modern U-Pb chronometry of meteorites: advancing to higher time resolution reveals new problems. Geochim. Cosmochim. Acta vol.73, 5212–5223.

Araujo, D.P., Griffin, W.L., O'Reilly, S.Y., Grant, K.J., Ireland, T.R., Holden, P., van Achterbergh, E. (2009) Micro-inclusions in monocrystalline octahedral diamonds and coated diamonds from Diavik, Slave Craton: Clues to diamond genesis. Lithos, 112S, 724-735, doi: 10.1016/j.lithos.2009.04.021.

Arculus, R., Campbell, I.H., McLennan, S.M., Taylor, S.R. (2009) Asteroids and andesites. Nature, 459, E1-E1.

Barker, Shaun L.L. Bennett, Vickie C., Cox, Stephen F., Norman, Marc D. and Gagan, Michael K. (2009) Sm-Nd, Sr, C and O isotopic systematics in hydrothermal calcite-fluorite veins: implications for fluid-rock reaction and geochronology. Chemical Geology, Vol. 268, Issues 1-2, 58-66.

Beltrando, M., Lister, G., Forster, M., Dunlap, W., Fraser, G., Hermann, J. (2009) Dating microstructures by the 40Ar/39Ar step-heating technique: deformation pressure-temperature-time history of the Penninic Units of the Western Alps. Lithos, doi:10.1016/j.lithos.2009.07.0069.

Brocks, J. J., and Butterfield, N. J. (2009) Early animals out in the cold. *Nature* 457, 672-673.

Buick, I.S., Storkey, A. & Williams, I.S. (2009) Timing relationships between pegmatite emplacement, metamorphism and deformation during the intra-plate Alice Springs Orogeny, central Australia. Journal of Metamorphic Geology, Vol 26, 915–936.

Chen B., Suzuki K., Tian W., Jahn B. M., Ireland, T. (2009) Geochemistry and Os–Nd–Sr isotopes of the Gaositai Alaskan- type ultramafic complex from the northern North China craton: implications for mantle–crust interaction. Contrib. Mineral. Petrol. 158, 683-702, DOI 10.1007/s00410-009-0404-7.

Chichorro, M., Pereira, M.F., Díaz-Azpiroz, M., Williams, I.S., Fernández, C., Pin, C. & Silva, J.B., (2008) Cambrian ensialic rift-related magmatism in the Ossa-Morena Zone (Évora-Aracena metamorphic belt, SW Iberian Massif): Sm-Nd isotopes and SHRIMP zircon U-Th-Pb geochronology. Tectonophysics, Vol 461, 91–113.

Chopra, A. What is Life made of? (2009) The Australian National University's Undergraduate Research Journal, ISSN 1837-2872, Vol 1, 1-6.

Chopra, A., Lineweaver, C.H. (2009) The Major Elemental Abundance Differences between Life, the Oceans and the Sun, Australian Space Science Conference Series: 8th Full Refereed Conference Proceedings ISBN 13:978-0-9775740-2-5

Chopra, A., Lineweaver, C.H., Brocks, J.J., Ireland, T.R. (2009) Palaeoecophylostoichiometrics: Searching for the Elemental Composition of the Last Universal Common Ancestor, Australian Space Science Conference Series: Proceedings of the 9th Australian Space Science Conference,

eds W. Short & I. Cairns National Space Society of Australia Conference held in Sydney, Australia Sept. 27 - Oct 1, 2009.

Darrenougue, N., De Deckker, P., Fitzsimmons, K.E., Norman, M.D., Reed, E., van der Kaars, S., Fallon, S.J. (2009) A late Pleistocene record of aeolian sedimentation in Blanche Cave, Naracoorte, South Australia, Quaternary Science Reviews, Volume 28, Issues 25-26, Pages 2600-2615, ISSN 0277-3791, DOI:

Davies, P.C.W., Benner, S.A., Cleland, C.E., Lineweaver, C.H., McKay, C.P., Wolfe - Simon, F. (2009) Signatures of a Shadow Biosphere, *Astrobiology* 9, 2, 241-249.

Dobbie, P., Kuncic, Z., Bicknell, G., Salmeron, R. (2009) Enhanced MHD Transport in Astrophysical Accretion Flows: Turbulence, Winds and Jets. Proceedings of the 14th International Congress on Plasma Physics. (8 pages).

Dobbie, P., Kuncic, Z., Bicknell, G. & Salmeron, R. (2009) New Global 3D MHD Simulations of Black Hole Disk Accretion and Outflows. In Cosmic Magnetic Fields: from Planets to Stars and Galaxies Proceedings IAU Symposium 259, ed. K. G. Strassmeier, A. G. Kosovichev & J. E. Beckman, 129– 130. (2 pages).

Dusel-Bacon, C. & Williams, I.S. (2009) Evidence for prolonged mid-Paleozoic plutonism and ages of crustal sources in east-central Alaska from SHRIMP U-Pb dating of syn-magmatic, inherited and detrital zircon. Canadian Journal of Earth Sciences, Vol 46, 21-39.

Ewing, T., Rubatto, D., Eggins, S. (2009) *In situ* measurement of Hf isotopes in rutile by LA-MC-ICPMS, Geochimica et Cosmochimica Acta, Vol 73, Supplementary Issue 13, A347.

Finzi-Hart, J.A. and Pett-Ridge, J., Weber, P.K., Popa, R., Fallon, S.J., Gunderson, T., Hutcheon, I.D., Nealson, K.H., Capone, D.G. (2009) Fixation and fate of C and N in the cyanobacterium Trichodesmium using nanometer-scale secondary ion mass spectrometry, Proceedings of the National Academy of Sciences, 106, 15, 6345-6350.

Fonseca, R.I.O.C., Campbell, I.H., O'Neill H. St.C., Allen, C.M. (2009) Solubility of Pt in sulphide mattes: Implications for the genesis of PGE-rich horizons in layered intrusions. Geochimica et Cosmochimica Acta, 73, 5764–5777.

Forster, M. and G. Lister, G. (2009) Core complex related extension of the Aegeanlithosphere initiated at the Eocene-Oligocene transition. J. Geophys. Res., doi: 10.1029/2007JB005382.

Gillen D., Honda M., Chivas A.R., Yatsevich I., Patterson D.B., Carr P.F. (2009) Cosmogenic 21Ne exposure dating of young basaltic lava flows from the Newer Volcanic Province, western Victoria, Australia. Quaternary Geochronology 5, 1–9.

Gray, C. M. and McDougall, I. (2009) K-Ar geochronology of basalt petrogenesis, Newer Volcanic Province, Victoria. Australian Journal of Earth Sciences, 56, 245-258.

Groppo, C., Forster, M., Lister, G. and Compagnoni, R. (2009) Glaucophane schists and associated rocks from Sifnos (Cyclades, Greece): New constraints on the P-T evolution from oxidized systems. Lithos 109, 254-273, doi: 10.1016/j.lithos.2008.10.005

Guilderson T.P., Fallon, S.J., Moore, M.D., Schrag, D.P., Charles, C.D. (2008) Seasonally resolved surface water Δ 14 C variability in the Lombok Strait: A coralline perspective, J. Geophys. Res., 114, C07029, doi:10.1029/2008JC004876.

Handler, M.,R., Baker, J.,A., Schiller, M., Bennett, V.C., Yaxley, G.M. (2009) Magnesium stable isotope composition of Earth's upper mantle, Earth and Planet Sci. Letters, 282, 306-313.
He, B., Xu. Y., and Campbell, I.H. (2009) Pre-eruptive uplift in the Emeishan? Nature Geoscience, 2, 530 – 531.

Heck, P.R., Gyngard, F., Ott, U., Meier, M.M.M., Ávila, J.N., Amari S., Zinner, E., Lewis, R.S., Baur, H., Wieler. (2009) Interstellar Residence Times of Presolar Dust Grains from the Murchison Carbonaceous Meteorite. Astrophysical Journal v. 698, p. 1155-1164.

Hiess J., Bennett V.C, Nutman A.P. and Williams I.S. (2009) In situ UPb, O and Hf isotopic compositions of zircon from Eoarchaean tonalite and felsic volcanic rocks, Itsaq Gneiss Complex, southern West Greenland: New constraints on the source materials for the early crust. Geochimica et Cosmochimica Acta 73, 4489-4516.

Holden P., Lanc P., Ireland T. R., Harrison T. M., Foster J. J., and Bruce Z. (2009) Mass spectrometric mining of Hadean zircons by automated SHRIMP multi-collector and single-collector U/Pb zircon age dating: The first 100,000 grains. Int. J. Mass Spectrom. 286, 53-63.

Iizuka, T., Komiya, T., Johnson, S.P., Kon, Y., Maruyama, S., Hirata, T. (2009) Reworking of Hadean crust in the Acasta gneisses, northwestern Canada: Evidence from in-situ Lu-Hf isotope analysis of zircon. Chemical Geology, Vol 259, 230–239.

Jagoutz, O.E., Burg, J.-P., Hussian, S., Dawood, H., Pettke, T., Iizuka, T., Maruyama, S. (2009) Construction of the granitoid crust of an island arc part I: geochronological and geochemical constraints from the plutonic Kohistan (NW Pakistan). Contributions to Mineralogy and Petrology, Vol 158, 739–755.

Jenner, F.E., Bennett, V.C., Nutman, A.P., Friend, C.R.L., Norman, M.D., and Yaxley, G. (2009) Evidence for subduction at 3.8 Ga: Geochemistry of arc- like metabasalts from the southern edge of the Isua Supracrustal Belt. Chemical Geology 261, 82-99.

Jones, E.G., Lineweaver, C.H. (2009) Pressure-temperature phase diagram of the Earth, in Pathways Towards Habitable Planets, Eds. V. C. du Foresto, D.M. Gelino, and I. Ribas. Astron. Soc. Of the Pacific Conf. Series, 14-18 September, 2009 at Barcelona, Spain.

Kim, Y., Cheong, C-S, Lee, Y. & Williams, I.S. (2009) SHRIMP allanite U-Th-Pb dating of bimodal Triassic metamorphism of Neoarchean tonalitic gneisses, Daeijak Island, central Korea, Geosciences Journal, Vol 13, 305–315.

Kolodner K., Avigad D., Ireland T., and Garfunkel Z. (2009) Origin of Lower Cretaceous ("Nubian") sandstones of North-East Africa and Arabia from detrital zircon U-Pb SHRIMP dating. Sedimentology, 56: 7, p. 2010-2023(14). DOI: 10.1111/j.1365-3091.2009.01067.x
Konigl, A., Salmeron, R. & Wardle, M. (2009) Bipolar outflows in protostellar accretion discs. Part I: Formulation and parameter constraints M.N.R.A.S. (23 pages).

Krot, A.N., Amelin, Y., Bizzarro, M., Bland, P., Ciesla, F.J., Connelly, J., Davis, A.M., Huss, G.R., Hutcheon, I.D., Makide, K., Nagashima, K., Russell, S.S., Scott, E.R.D., Thrane, K., Yurimoto, H., and Yin, Q.-Z. (2009) Origin and chronology of chondritic components: review. Geochim. Cosmochim. Acta vol.73 4963–4997.

Krzemińska, E., Wiszniewska, J., Skridlaite, G. & Williams, I.S. (2009) Late Svecofennian sedimentary basins in the crystalline basement of NE Poland and adjacent area of Lithuania: ages, major sources of detritus, and correlations. Geological Quarterly, Vol 53, 255–272.

Lineweaver, C.H. (2009) Cosmobiology: Our Place in the Universe, chapter in "Genes to Galaxies: The lecture series of the 35th Professor Harry Messel International Science School" Eds A. Selinger, A. Greene, ISBN 978-0-9599471-2-0, p 182-197.

Lineweaver, C.H. (2009) Are We Alone? in "Astronomy 2010 Australia: your guide to the night sky" Ed K. Wallace, G. Dawes and P. Northfield, Quasar Publishing.

Lineweaver, C.H. & Norman, M. (2009) The Bombardment History of the Moon and the Origin of Life on Earth, Australian Space Science Conference Series: Proceedings of the 8th

Australian Space Science Conference, eds W. Short & I. Cairns National Space Society of Australia, pp 34-40 Conference held in Canberra, Australia Sept. 29 - Oct 2, 2008, ISBN 13:978-0-9775740-2-5.

Lister, G. and Forster, M. (2009) Tectonic mode switches and the nature of orogenesis. Lithos 113, 274-291.

Liu M-C., McKeegan, K.D., Goswami, J.N., Marhas, K.K., Sahijpal, S., Ireland, T.R., Davis, A.M. (2009) Isotopic records in CM hibonites: Implications for timescales of mixing of isotope reservoirs in the solar nebula. Geochimica et Cosmochimica Acta 73: 5051-5079.

Maier, W.D., Barnes, S.J., Campbell, I.H., Fiorentini, M.L., Peltonen, P., Barnes, S-J., Smithies, H. (2009) Progressive mixing of meteoritic veneer into the early Earth's deep mantle. Nature, 460, 620-623.

Mazhari, S.A., Bea, F., Amini, S., Ghalamghash, J., Molina, J.F., Montero, P., Scarrow, J.H. & Williams, I.S. (2009) The Eocene bimodal Piranshahr massif of the Sanandaj-Sirjan Zone, NW Iran: a marker of the end of the collision in the Zagros orogen. Journal of the Geological Society, London, Vol 166, 53–69.

McDougall, I. and Brown, F.H. (2009) Timing of volcanism and evolution of the northern Kenya Rift. Geological Magazine, 146, 34-47.

Nadolinny, V.A., Yuryeva, O.P., Shatsky, V.S., Stepanov, A.S., Golushko, V.V., Rakhmanova, M.I. (2009) New Data on the Nature of the EPR OK1 and N3 Centers in Diamond, Applied Magnetic Resonance, Vol 36, Issue 1, 97-108.

Neiva, A.M.R., Williams, I.S., Ramos, J.M.F., Gomes, M.E.P., Silva, M.M.V.G. & Antunes, I.M.H.R. (2009) Geochemical and isotopic constraints on the petrogenesis of Early Ordovician granodiorite and Variscan two-mica granites from the Gouveia area, central Portugal, Lithos, Vol 111, 186–202.

Nutman, A.P., Bennett, V.C., Friend, C.R.L., Jenner, F., Wan, Y., Liu, D.-Y. (2009) Episodic Eoarchaean crustal accretion (3.87 to 3.66 Ga) in West Greenland (Itsaq Gneiss Complex) and in northeastern China. In: Cawood, P.A. & Kröner, A. (eds) Earth Accretionary Systems in Space and Time. Special Publication of the Geological Society, 318, 127-154.

Pereira, M.F., Chichorro, M., Williams, I.S. & Silva, J.B., (2008) Zircon U-Pb geochronology of paragneisses and biotite granites from the SW Iberian Massif (Portugal): evidence for a palaeogeographic link between the Ossa-Morena Ediacaran basins and the West African craton. *In:* Nasser, E. & Liegeois, J.P. (eds), The boundaries of the West African Craton. Geological Society Special Publication, Vol 297, 385–408.

Roark, E.B., Guilderson, T.P., Dunbar, R.B., Fallon, S.J., Mucciarone, D.A. (2009) Extreme longevity in proteinaceous deep-sea corals, Proceedings of the National Academy of Sciences, 106, 13, 5204-5208.

Robles, J.A. Egan, C.A., Lineweaver, C.H. (2009) Statistical Analysis of Solar and Stellar Properties, Australian Space Science Conference Series: Proceedings of the 8th Australian Space Science Conference, eds W. Short & I. Cairns National Space Society of Australia, pp 28-33 ISBN 13:978-0-9775740-2-5.

Salmeron, R. (2009) The role of magnetic fields in star formation. In Australian Space Science Conference Series: 7th Conference Proceedings. NSSA Full Refereed Proceedings CD, (ed) National Space Society of Australia Ltd, edt. W. Short. (7 pages).

Salmeron, R. (2009) MRI and outflows: angular momentum transport in protoplanetary discs. In Protostellar Jets in Context, eds. T. Ray & K. Tsinganos (2 pages).

Sherwood, O.A., Thresher, R.E., Fallon, S.J., Davies, D.M., Trull, T.W. (2009) Multi-century time-series of 15N and 14C in bamboo corals from deep Tasmanian seamounts: Evidence for stable oceanographic conditions, Marine Ecology Progress Series, Vol 397, 209-218.

Solá, A.R., Pereira, M.F., Williams. I.S., Ribeiro, M.L., Neiva, A.M.R., Montero, P., Bea, F. & Zinger, T., (2009) New insights from U-Pb zircon dating of Early Ordovician magmatism on the northern Gondwana margin: the Urra Formation (SW Iberian Massif, Portugal), Tectonophysics, Vol 461, 114–129.

Solá, A.R., Williams, I.S., Neiva, A.M.R. & Ribeiro, M.L., (2009) U-Th-Pb SHRIMP ages and oxygen isotope composition of zircon from two contrasting late Variscan granitoids, Nisa-Albuquerque batholith, SW Iberian Massif: Petrologic and regional implications. Lithos, Vol 111, 156–167.

Thresher, R.E., MacRae, C.M., Wilson, N.C., Fallon, S.J. (2009) Feasibility of age determination of deep-water bamboo corals (Gorgonacea; Isididae) from annual cycles in skeletal composition, Deep Sea Research Part I: Oceanographic Research Papers, Volume 56, Issue 3, Pages 442-449, ISSN 0967-0637, DOI: 10.1016/j.dsr.2008.10.003.

Wadhwa, M., Amelin, Y., Bogdanovski, O., Shukolyukov, A., Lugmair, G.W. and Janney, P. (2009) Ancient relative and absolute ages for a basaltic meteorite: Implications for timescales of planetesimal accretion and differentiation. Geochim. Cosmochim. Acta vol.73, 5189–5201.

Wang, C.Y., Campbell, I.H., Allen. C.M., Williams, I.S., and Eggins S.M. (2009) Rate of growth of the preserved North American continental crust: evidence from Hf and O isotopes in Mississippi detrital zircons. Geochimica et Cosmochimica Acta. 73, 712-728.

Wang, K.-L. O'Reilly, S.Y., Honda, M., Matsumoto, T., Griffin, W.L., Pearson, N.J., Zhang, M.. (2010). Journal of Asian Earth Sciences 37, 229–245.

Wang, C.Y., Campbell, I.H., Allen, C.A., Williams, I.S. & Eggins, S.M., (2009) Rate of growth of the preserved North American continental crust: Evidence from Hf and O isotopes in Mississippi detrital zircons. Geochimica et Cosmochimica Acta, Vol 73, 712–728.

Williams, I.S., Cho. D-Y. & Kim, S.W., (2009) Geochronology, and geochemical and Nd-Sr isotopic characteristics, of Triassic plutonic rocks in the Gyeonggi Massif, South Korea: Constraints on Triassic post-collisional magmatism. Lithos, Vol 107, 239–256.

Williams, I.S., Krzemińska, E. & Wiszniewska, J., (2009) An extension of the Svecofennian orogenic province into NE Poland: Evidence from geochemistry and detrital zircon from Paleoproterozoic paragneisses. Precambrian Research, Vol 172, 234–254.

Earth Environment

Antonioli F., Ferranti L., Fontana A., Amorosi A., M., Bondesan A, Braitenberg C., Dutton A., Fontolan G., Furlani S., Lambeck K., Mastronuzzi G., Monaco C., Spada G., and P. Stocchi (2009) Holocene relative sea-level changes and vertical movements along the Italian and Istrian coastlines, Quaternary International, Vol 206, 102-133. doi: 10.1016/j.quaint.2008.11.008.

Antonioli, F. and Dutton, A. (2009) Underwater treasures, Nature Geoscience, Vol 2(5), E8. 10.1038/ngeo508 (Not peer-reviewed)

Basak, C., Rathburn, A.E., Perez, M.E., Martin, J.B., Kluesner, J.W., Levin, L.A., De Deckker, P., Gieskes, J.M., Abriani, M. 2009. Carbon and oxygen isotope geochemistry of live (stained) benthic foraminifera from the Aleutian Margin and the Southern Australian Margin. Marine Micropaleontology 70, 89-101.

Bostock, H.C. Opdyke, B.N., Gagan, M.K., and Fifield, L.K.,Late Quaternary siliciclastic/carbonate sedimentation model for the Capricorn Channel, southern Great Barrier Reef. Marine Geology, 257 (1), p. 107-123, Feb 2009.

Cunningham HS, Turner SP, Patia H, Wysoczanski R, Nichols ARL, Eggins S, Dosseto A (2009) 210Pb/226Ra) variations during the 1994–2001 intracaldera volcanism at Rabaul Caldera. J. Volcanology Geothermal Research 184 (3-4) 416-426.

Cunningham HS, Turner SP, Dosseto A, Patia H, Eggins S, Arculus R (2009) Temporal Variations in U-series Disequilibria in an Active Caldera, Rabaul, Papua New Guinea. J. Petrology 50 (3) 507-529.

Darrenougue, N., De Deckker, P., Fitzsimmons, K. E., Norman, M. D., Reed E., van der Kaars, S., Fallon, S. (2009). A late Pleistocene record of aeolian sedimentation in Blanche Cave, Naracoorte, South Australia, Quaternary Science Reviews, Volume 28, Issues 25-26, December 2009, Pages 2600-2615.

David, B., Araho, N., Barker, B., Kuaso, A. and Moffat, I., (2009) Keveoki I: Exploring the Hiri Ceramics Trade at a Short-Lived Village Site near the Vailala River, Papua New Guinea, Australian Archaeology, Number 68, 11-22.

De Deckker, P. & Yokoyama, Y.2009. Micropalaeontological evidence for Late Quaternary sea-level changes in Bonaparte Gulf, Australia *Global and Planetary Change Science* 66, 85-92.
Dutton, A., Bard, E., Antonioli, F., Esat, T. M., Lambeck, K., McCulloch, M. (2009) Phasing and amplitude of sea level and climate change during the penultimate interglacial, Nature Geoscience, Vol 2, 355-359. doi: 10.1038/NGEO470.

Dutton, A., Scicchitano, G., Antonioli, F., Desmarchelier, J., Esat, T. M., Lambeck, K., McCulloch, M.T., Mortimer, G. (2009) Uplift rates defined by 14C and U-series ages of serpulid-encrusted speleothems from submerged caves near Siracusa, Sicily (Italy), Quaternary Geochronology, Vol 4, 2-10. doi:10.1016/j.quageo.2008.06.003

Dutton, A., Pearson, P., Bralower, T., Wade, B., Eggins, S. and C. Thompson (2009) Elemental geochemistry and diagenesis in Eocene tropical planktonic foraminifera: Insights from laser-ablation profiling, GNS Science Miscellaneous Series, Vol 18, 47-50. (Not peer-reviewed)
Dutton, A., Antonioli, F., Bard, E. (2009) A new chronology of sea level highstands for the penultimate interglacial, PAGES News, Vol 17(2), 66-68. (Not peer-reviewed)

Duval, M., Grün, R., Falgueres, C., Bahain, J.J., Dolo, J.M. (2009). ESR dating of Lower Pleistocene fossil teeth: limits of the single saturating exponential (SSE) model for the equivalent dose determination. Radiation Measurements 44: 477-482.

Fitzsimmons, K.E. (2009) Linear dune formation: Longitudinal elongation or local wind rifting? An example from the Strzelecki Desert, central Australia, Online vignette supporting: Bierman, P. and Montgomery, D. (Eds.) Key concepts in Geomorphology, W.H. Freeman, Vermont. http://serc.carleton.edu/NAGTWorkshops/geomorph/vignettes/35390.html

Fitzsimmons, K.E. (2009) Regional trends in desert dune morphology and orientation: Examples from the Australian deserts, Online vignette supporting: Bierman, P. and Montgomery, D. (Eds.) Key concepts in Geomorphology, W.H. Freeman, Vermont. http://serc.carleton.edu/NAGTWorkshops/geomorph/vignettes/35389.html

Fitzsimmons, K.E., Magee, J.W., Amos, K.J., (2009) Characterisation of aeolian sediments from the Strzelecki and Tirari Deserts, Australia: Implications for reconstructing palaeoenvironmental conditions, Sedimentary Geology, Vol 218, 61-73.

Griffiths, M.L., Drysdale, R.N., Gagan, M.K., Zhao, J.-x., Ayliffe, L.K., Hellstrom, J.C., Hantoro, W.S., Frisia, S., Feng, Y.-x., Cartwright, I., St. Pierre, E., Fischer, M. and Suwargadi, B.W. (2009)

Increasing Australian-Indonesian monsoon rainfall linked to early Holocene sea-level rise, Nature Geoscience, Vol 2, 636-639.

Grün, R. (2009). The DATA program for the calculation of ESR age estimates on tooth enamel. Quaternary Geochronology 4: 231-232.

Grün, R. (2009). The relevance of parametric U-uptake models in ESR age calculations. Radiation Measurements 44: 472-476.

Grün, R. (2009). The "AGE" program for the calculation of luminescence age estimates. Ancient TL 27: 45-46.

Hill, P.J., De Deckker, P., Von Der Borch, C.C. & Murray-Wallace, C.V. 2009. Ancestral Murray River on the Lacepede Shelf, southern Australia: Late Quaternary migrations of a major river outlet and strandline development. *Australian Journal of Earth Science* 56, 135-157.

Joannes-Boyau, R., Grün, R. (2009). Thermal behaviour of orientated and non-orientated CO2-radicals in tooth enamel. Radiation Measurements 44: 505-511.

Mallela J, Crabbe MJC (2009) Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago. Marine Environmental Research 68:158–162.

McLaren, S., Wallace, M.W., Pillans, B., Gallaghers, J., Miranda, J.A. & Warne, M.T., (2009). Revised stratigraphy of the Blanchetown Clay, Murray Basin: constraints on the evolution of mega-lake Bungunnia. Australian Journal of Earth Sciences Vol 56, 259-270.

Moros, M., De Deckker, P., Jansen, E., Perner, K., Telford, R. J. 2009. Holocene variability in the Southern Ocean recorded in a deep-sea sediment core off South Australia. *Quaternary Science Reviews.* 28, 1932-1940.

Passey, B.H., Ayliffe, L.K., Kaakinen, A., Zhang, Z., Eronen, J.T., Yanming, Z., Liping, Z., Cerling, T.E. and Fortelius, M. (2009) Strengthened East Asian summer monsoons during a period of high-latitude warmth? Isotopic evidence from Mio-Pliocene fossil mammals and soil carbonates from northern China, Earth and Planetary Science Letters, Vol 277, 443-452.

Patnaik, R., Sahni, A., Cameron, D., Pillans, B., Chatrath, P., Simons, E., Williams, M. & Bibi, F., (2009). Ostrich-like eggshells from a 10.1 million-yr-old Miocene ape locality, Haritalyangar, Himachal Pradesh, India. Current Science, Vol 96, 1485-1495.

Prideaux, G.J., Ayliffe, L.K., DeSantis, L.R.G. , Schubert, B.W., Murray, P.F., Gagan, M.K. and Cerling, T.E. (2009) Extinction implications of a chenopod browse diet for a giant Pleistocene kangaroo, Proceedings of the National Academy of Sciences, Vol 106, 11646-11650.

Russon, T., Elliot, M., Kissel, C., Cabioch, G., De Deckker, P., Corrège, T. 2009. Mid-Late Pleistocene Deep Water Circulation in the Southwest Subtropical Pacific. *Paleoceanography* 24, PA4205, doi:10.1029/2009PA001755.

Sadekov, A., Eggins, S. M., De Deckker, P., Ninnemann, U., Kuhnt, W., Bassinot, F. 2009. Surface and subsurface seawater temperature reconstruction using Mg/Ca microanalysis of planktonic foraminifera *Globigerinoides ruber*, *Globigerinoides sacculifer*, and *Pulleniatina obliquiloculata*, *Paleoceanography*, 24, PA3201, doi:10.1029/2008PA001664.

Smith, M.L, Pillans, B.J. & McQueen, K.G., (2009). Palaeomagnetic evidence for periods of intense oxidative weathering, McKinnons mine, Cobar, NSW. Australian Journal of Earth Sciences, Vol 56, 201-212.

Sosdian,S. and Y. Rosenthal (2009) Deep Sea Temperature and Ice Volume Change across the Pliocene-Pleistocene Climate Transitions, Science, V. 325, pp.306-310.

Telford, K., Maher, W., Krikowa, F., Foster, S., Ellwood, M.J., Ashley, P.M., Lockwood, P.V. and Wilson, S.C., 2009. Bioaccumulation of antimony and arsenic in a highly contaminated stream adjacent to the Hillgrove Mine, NSW, Australia. Environmental Chemistry, 6(2): 133-143.

Vopel, K., Pilditch, C.A., Wilson, P. and Ellwood, M.J., 2009. Oxidation of surface sediment: effects of disturbance depth and seawater flow speed. Marine Ecology Progress Series, 392(doi:10.3354/meps08179): 43-55.

Wallis, L.A., Keys, B., Moffat, I. and Fallon, S., (2009) Gledswood 1 Shelter: initial radiocarbon dates from a Pleistocene aged rockshelter site in north Queensland, Australian Archaeology, Number 69, 71-74.

Wang CY, Campbell IH, Allen CM, Williams IS, Eggins SM (2009) Rate of growth of the preserved North American continental crust; evidence from Hf and O isotopes in Mississippi detrital zircons. Geochimica et Cosmochimica Acta, 73, 712-728.

Wille, M., Naegler, T.F., Lehmann, B. Schroeder, S., Kramers, J., (2009) Early Cambrian ocean anoxia in South China Reply, Nature, Vol 459, E6.

Young, G.C. 2009. New arthrodires (Family Williamsaspididae) from Wee Jasper, New South Wales (Early Devonian), with comments on placoderm morphology and palaeoecology. Acta Zoologica [Stockholm] 90 (Suppl. 1): 69-82.

Young, G.C. 2009. An Ordovician vertebrate from western New South Wales, with comments on Cambro-Ordovician vertebrate distribution patterns. Alcheringa **33**: 79-89.

Earth Materials & Processes

Arculus, R., Campbell, I.H., McLennan, S.M. and Taylor, S.R., 2009. Asteroids and andesites. Nature, 459 (7246) E1, doi:10.1038/nature08077

Barker, S.L.L., Bennett, V.C., Cox, S.F., Norman, M.D. and Gagan, M.K., 2009. Sm–Nd, Sr, C and O isotope systematics in hydrothermal calcite–fluorite veins: Implications for fluid–rock reaction and geochronology. Chemical Geology, doi:10.1016/j.chemgeo.2009.07.009.

Beltrando, M., Lister, G., Forster, M., Dunlop, W.J., Fraser, G. and HERMANN, J., (2009). Dating microstructures by the 40Ar/39Ar step-heating technique: Deformation–pressure–temperature–time history of the Penninic Units of the Western Alps. Lithos 113, 801-819.

Berry, A.J., O'Neill, H.St.C. and Mosselmans, J.F.W., 2009. The oxidation state of uranium in zircon. 19th Annual V M Goldschmidt Conference, Switzerland, Geochimica et Cosmochimica Acta, 73, A117-A117.

Christy, A.G. (2009) A Monte Carlo study of short- and long-range order of tetrahedral cations in sapphirine and khmaralite. *Amer. Mineral.* **94**: 270-282.

Cunningham, H.S., Turner, S.P., Dosseto, A., Patia, H., Eggins, S.M., Arculus, R.J. (2009) Temporal variations in U-series disequilibria in an active caldera, Rabaul, Papua New Guinea, Journal of Petrology, Vol 50, Issue 3, pages 507-529.

De Caritat, P., McPhail, D.C., Kyser, K. and Oates, C.J. (2009) Using groundwater chemical and isotopic composition in the search for base metal deposits: Hydrogeochemical investigations in the Hinta and Kayar Pb-Zn districts, India, Geochemistry: Exploration, Environment, Analysis, 9, 215-226.

Evans, K.A., O'Neill, H.St.C., Mavrogenes, J.A., Keller, N.S., Jang, L.-Y. and Lee, J-F. XANES evidence for sulphur speciation in Mn-, Ni and W-bearing silicate melts. Geochim. Cosmochim. Acta 73, 6847-6867 (doi:10.1016/j.gca.2009.08.013).

Fonseca, R.O.C., Campbell, I.H., O'Neill, H.St.C., and Allen, C.M. Solubility of Pt in sulphide mattes: Implications for the genesis of PGE-rich horizons in layered intrusions. Geochim. Cosmochim. Acta 73, 5764-5777 (doi:10.1016/j/gca.2009.06.038).

Gregory, C., Buick, I.S., HERMANN, J., and Rubatto, D. (2009) Mineral-scale trace element and U-Th-Pb age constraints on metamorphism and melting during the Petermann Orogeny (central Australia). J. Petrol. 50, 251-287.

Gregory, C., McFarlane, C.R.M., HERMANN, J., Rubatto, D. (2009) Tracing the evolution of calc-alkaline magmas: in-situ Sm-Nd isotope studies of accessory minerals in the Bergell Igneous Complex, Italy. Chem. Geol. 260, 73-86.

HALFPENNY, A. and Cox, S.F., 2009. Development and Evolution of Fracture-Controlled Flow Regimes and Gold Mineralisation, Porgera Gold Deposit, PNG, 10th Biennal SGA Meeting, Townsville, Australia. Smart Science for Exploration and Mining: proceedings of the 10th biennial SGA meeting, Townsville, Australia, 17th-20th August 2009 (EDS) P.J.Williams et al, 815-817.

Harrison, T.M., Célérier, J., Aikman, A.B., HERMANN, J. and Heizler, M.T. (2009): Diffusion of 40Ar in muscovite. Geochim. Cosmochim. Acta 73, 1039-1051.

Hermann, J., and Rubatto, D. (2009) Accessory phase control on the trace element signature of sediment melts in subduction zones. Chem. Geol. 265, 512-526.

Jackson, I., Barnhoorn, A., Aizawa, Y., Saint, C. (2009). Improved experimental procedures for the study of high-temperature viscoelastic relaxation, Phys. Earth Planet. Interiors 172, 104-115.

Jelsma, H., Barnett, W., Richards, S. and Lister, G. (2009 online) Tectonic settings of kimberlites, Lithos, doi:10.1016/j.lithos.2009.06.030

Jenner, F.E., Holden, P., Mavrogenes, J.A., O'Neill, H.St.C. and Allen, C. Determination of selenium concentrations in NIST SRM 610, 614 and geological glass reference materials using the electron probe, LA-ICP-MS and SHRIMP II. Geostandards and Geoanalytical Research, 33, 309-317.

Jung, C., Jung, S., Nebel, O., Hellebrand, E., Masberg, P., Hoffer, E. (2009): Fluid-present melting of meta-igneous rocks and the generation of leucogranites – Constraints from garnet major and trace element data, Lu-Hf whole rock-garnet ages and whole rock Nd-Sr-Hf-O isotope data; Lithos 111, Issue 3-4, 220-235

Kennett, B. L. N., I. Jackson Optimal equations of state for mantle minerals from simultaneous non-linear inversion of multiple datasets. *Phys. Earth Planet. Interiors* 176, 98-108.

Kovacs, I., O'Neill, H.St.C., Hermann, J. and Hauri, E., 2009. O-H absorption coefficients of four common mechanisms for water substitution in olivine. 19th Annual V M Goldschmidt Conference, Switzerland, Geochimica et Cosmochimica Acta, 73, A690-A690.

Laurenz, V., Ballhaus, C. O'Neill, H.St.C., Wohlgemuth-Ueberwasser, C.C. and Fonseca, R.O.C., 2009. Ir partitioning between chromite and silicate melt – The influence of FO(2). 19th Annual V M Goldschmidt Conference, Switzerland, Geochimica et Cosmochimica Acta, 73, A727-A727.

Lupton, J.E., Arculus, R.J., Greene, R.R., Evans, L.J., Goddard, C.I. (2009) Helium isotope variations in seafloor basalts from the Northwest Lau Backarc Basin: mapping the influence of the Samoan hotspot, Geophysical Research Letters, Vol 36, L17313, doi:10.1029/2009GL039468.

Malaspina, N., HERMANN, J. and Scambelluri, M. (2009): Fluid/mineral interaction in UHP garnet peridotite. Lithos 107, 38-52.

Mallmann, G., O'Neill, H.St.C., Klemme, S., (2009) Heterogeneous distribution of phosphorus in olivine from otherwise well-equilibrated spinel peridotite xenoliths and its implications for the mantle geochemistry of lithium, Contributions to Mineralogy and Petrolohy, 158, 485-504.

Mallmann, G., O'Neill, H.St.C., (2009) The crystal/melt partitioning of V during mantle melting as a function of oxygen fugacity compared with some other elements (Al, P, Ca, Sc, Ti, Cr, Fe, Ga, Y, Zr and Nb), Journal of Petrology, 50, 1764-1794.

Mavrogenes, J.A., Jenner, F., O'Neill, H.St.C. and Arculus, R.J. 2009. The magnetite crisis in evolving arc magmas. 2009 Portland GSA Annual Meeting, Oregon, 158-3.

Métrich, N., Berry, A.J., O'Neill, H.St.C. and Susini, J. The oxidation state of sulfur in synthetic and natural glasses determined by X-ray absorption spectroscopy. Geochim. Cosmochim. Acta, 73, 2382-2399, (doi:10.1016/j.gca.2009.01.025)

Mills, S.J., Christy, A.G., Chen, E.C-C., Raudsepp, M. (2009) Revised values of the bond valence parameters for [6]Sb(V)–O and [3–11]Sb(III)–O. *Z. Kristall.* 224: 423-431.

Mills, S.J., Kampf, A.R., Raudsepp, M., Christy, A.G. (2009) The crystal structure of Ga-rich plumbogummite from Tsumeb, Namibia. *Mineral. Mag.* 73: 837-845.

Morris, S.J.S., Jackson, I., (2009) Implications of the similarity principle relating creep and attenuation in finely-grained solids. Mat. Sci. Eng. A 521-522, 124-127.

Morris, S.J.S., Jackson, I., (2009) Diffusionally-assisted grain-boundary sliding and viscoelasticity of polycrystals. J. Mech. Phys. Solids 57, 744-761.

Nebel, O. , Morel, M.L.A. Vroon, P.Z.(2009): Isotope dilution concentration analyses ofLu, Hf, Zr, Ta and W, and Hf isotope compositions of NIST SRM-610 and SRM-612 glass wafers, Geostandards and Geoanalytical Research, 33 Issue 4.

Rolland, Y., Cox, S.F., and Corsini, M., 2009. Constraining deformation stages in brittle-ductile shear zones from combined field mapping and 40Ar/39Ar dating: The structural evolution of the Grimsel Pass area (Aar Massif, Swiss Alps), Journal of Structural Geology, 31, 11, 1377-1394

Rubatto, D., HERMANN, J., Berger, A., and Engi, M. (2009). Protracted fluid-induced melting during Barrovian metamorphism in the Central Alps. Contrib. Mineral. Petrol., 158, 703-722.

Tuff, J. and O'Neill, H.St.C., 2009. Olivine-melt Ni partitioning as a function of sulfur content in basaltic systems. 19th Annual V M Goldschmidt Conference, Switzerland, Geochimica et Cosmochimica Acta, 73, A1351-A1351.

Usher, A., McPhail, D.C. and Brugger, J. (2009) A spectrophotometric study of aqueous Au(III)-halide-hydroxy complexes at 25°C. Geochimica et Cosmochimica Acta, 73, 3359-3380.

Wang, R. P., A. Smith, B. Luther-Davies, H. Kokkonen and I. Jackson Observation of two elastic thresholds in GexAsySe1-x-y glasses. *J. Appl. Phys.* 105, 056109.

Wasch, L.J., v.d.Zwan, F.M., Nebel, O., Morel, M.L.A., Hellebrand, O.E.W.G., Pearson, D.G., Davies, G.R. (2009): an alternative mechanism of silica enrichment in the Kaapvaal subcontinental lithospheric mantle, Geochimica et Cosmochimica Acta, 73, Issue 22, 6894-6917

Welch, S.A., Christy, A.G., Isaacson, L., Kirste, D. (2009) Mineralogical control of rare earth elements in acid sulfate soils. *Geochim. Cosmochim. Acta* **73**: 44-64.

Witt-Eickschen, G., Palme, H., O'Neill, H.St.C. and Allen, C.M. The geochemistry of the volatile trace elements As, Cd, Ga, In and Sn in the Earth's mantle: New evidence from in situ analyses of mantle xenoliths. Geochim. Cosmochim. Acta. 73, 1755-1778 (doi:10.1016/j.gca.2008.12.013)

Zhang, G., Ellis, D.J., Christy, A.G., Zhang, L., Niu, Y., Song, S. (2009 online) UHP metamorphic evolution of coesite-bearing eclogite from the Yuka terrane, North Qaidam UHPM belt, NW China. *Eur. J. Mineral.* Doi:10.1127/0935-1221/2009/0021-1989

Earth Physics

Bodin, T., Sambridge, M. and Gallagher, K. (2009). A self-parametrizing partition model approach to tomographic inverse problems. Inverse Problems 25 (2009) 055009 (22p)

Bodin, T. and Sambridge, M. (2009). Seismic tomography with the reversible jump algorithm. Geophys. J. Int. (2009) 178, 1411–1436.

Brodie, R., and Sambridge, M., (2009) Holistic inversion of frequency-domain airborne electromagnetic data with minimal prior information, *Explor. Geophys.*, **40**, 765-778.

Davies, G. F., (2009) Reconciling the geophysical and geochemical mantles: plume flows, heterogeneities and disequilibrium, Geochem. Geophys. Geosystems, Vol 10, 19 pp., doi:10.1029/2009GC002634

Davies, G. F., (2009) Effect of plate bending on the Urey ratio and the thermal evolution of the mantle, Earth Planet. Sci. Lett., Vol 287, 513-518.

Fichtner, A., Igel, H., Bunge, H.-P. & Kennett, B.L.N., (2009), Simulation and inversion of seismic wave propagation on continental scales based on a spectral-element method, *J. Num. Anal. Indust. Appl. Math.,* **4**, 11-22.

Fontaine, F., Barruol, G., Kennett, B.L.N., Bokelmann, G.H.R. & Reymond, D., (2009), Upper mantle anisotropy beneath Australia and Tahiti from P wave polarization: Implications for real-time earthquake location, *J. Geophys. Res.*, **114**, B03306, doi:10.1029/2008JB005709

Gallagher, K., Charvin, Nielsen, S., Sambridge, M., and Stephenson, J., (2009) Markov chain Monte Carlo (MCMC) sampling methods to determine optimal models, model resolution and model choice for Earth Science problems , *Marine and Petrol. Geol.*, **26**, 525-535, doi:10.1016/j.marpetgeo.2009.01.003.

Hogg, A.McC., Dewar, W.K., Berloff, P., Kravtsov, S. & Hutchinson, D.K., (2009) The effects of mesoscale ocean-atmosphere coupling on the large-scale ocean circulation. J. Climate, Vol 22, 4066-4082.

Hughes, G.O., Hogg, A.McC. & Griffiths, R.W., (2009) Available potential energy and irreversible mixing in the meridional overturning circulation, J. Phys. Oceanogr., Vol 39, 3130-3146. DOI: 10.1175/2009JPO41612.1

Jianping Huang, Elizabeth Vanacore, Fenglin Niu, and Alan Levander (2009) Mantle transition zone beneath the Caribbean-South American plate boundary and its tectonic implications. EPSL [Corrected Proof available on-line Dec 5, 2009].

Kennett, B.L.N. & Jackson, I., (2009), Optimal equations of state for mantle minerals from simultaneous non-linear inversion of multiple datasets, *Phys. Earth Planet. Inter*, **176**, 98-108, doi:10.1016/j.pepi.2009.04.00

Kerr, R.C., (2009) Thermal erosion of felsic ground by the laminar flow of a basaltic lava, with application to the Cave Basalt, Mount St. Helens, Washington, J. Geophys. Res., Vol 114, B09204, doi:10.1029/2009JB006430.

Leblanc, M., P. Tregoning,, G. Ramillien, S. Tweed, A. Fakes. Basin scale, integrated observations of the early 21st Century multi-year drought in southeast Australia, *Water Resources Res.,* **45,** W04408, doi:10.1029/2008WR007333, 2009.

Melachroinos, S., J-M Lemoine, P. Tregoning,, R. Biancale. Quantifying aliased S2 tidal errors from multiple space-geodesy techniques, GPS and GRACE, over North West Australia, *Journal of Geodesy,***83**, 915-923, doi:10.1007/s00190-009-0309-2, 2009.

Prastowo, T., Griffiths, R.W., Hughes, G.O. & Hogg, A.McC. 2009 Effects of topography on the cumulative mixing efficiency in exchange flows, J. Geophys. Res., Vol 114, C08008, doi:10.1029/2008JC005152.

Revets, S., Keep, M. & Kennett B.L.N. (2009), NW Australian intraplate seismicity and stress regime, *J. Geophys. Res.*, **114**, B10305, doi:10.1029/2008JB006152

Roderick, M., Hobbins, M., Farquhar, G. (2009) Pan Evaporation Trends and the Terrestrial Water Balance I. Principles and Observations, Geography Compass, Vol 3, 746-760.

Roderick, M, Hobbins, M., Farquhar, G. (2009) Pan Evaporation Trends and the Terrestrial Water Balance II. Energy Balance and Interpretation, Geography Compass, Vol 3, 761-780.

Schellart , W.P., Kennett B.L.N., Spakman W. & Amaru, M. (2009) Plate reconstructions and tomography reveal a fossil lower mantle slab below the Tasman Sea, *Earth Planet. Sci. Lett.*, **278**, 143–151.

Schymanski, S., Sivapalan, M., Roderick, M., Hutley, L., Beringer, J., (2009) An optimality-based model of the dynamic feedbacks between natural vegetation and the water balance, Water Resources Research, Vol 45, W01412, doi:10.1029/2008WR006841.

Shuttleworth, W., Serrat-Capdevila, A., Roderick, M., Scott, R. (2009) On the theory relating changes in area-average and pan evaporation. Quarterly Journal of the Royal Meteorological Society, Vol 135, 1230-1247.

Dr H TKALČIĆ, D. S. Dreger, G. R. Foulger and B. R. Julian, The puzzle of the Bardarbunga, Iceland earthquake: No volumetric component in the source mechanism, *Bull. Seismol. Soc. Am.,* 99, 3077-3085, 2009.

Dr H TKALČIĆ, V.F. Cormier, B.L.N. Kennett and K. He, Steep reflections from the Earth's core reveal small-scale heterogeneity in the upper mantle, *Physics Earth Planet. Int.*, DOI:10.1016/j.pepi.2009.08.004, 2009.

Dr H TKALČIĆ, B.L.N. Kennett and V.F. Cormier, On the inner-outer core density contrast from PKiKP/PcP amplitude ratios and uncertainties caused by seismic noise, *Geophys. J. Int.*, DOI:10.1111/j.1365-246X.2009.04294.x, 2009.

Tregoning, P., C. Watson, G. Ramillien, H. McQueen and J. Zhang. Detecting hydrologic deformation using GRACE and GPS, *Geophys. Res. Lett.* **36**, L15401, doi:10.1029/2009GL038718, 2009.

Tregoning, P., G. Ramillien, H. McQueen and D. Zwartz. Glacial isostatic adjustment and non-stationary signals observed by GRACE, *J. Geophys. Res.,* **114**B06406, doi:10.1029/2008JB006161, 2009.

Tregoning, P. and C. Watson. Atmospheric effects and spurious signals in GPS analyses, *J. Geophys. Res.,* **114**, B09403, doi:10.1029/2009JB006344, 2009.

Visser, K., Trampert, J. & Kennett, B.L.N. (2009) Reply to comment by S. Crampin on 'Global anisotropic phase velocity maps for higher mode Love and Rayleigh waves', *Geophys. J. Int.*, **177**, 99-103.

IODP

R. Boyd, J. Keene, T. Hubble, J. Gardner, K. Glenn, K. Ruming, Neville Exon and the crews of Southern Surveyor 10/2006 and 12/2008, Southeast Australia, 2009: A Cenozoic Continental Margin Dominated by Mass Transport. Chapter 39 *In* D. Mosher et al. (eds.), 2009, *Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research*, Vol. 28, Springer Science + Business Media B.V. 2009, p. 483-495.

PRISE

Anma R., Armstrong R., Orihashi Y., Ike S-i., Shin K-C., Kon Y., Komiya T., Ota T., Kagashima S-i., Shibuya T., Yamamoto S., Veloso E.E., Fanning M., Hervé F., (2009) Are the Taitao granites formed due to subduction of the Chile ridge?, Lithos, Vol 113, 246-258

Barker S.L.L., Bennett V.C., Cox S.F., Norman M.D., Gagan M.K., (2009) Sm-Nd, Sr, C and O isotopic systematics in hydrothermal calcite-fluorite veins: implications for fluid-rock reaction and geochronology, Chemical Geology, Vol 268, 58-66

Campbell G.P., Curran J.M., Miskelly G.M., Coulson S., Yaxley G.M., Grunsky E.C., Cox S.C., (2009) Compositional data analysis for elemental data in forensic science, Forensic Science International, Vol 188, 81-90.

Cardona A., Cordani U.G., Ruiz J., Valencia V.A., Armstrong R., Chew D., Nutman A., Sanchez A.W., (2009) U-Pb zircon geochronology and Nd isotopic signatures of the Pre-Mesozoic metamorphic basement of the eastern Peruvian Andes: Growth and provenance of a late Neoproterozoic to carboniferous accretionary orogen on the northwest margin of Gondwana, Journal of Geology, Vol 117, 285-305.

Cocherie A., Fanning C.M., Jezequel P., Robert M., (2009) LA-MC-ICPMS and SHRIMP U-Pb dating of complex zircons from Quaternary tephras from the French Massif Central: Magma residence time and geochemical implications, Geochimica et Cosmochimica Acta,Vol 73, 1095-1108.

Colombo F., Baldoa E.G.A., Casquet C., Pankhurst R.J., Galindo C., Rapela C.W., Dahlquist J.A., Fanning, C.M., (2009) A-type magmatism in the sierras of Maz and Espinal: A new record of Rodinia break-up in the Western Sierras Pampeanas of Argentina, Precambrian Research, Vol 175, 77-86.

Darrénougué N., De Deckker P., Fitzsimmons K.E., Norman M.D., Reed L., van der Kaars S., Fallon S., (2009) A late Pleistocene record of aeolian sedimentation in Blanche Cave, Naracoorte, South Australia, Quaternary Science Reviews, Vol 28, 2600-2615.

Del Rio P., Barbero L., Mata P., Fanning C.M. (2009) Timing of diagenesis and very low-grade metamorphism in the eastern sector of the Sierra de Cameros (Iberian Range, Spain): a U-pb SHRIMP study on monazite, Terra Nova, Vol 21, 438-445.

Figueiredo F.T., Paes de Almeida R., Tohver E., Babinski M, Dunyi Liu, Fanning C.M., (2009) Neoproterozoic glacial dynamics revealed by provenance of diamictites of the Bebedouro Formation, Saõ Francisco Craton, Central Eastern Brazil, Terra Nova, Vol 21, 375–385.

Foley S.F., Yaxley G.M., Rosenthal A., Buhre S., Kiseeva E.S., Rapp R.P., Jacob D.E., (2009) The composition of near-solidus melts of peridotite in the prescence of CO2 and H2O between 40 and 60 Kbar, Lithos, Vol 112S, 274-283.

Handler M.R., Baker J.A., Schiller M., Bennett V.C., Yaxley G.M., (2009) Magnesium stable isotope composition of Earth's upper mantle, Earth and Planetary Science Letters, Vol 282, 306-313.

Hodges M.K.V., Link P.K., Fanning C.M., (2009) The Pliocene Lost River found to west: Detrital zircon evidence of drainage disruption along a subsiding hotspot track, Journal of Volcanology and Geothermal Research, 188, 237-249.

Jenner F., Bennett V.C., Nutman A.P., Friend C.L.R., Norman M.D., Yaxley G., (2009) 3.8 Ga arc-like metabasalts from the southern edge of the Isua Supracrustal Belt: More geochemical evidence for Eoarchean plate tectonics, Chemical Geology, Vol 261, 82-97.

Jinnah Z.A., Roberts E.M., Deino A.L., Larsen J.S., Link P.K., Fanning C.M., (2009) New 40Ar-39Ar and detrital zircon U-Pb ages for the Upper Cretaceous Wahweap and Kaiparowits formations on the Kaiparowits Plateau, Utah: implications for regional correlation, provenance, and biostratigraphy, Cretaceous Research, Vol 30, 287–299.

Klein E.L., Luzardo R., Moura C.A.V., Lobato D.C., Brito R.S.C., Armstrong, R.A., (2009) Geochronology, Nd isotopes and reconnaissance geochemistry of volcanic and metavolcanic rocks of the São Luís Craton, northern Brazil: Implications for tectonic setting and crustal evolution, Journal of South American Earth Sciences, Vol 27, 129-145.

Liati A., Gebauer D., Fanning C.M., (2009) Geochronological evolution of HP metamorphic rocks of the Adula nappe, Central Alps, in pre-Alpine and Alpine subduction cycles, Journal of the Geological Society, London, Vol 166, 797–810.

Lineweaver C.H., Norman M.D., (2009) The bombardment history of the Moon and the origin of life on Earth, Proceedings of the 8th Australian Space Science Conference (Short W. and Cairns I., editors), 34-40.

Mendonidis P., Armstrong R.A., Grantham G.H., (2009) U-Pb SHRIMP ages and tectonic setting of the Munster Suite of the Margate Terrane of the Natal Metamorphic Belt, Gondwana Research, Vol 15, 28-37.

Miles N.G., West R.J., Norman M.D., (2009) Does otolith chemistry indicate diadromous lifecycles for five Australian river fishes?, Marine and Freshwater Research Vol 60, Number 9, 904-911.

Morton A., Hallsworth C., Strogen D., Whitham A., Fanning M., (2009) Evolution of provenance in the NE Atlantic rift: The Early-Middle Jurassic succession in the Heidrun Field, Halten Terrace, offshore Mid-Norway, Marine and Petroleum Geology Vol 26, Issue 7, 1100-1117.

Morton A.C., Hitchen K., Fanning C.M., Yaxley G., Johnson H., Ritchie J.D., (2009) Detrital zircon age constraints on the provenance of sandstones on Hatton Bank and Edoras Bank, NE Atlantic, Journal of the Geological Society, London, Vol 166, 137-146.

Myrow P.M., Hughes N.C., Searle M.P., Fanning C.M., Peng S.-C., Parcha S.K., (2009) Stratigraphic correlation of Cambrian–Ordovician deposits along the Himalaya: Implications for the age and nature of rocks in the Mount Everest region, GSA Bulletin, Vol 120, 323-332.

Norman M.D., Duncan R.A., Huard J.J., (2009) Imbrium Provenance for the Apollo 16 Descartes terrain: argon ages and geochemistry of lunar breccias 67016 and 67455, Geochimica et Cosmochimica Acta, Vol 764, 763-783.

Rajesh H.M., Mukhopadhyay J., Beukes N.J., Gutzmer J., Beyanin G.A., Armstrong R.A., (2009) Evidence for an early Archaean granite from Bastar craton, India, Journal of the Geological Society, Vol 166, 193-196.

Rosenthal, A., Foley, S.F., Pearson, D.G., Nowell, G.M., Tappe, S., (2009) Petrogenesis of strongly alkaline primitive volcanic rocks at the propagating tip of the western branch of the East African Rift, Earth and Planetary Science Letters, Vol 284, 236-248.

Siddoway C.S., Fanning C.M., (2009) Paleozoic tectonism on the East Gondwana margin: Evidence from SHRIMP U-Pb zircon geochronology of a migmatite-granite complex in West Antarctica, Tectonophysics, Vol 477, 262-277.

Solari L.A. Ortega-Gutiérrez F., Elías-Herrera M., Schaaf P., Norman M., Torres de León R., Ortega-Obregón C., Chiquín M., Morán Ical S., (2009) U-Pb zircon geochronology of Paleozoic units in Western and Central Guatemala: insights into the tectonic evolution of Middle America, In: The Origin and Evolution of the Caribbean Plate (James K.H., Lorente M.A. & Pindell J.L, editors). Geological Society, London, Special Publications 328, 293–311.

Suárez M., De La Cruz R., Aguirre-Urreta B., Fanning M., (2009) Relationship between volcanism and marine sedimentation in northern Austral (Aisén) Basin, central Patagonia: Stratigraphic, U-Pb SHRIMP and paleontologic evidence, Journal of South American Earth Sciences, Vol 207, 309-325.

Visiting Fellows

Arculus, R., Campbell, I. H., McLennan, S. M. and Taylor, S. R. (2009) Asteroids and andesites. Nature doi:10/1038/Nature 08077

Arne, D, House, E., Turner, G., Scott, K., Dronseika,E., (2009) Exploration for deeply buried gold deposits in the Bendigo region, Victoria, Australia: regolith geochemistry of the Lockington area. Proceedings 24th IAGS Fredericton 2009, 3-6.

Campbell, Kenton S.W. & Richard E. Barwick, 2009, A new group of fishes from the Gogo Formation, Western Australia.', 42pp, 27 Figures.

Campbell, K.S.W., Barwick, R.E. & Senden, T.J. 2009 Evolution of dipnoans (lungfish) in the Early Devonian of south eastern Australia. *Alcheringa* 33. 59-78. 04408

Colin Bull 2009 "Innocents in the Dry Valleys: an account of the Victoria University of Wellington Antarctic Expedition , 1958-59", Victoria University Press, 267 pp. 90 figs. 040399

Findlayson, D.M. 2009 A Geological Guide to Canberra Region and Namadji National Park. Published by the Geological Society of Australia, (Contributor to this volume). 04399

Klootwijk, C.T., (2009) Sedimentary basins of eastern Australia: palaeomagnetic constraints on geodynamic evolution in a global context. Australian Journal of Earth Science, Vol56, 273-308.

Mayer, W. 2009. Geological observations by the Reverend Charles P. N. Wilton (1795-1859) in New South Wales and his views on the relationship between religion and science, In: Kölbl-Ebert, M (ed.) Geology and Religion: A History of Harmony and Hostility, The Geological Society, London, Special Publications, Vol 310, 197-209.

Mayer, W. 2009. The geological work of the Baudin expedition in Australia (1801-1803): The mineralogists, the discoveries and the legacy, Earth Sciences History, Vol 28, 293-324.

Mayer, W. 2009. *Images in Stone: A Guide to the Building Stones of Parliament House*. Geological Society of Australia, ACT Division, Canberra.

Scott, K.M., Lorrigan A.N., (2009) Exploration for Zn-rich mineralisation in semi-arid environments: an example from the Cobar region, NSW, Australia. Proceedings 24th IAGS Fredericton 2009, 87-90.

Strusz, D.L. (2009) Silurian rhynchonellide brachiopods from Yass, New South Wales. Proceedings of the Linnean Society of New South Wales, 130, 139-146.

Taylor, S. R. and McLennan, S. M. (2009) *Planetary crusts: their composition, origin and evolution.* Cambridge Univ. Press 378 pp.

NEW Grants Commenced In 2009

Australian Research Council Grants

Discovery Project Grants

Dr. P. Tregoning: Tracking the response of terrestrial and ocean waters to climate variations using space gravity observations.
$480,000 (2009-2011)

Dr. H. Masahiko: The Cosmogenic 21Ne Exposure Dating Method: Calibration for Application to Volcanic Chronology, Landscape Evolution and Palaeo-Climate Change.
$97,500 (2009-2011) Led by University of Melbourne.

Dr. A. Hogg: Mixing and dissipation in the ocean: Processes for the next generation of climate models. $370,000 (2009-2011)

Dr. N. Rawlinson: Seismic tomography using signal and noise: A new window into deep Earth.
$300,000 (2009-2011)

Linkage Infrastructure Equipment & Facilities Grants

Dr. D. McPhail: Groundwater dynamics and surface water interactions in the Lower Murrimbidgee Catchment New South Wales.
$180,000 (2009-2011)

Dr. N. Rawlinson: 3D seismic velocity structure for geothermal exploration: a novel approach combining ambient and passive seismic methods.
$6,400 (2009-2011) Led by University of Tasmania.

Prof. G. Lister: Crustal Growth in the Northern Tasmanides.
$30,000 (2009-2011) Led by James Cook University.

Linkage International Grants

Dr. M. Gagan: A high performance stable-isotope microanalytical facility for environmental Earth science and climate change research.
$200,000 (2009)

Dr. S. Eggins: Instrumentation for Innovative Marine Biogeochemistry.
$1,016,500 (2009)

Future Fellowship Grants

Dr. G. Yaxley: Redox conditions in the earth's upper mantle and the implications for kimberlite petrigenesis formation and mantle metasomatism.
$686,400 (2009-2013)

Other Grants

Australian Synchrotron Company Ltd. Grants

Prof H. O'Neill: The effect of Kin the oxidation state of Cr in silicate mets and of pressure on Ni coordination.
$7,780 (2009)

Prof. H. O'Neill: X-ray fluorescence microprobe.
$1,415 (2009)

Prof. H. O'Neill: The oxidation state of Fe in melt.
$7,451 (2009)

Prof. R. Arculus: Hydrothermal plume and structural geology mapping in the Tonga/Fiji region.
$2,540,000 (2009)

Dr. N. Rawlinson: Eastern Australia Linkage (EAL) seismic tomography survey.
$150,000 (2009-2011)

Commonwealth Department of Innovation Industry Science and Research Grants

Prof. M. Sambridge: A new approach for imaging the Earth's interior.
$22,000 (2009-2012)

NATIONAL AND INTERNATIONAL LINKS 2009

COLLABORATION WITH AUSTRALIAN UNIVERSITIES, CSIRO & INDUSTRY

Earth Chemistry

Dr Y. AMELIN, with Dr. I. Metcalfe (University of New England) and Dr. R. Nicoll (Geoscience Australia) on the timescale of Permian-Triassic transition in Australia.

Dr J.J. BROCKS, with Prof S. George and S. Bray (Macquarie University), The organic geochemistry, geochronology and microbial history of saline Lake Tyrrell in outback Victoria.

Dr J.J. BROCKS, with Prof B. Rasmussen (Curtin University of Technology), The carbon isotopic composition of Precambrian organic matter and the syngeneity of ancient biomarkers.

Dr J.J. BROCKS, with Prof A. Cooper (University of Adelaide), The preservation of lipids, proteins and DNA in the Devonian Gogo Fish.

Dr J.J. BROCKS, with Dr J. Moreau, Dr. S. McLaren (Melbourne University), Dr D. Gleeson, Dr J. Cliff and Dr M. Kilburn (University of Western Australia), Seafloor clay mineral diagenesis and seismicity in the Nankai Trough Subduction Zone: a microbially-mediated process?

Dr J.J. BROCKS, with Mr R. Schinteie (RSES, ANU) and Dr G. Halverson (University of Adelaide), The geochemical and biological evolution of the oceans in the Neoproterozoic.

Dr J.J. BROCKS, with Prof Patrick De Deckker (RSES, ANU), Dr Gwen Allison and Chris Munday (BamBi, ANU), Biomarkers in Australian Dust and Desert Crusts

Professor I.H. Campbell and Dr C. Allen, with Professor R. Cass and Dr R. Squire, (Monash University); Understanding the stratigraphic and structural architecture of late Archean basins and the context of their gold deposits.

Professor I.H. Campbell and Dr C. Allen, with Dr A. Harris (University of Tasmania); U-Pb dating of felsic intrusions from Cadia NSW.

Professor I.H. Campbell and Dr C. Allen, with Dr A. Harris (University of Tasmania) and Newcrest Mining; U-Pb dating, O and Hf and Ce 4+/3+ measurements of zircons from felsic intrusions associated with major porphyry Cu-Au deposits.

Professor I.H. Campbell, with Dr W.D. Maier of the University of Western Australia and Dr S.J. Barnes of the CSIRO on the platinum group element geochemistry of komatiites.

Dr. S.J. FALLON, with Dr. R. Thresher (CSIRO, Climate from Deep Sea Corals); M. Cheetham (Southern Cross University, history of rainfall in N. Queensland); Dr. J. Lough (Australian Institute of Marine Science, climate records from tropical corals); Dr. E. Krull (CSIRO, history of Coorong Delta); Dr. L. Wallis (Flinders University, dating of Coorong settlement); Dr. L. Reed (Flinders Universtiy, Vegetation history of Naracoorte Cave region); Prof. A. Cooper (Adelaide University, Dating of fossils for ancient DNA analysis.

Dr M.A. FORSTER, with Dr K. Dadd (Macquarie University, N.S.W.) for geochronology of oceanic basalts emplacement age;

Dr M.A. FORSTER, with Dr W. Collins (James Cook University, Qld) for geochronology of movement zones in 'Far North' Queensland, Australia.

Dr M.A. FORSTER, with TANG3O (Thermochronology and Noble Gas, Geochronology and Geochemistry Organisation): involving collaboration with University of Queensland, University of Melbourne, University of Western Australia, Curtin University and The Australian National University.

Dr M. Honda, with A/Prof D. Phillips (The University of Melbourne) and Prof A. Chivas (The University of Wollongong), Continuation of collaboration on cosmogenic noble gas studies in young basalts; A/Prof D. Phillips (The University of Melbourne), Continuation of collaboration on noble gas studies in diamonds; Dr M. Kendrick (The University of Melbourne), Continuation of collaboration on noble gas studies in ore-forming minerals.

Prof T.R. IRELAND continued collaborations with Australian Scientific Instruments, Geoscience Australia, Dr P. Vasconcelos (University of Queensland), Dr P. Carr & Dr C Fergusson (University of Wollongong), Dr G. Clarke (University of Sydney), Dr R. Large and Dr G. Davidson (University of Tasmania), Dr J Hellstrom (University of Melbourne), Dr A. Kennedy and Dr P. Kinny (Curtin University), and Dr B. McInnes (CSIRO), SHRIMP SI Project.

Prof T.R. IRELAND, with Dr P. Vasconcelos, University of Queensland, Chief Investigator of ARC grant "Investigating the structure and evolution of the Continental Crust: A Virtual Facility for thermochronology, noble gas geochemistry and geochronology".

Dr C.H. Lineweaver, with Dr T. Davis, University of Queensland on misconceptions about the big bang, energy conservation in cosmology and the relationship between entropy and gravity.

Emeritus Professor I. McDougall, with Dr P. Vasconcelos, Earth Sciences, University of Queensland, in relation to further precise dating of the hominin-bearing stratigraphic sequences in the Turkana Basin, northern Kenya and southern Ethiopia.

Dr R. SALMERON, with Prof. M. Wardle (Physics Department, Macquarie University) and A/Prof. Z. Kuncic (The University of Sydney), on the structure and dynamics of star-forming accretion disks.

Mr R. Schinteie, with thesis co-advisors Dr. E. Grosjean, (Geoscience Australia, Canberra), and Dr G. Halverson (University of Adelaide).

Dr I.S. WILLIAMS, with Australian Scientific Instruments – SHRIMP development and marketing, and Prof B.W. Chappell (University of Wollongong) – granite geochemistry.

Earth Environment

Dr M. AUBERT collaborates with Prof Paul S.C. Taçon, (Griffith University) on the dating of Chinese rock art.

Dr L. K. AYLLIFFE collaborates with Dr G. J. Prideaux (Flinders University), Dr J Hellstrom (University of Melbourne), Dr R. N. Drysdale (University of Newcastle), Dr J-x Zhao (University of Queensland)

Mr. N. DARRENOUGUE collaborates with Dr Daniel Ierodiaconou, Deakin University, Warrnambool (Vic) helped organise and will participate in a fieldtrip planned in Victoria in 2010.

Prof. P. De Deckker collaborates with Dr. J. Reeves of RMIT on groundwater ostracods in the Pilbara region. He also collaborated with Ass. Prof. I. Goodwin from Macquarie University and Dr A. Wain form the Bureau of Meteorology on the transport of Australian dust over the last 150,000 years to Antarctica.

Prof. P. De Deckker collaborates with Dr. G. Alison of the ANU Medical School on the microbiology of aerosols and with Prof. N. Tapper and Dr T. O'Loinsigh of Monash University on climatological conditions that lead to dust deflation and transport.

Dr A. DUTTON collaborates with Prof M. McCulloch (University of Western Australia on last interglacial fossil reefs in Western Australia.

Dr A. DUTTON collaborates with Dr S. Smithers (James Cook University), Dr C. Woodroffe (University of Wollongong) on Holocene Sea Level in the Australian Region.

Dr A. DUTTON collaborates with Dr J.M. Webster (University of Sydney) on last interglacial sea level records from the Seychelles and Hawaii.

Dr S.M. EGGINS and Dr. C. ALIBERT with Dr C. Chague-Goff (University of New South Wales), Trace metal proxies for environmental change in *Nothofagus* spp. tree cores from New Zealand.

Dr S.M. EGGINS, Dr. M. ELLWOOD and Mr G. NASH with Prof. W. Maher (University of Canberra) and others on heavy metal cycling in Lake Macquarie, NSW.

Dr S.M. EGGINS collaborates with Dr B. Landenberger (University of Newcastle) on the isotopic evolution of granodiorites from the Barrington Tops region.

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

Dr K. FITZSIMMONS collaborates with Dr N. Stern (La Trobe University) and Prof. R. Grün (ANU), on human-environmental interactions in the Willandra Lakes World Heritage Area.

Dr K. FITZSIMMONS collaborates with Prof. J.M. Bowler (University of Melbourne), Prof. P. Veth (ANU), Prof. M. Smith (National Museum of Australia), Dr J.W. Magee (ANU), Prof. N. Spooner (University of Adelaide) on human-environmental interactions at Mulan, northwestern Australia.

Dr K. FITZSIMMONS collaborates with Dr H. Timmers and Mr J. Warner (UNSW@ADFA) on radioactive system disequilibrium for luminescence dating.

Dr K. FITZSIMMONS collaborates with Dr J. Brocks (ANU) and Mr S. Bray (Macquarie University) on high resolution palaeoenvironmental reconstruction at Lake Tyrrell, semi-arid zone.

Dr K. FITZSIMMONS collaborates with Dr A. Keene and Mr M. Cheetham (Southern Cross University) on fluvial geomorphology in eastern Australia.

Dr K. FITZSIMMONS collaborates with Dr M. Reid (University of Canberra) on fluvial ecosystem change in southeastern Australia.

Dr K. FITZSIMMONS collaborates with Dr L. Wallis (Flinders University/University of Queensland) on human colonization of northern Australia.

Dr K. FITZSIMMONS collaborates with Mr D. Horne (UNSW@ADFA) on coastal dune development and sea level change in northern Australia.

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

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

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

Dr J. MALLELA collaborates with Prof. Malcolm McCulloch, University of Western Australia (UWA) and researchers in the ARC Centre of Excellence Coral Reef Studies, on a range of coral reef projects. The Centre 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), The University of Queensland (UQ) and most recently the University of Western Australia (UWA).

Dr J. MALLELA collaborates with Prof. Malcolm McCulloch (UWA), Drs Steve Lewis (JCU) and John Brody (JCU), Dr J Lough (AIMS), Dr A Decker (CSIRO) and scientists at GBRMPA on the effects of changing land-use, river runoff and climate change on reefs in the central Great Barrier Reef using traditional and novel geochemical techniques (LA-ICPMS) to assess how changes in land use influence water quality and subsequent reef calcification. This work is supported by the Marine and Tropical Science Research Facility (MTSRF).

Mr I. MOFFAT collaborated with Dr Lynley Wallis (University of Queensland) and Rob Koch (TAFESA) on a project focused on the geophysical detection of heat retainer hearths in Northwest Queensland.

Dr B.N. OPDYKE and Dr. S. EGGINS collaborate with Dr D. Kline, Prof. O. Hoegh-Guldberg (University of Queensland) and others on the ARC LIEF funded The Heron Island Climate Change Observatory

Dr B.N. OPDYKE collaborates with Dr. J. Lough & Dr. K. Burns at the Australian Institute of Marine Science

Dr B.N. OPDYKE collaborates with Dr. L. Collins at Curtin University.

Dr B.N. OPDYKE collaborates with Dr. Gregg Webb at the Queensland Institute of Technology.

Prof B.J. PILLANS with Prof M.A.J. Williams (University of Adelaide) and Prof R. Bourman (University of South Australia) on landscape evolution in southern South Australia.

Prof B.J. PILLANS with Dr B. Kohn (University of Melbourne) on apatite fission track thermochronology and landscape evolution in the Tanami Desert.

Prof B.J. PILLANS with Dr M. Paine (Rio Tinto Iron Ore) on weathering profiles on Marra Mamba and Brockman Iron Formations, Pilbara region, Western Australia

Ms J SUTTON collaborates with Alan Williams and Monika Schlacher-Hoenlinger for Tasmanian sponge material collect on Southern Surveyor voyage SS0207. Financial Support for this voyage was through the Australian Government Department of Environment, Water, Heritage and the Arts, the CSIRO Wealth from Oceans Flagship, and Australia's Marine National Facility vessel. Funding to facilitate the collection of the East Antarctic sponges was from the Australian Antarctic Division and two Australian Research Council grants DP0770820 and DP0771519.

Miss C.M. THOMPSON collaborates with supervisors Dr M. Ellwood (ANU) and Dr M. Wille (ANU) on copper measurement in seawater.

Dr. M. WILLE collaborates with Prof. William Maher (University of Canberra)

Dr G. YOUNG collaborates with Dr John Long (Museum Victoria).

Dr G. YOUNG collaborates with Drs I. Percival, J. Pickett and L. Sherwin (NSW Geological Survey).

Dr G. YOUNG collaborates with Dr E. Papp (Papp Geophysical Survices).

Dr G. YOUNG collaborates with Dr C. Burrow (Queensland Museum).

Dr G. YOUNG collaborates with Dr K. Trinajstic (Curtin University).

Dr G. YOUNG collaborates with Dr Yong-Yi Zhen and Mr R. Jones (Australian Museum).

Earth Materials & Processes

Prof R.J. ARCULUS collaborates with Drs C Yeats and J Parr (CSIRO), Ass. Prof D Gust (Queensland University of Technology), Dr K Knesel (University of Queensland), Prof S Turner (Macquarie University),
Dr K J A Wills (Maximus Resources) and staff of the West Australian Geological Survey.

Dr A.G. CHRISTY is collaborating with Prof. M.A. Knackstedt and other members of the Applied Mathematics Department, RSPhysE, ANU, on the origins of acoustic wave anisotropy in reservoir sandstones.

Dr A.G. CHRISTY is collaborating with Dr. J. Brugger (South Australian Museum, Adelaide) on thermodynamic modelling of sulfide-arsenide solid solutions.

Dr A.G. CHRISTY is collaborating with Dr. L. Puskar and Dr M. Tobin (Australian Synchrotron, Melbourne) on infrared studies of minerals at high pressure in the diamond anvil cell.

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

Dr A. Halfpenny collaborates with Dr D.R. Cooke at the University of Tasmania, Centre of Excellence for Ore Deposits, Hobart

Dr J. HERMANN collaborates with Dr C. Spandler (James Cook University, Townsville), on element recycling in subduction zones.

Dr J. HERMANN collaborates with Dr C. Gregory (Curtin University, Perth) on the timing of Barrovian metamorphism in the Central Alps.

Prof I. JACKSON collaborated with R.P. Wang (RSPSE, ANU) and Z.H. Stachurski (Dept. of Engineering, CECS, ANU).

Prof G. LISTER collaborated with Prof Hans Mulhaus (University of Queensland), Prof. William Collins and Dr Simon Richards (James Cook University).

Dr L. MARTIN collaborates with Pr. S. Turner and Dr T. Rushmer (Macquarie University, Sydney), on element recycling in subduction zones.

Dr D.C. "BEAR" McPHAIL collaborates with Prof J. Brugger of Adelaide University and the South Australian Museum in the study of gold chemistry;

Dr D.C. "BEAR" McPHAIL collaborates with Dr S. Wakelin of CSIRO Land & Water on a successful proposal to study uranium isotope geochemistry;

Dr D.C. "BEAR" McPHAIL collaborates with Dr W. McLean of Parsons Brinckerhoff (Sydney) in the study of groundwater dynamics in the Lower Murrumbidgee catchment;

Dr D.C. "BEAR" McPHAIL collaborates with Dr P. de Caritat of Geoscience Australia in the study of hydrogeochemistry for mineral exploration and regolith geochemistry; and

Dr D.C. "BEAR" McPHAIL collaborates with Dr P. Polito of Anglo American (Perth) in the study of hydrogeochemistry and regolith geochemistry for mineral exploration.

Dr. NEBEL collaborated with Dr. J. Woodhead, University of Melbourne, on the Hf isotope budget of the Island of Mangaia, as part of the Austral-Cook hotspot chain, to investigate the deep mantle origin of HIMU OIB.

Mr L. T. WHITE collaborates with Dr P. Lennox (UNSW) on mapping the extent and studying the nature of shear zones in the Wyangala Batholith, eastern Lachlan Fold Belt, NSW.

Earth Physics

Prof R.W. GRIFFITHS, Dr G.O. HUGHES and Ms M. O'BYRNE with Prof J. Middleton (University of New South Wales) on wake flows in coastal oceans, funded by a joint ARC Discovery grant.

Prof R.W. GRIFFITHS and Dr G.O. HUGHES with Prof. K. Lovegrove (Centre for Sustainable Energy Systems, ANU) on convective flows in solar thermal systems.

AuScope

A large reflection experiment with full crustal penetration was carried at the end of 2008 in central Australia with 200 km of the 580 km traverse supported by AuScope Earth Imaging funding through RSES. In November 2009 nearly 200 km of crustal reflection sounding was carried out across the Delamerian form Western Victoria into South Australia linking together older surveys to provide nearly continuous profiling across the Delamerian and southern Lachlan. Again this experiment was coordinated from RSES.

Dr. N. RAWLINSON collaborates with Geoscience Australia, New South Wales Geological Survey, University of Tasmania and Monash University.

Dr M.L. RODERICK with Mr Randall Donohue, Mt Tom VanNeil, Dr Tim McVicar of CSIRO, Hydrologic impacts of climate change.

Prof. M. SAMBRIDGE with Dr. Anya Reading (Univ. Tasmania) on nonlinear inversion methods and their applications across the Earth Sciences.

Prof. M. SAMBRIDGE and Prof. B.L.N. KENNETT with Prof. Klaus Regenaur-Lieb on forming a new.

Dr H TKALČIĆ with Dr. A. Reading (University of Tasmania) on using Antarctic data for studying the deep earth structure, and Dr A. Gorbatov of Geoscience Australia on the determination of seismic sources in Australia and surroundings using Geoscience Australia stations.

Dr P. TREGONING, with Prof. R. Coleman and Drs C. Watson and Dr R. Burgette (University of Tasmania), Professor W. Featherstone, Dr K. Fleming and Dr M. Kuhn (Curtin University of Technology), Dr M. Leblanc (James Cook University) and Drs J. Church, A. vanDijk and L. Renzullo (CSIRO).

Australian National Seismic Imaging Resource (ANSIR) Research Facility in Earth Sounding

Prof B.L.N. KENNETT is Director of ANSIR which continues as a National Research Facility, as a joint venture between The Australian National University, Geoscience Australia and the University of Adeliade, linking to the Earth Imaging component of AuScope. RSES supports the portable seismic instruments.

The ANSIR portable equipment is available via a competitive proposal scheme with support in 2009 for broadband instruments in Central Australia and short-period experiments in NSW and Tasmania

Integrated Ocean Drilling Program (IODP)

The Australian IODP Office (AIO) was established at RSES in 2008. The Australian Research Council, fourteen Universities, three Government Agencies, and a marine geoscience peak body (MARGO) provide funding for Australia's membership of the Integrated Ocean Drilling Program (IODP), a major international program. Naturally, the office has collaborated with a great number of individuals in Universities, Government agencies and foreign agencies.

PRISE

Dr R.A. ARMSTRONG collaborated with Dr I. Graham (University of NSW) on megacrystic zircons from Cenozoic intraplate basalts along the Indo-Pacific continental margins; Dr L. Shewan (University of Sydney) on studies of human mobility on Archaeological sites from Cambodia; Professor D. Phillips and Dr Bin Fu (University of Melbourne) on constraining the timing of metamorphism and hydrothermal alteration using monazite and xenotime; Dr Malcolm Roberts (Marengo Mining Ltd) on the geochronology of the Yandera region, Papua New Guinea; Dr M. Doyle (AngloGold-Ashanti) on geochronology of granite and gneiss.

Mr C.M. FANNING collaborated with Dr S. Boger (University of Melbourne) on the timing and tectonic evolution of Madagascar and Morocco; Professor G. Clarke (Sydney University) on the timing and tectonic evolution of Cordillera Darwin, Tierra del Fuego.

Mr S. HUI collaborated with Dr Fred Jourdan (Western Australia Argon Isotope Facility, Curtin University) on 39Ar-40Ar dating of Lunar Impact Spherules.

Ms E. KISEEVA collaborated with Prof V. Kamenetsky (CODES and School of Earth Sciences, University of Tasmania) and Dr R. Maas (University of Melbourne) on investigations of early melting of eclogite xenoliths from kimberlite pipes.

Dr M.D NORMAN collaborated with Prof. M. Walter (University of New South Wales), Dr. A. Nemchin &
Dr F. Jourdan (Curtin University), Ms. F. Best (University of Tasmania), Dr. N. Miles & Prof. R. West (University of Wollongong), and Mr. M. Smith (CSIRO).

Ms A. ROSENTHAL collaborated with Prof. David H. Green (CODES, University of Tasmania) on the role of water and of melting in the upper mantle at pressures to 6 GPa; Dr Terry Mernagh (Laser Raman Spectroscopy, Geoscience Australia) on ongoing studies of minor amounts of H_2O in melts of residual eclogite.

Dr G.M. YAXLEY collaborated with Prof V. Kamenetsky (University of Tasmania) and Dr G. Nichols (Macquarie University) on petrological and geochemical studies of igneous rocks with carbonatitic-kimberlitic affinities from the Prince Charles Mountains, Antarctica; Dr C. Spandler (James Cook University) on a high pressure experimental investigation of melting of recycled pelite in the upper mantle.

Visiting Fellows

Dr R. V. Burne collaborates with Prof. Brenton Knott, Department of Zoology, University of Western Australia, Dr Jenny Bevan, E. de C. Clarke Earth Science Museum, University of Western Australia, and Prof. Bruce Henry, Department of Mathematics, University of New South Wales.

Dr E. A. Felton is working with Dr D. Fink of the Australian Nuclear Science and Technology Organisation and Dr K. A. W. Crook, Earth and Marine Sciences, RSES, ANU on cosmogenic age dating of rock coastal geomorphic features.

Dr C Klootwijk collaborates with Dr P.W. Schmidt (CSIRO) and Dr B. Musgrave (NSWGS) as guest editors for a special volume on paleomagnetism and rock magnetism for the Australian Journal of Earth
Sciences.

KEITH SCOTT with CSIRO Exploration and Mining and MMG Ltd (David Wallace).

INTERNATIONAL COLLABORATION

Earth Chemistry

Dr Y. AMELIN, with Dr. C. Stirling, Otago University, NZ, on detecting small uranium isotopic variations in nature and evaluating their origin and significance

Dr Y. AMELIN, with Dr. A. Krot, University of Hawaii, USA, on the origin of chondrites and their parent asteroids

Dr Y. AMELIN, with Prof. S. Jacobsen, Harvard University, USA, on chronology of the Solar System's oldest solids.

Dr Y. AMELIN, with Dr. K. Kossert, Physikalisch-Technische Bundesanstalt, Germany, on determination of half-lives of short-lived isotopes.

Ms. Janaina N. Ávila, with Prof. E. Zinner, Dr. S. Amari and Mr. F. Gyngard, Laboratory for Space Sciences, Washington University, St. Louis, USA, and Dr. M. Lugaro, Centre for Stellar and Planetary Astrophysics, Monash University, Australia, on the study of heavy elements on presolar silicon carbide grains, and with Dr. P. Heck, University of Wisconsin, Madison, USA, on the study of interstellar residence times of presolar silicon carbide grains.

Dr. V.C. Bennett, with Dr A. Brandon, NASA-Johnson Space Center, on developing high precision isotopic methods to reconstruct the early histories of the Earth and Moon.

Dr V.C. Bennett, with Dr A.P. Nutman and Dr Wan Yusheng, Chinese Academy of Geological Sciences, Beijing, on studies of the oldest rocks sequences of the North China Craton.

Dr J.J. BROCKS with Prof J. Banfield, Claudia Jones (UC Berkeley), Dr K. Heidelberg (University of Southern California), Prof E. Allen (UC San Diego), Prof E. Roden (University of Wisconsin in Madison), Lipidomics and metagenomics of saline Lake Tyrrell, Victoria.

Dr J.J. BROCKS with Prof N. Butterfield, Ms M. Pawlowska (University of Cambridge) and Mr R. Schinteie (RSES, ANU), The Paleontology and organic geochemistry of Mesoproterozoic successions from Russia, and Molecular Taphonomic Models of the Proterozoic.

Dr J.J. BROCKS with Dr P. Wynn (Lancaster University), Molecular fossils and elemental iodine in Stalagmites.

Dr J.J. BROCKS with Dr A. Lepland (Geological Survey of Norway), Biomarkers in Palaeoproterozoic cores from the FAR DEEP project.

Dr J.J. BROCKS with Prof I. Fairchild (University of Birmingham), Biomarkers in Stromatolites of the Neoproterozoic Draken Formation.

Professor I.H. Campbell and Dr C. Allen, with Professor J. Gill (University of California at Santa Cruz); zircon age patterns from sandstones of Fiji, and their and oxygen and hafnium isotope composition

Professor I.H. Campbell and Dr C. Allen, with Professor Barbara Nash and Dr Henrietta Cathey (University of Utah); age, and oxygen and hafnium isotope composition of zircon from ancient Yellowstone volcanic centres

Professor I.H. Campbell and Dr C. Allen, with Dr Scott Bryan (University of Queensland/Kingston University, London) and Mr Aldo Ramos (Kingston University); age and inheritance history of zircons from the Sierra Madre Occidental.

Professor I.H. Campbell and Dr C. Allen, with Professor Wei Tian (Peking University) on the geochemistry of mafic and felsic volcanic rocks from the Tarim flood basalt.

Ms T.A. EWING, with Dr R. Anczkiewicz, Institute of Geological Sciences, Polish Academy of Sciences, on the accuracy of Hf isotope measurements on rutile by LA-MC-ICPMS.

Dr. S.J. Fallon, with Dr. B. Roark (Texas A&M) , Prof. R. Dunbar (Stanford University) and Dr. T. Guilderson (Lawrence Livermore National Laboratory) on climate records from North Pacific Deep Sea Corals; Dr. L. Skinner on ocean overturning from deep sea sediment cores; Drs. P. Montagna, S. Silenzi (ICRAM, Italy) on Mediterranean sea level and radiocarbon reservoir ages; Dr. O. Sherwood (Memorial University, on dating and climate from deep sea corals.

Dr M.A. FORSTER, with Prof T. Ahmad (Delhi University, India) on geochronology of the NW Himalaya; Dr M. Cottam (Royal Holloway College, University of London, UK) on the timing of exhumation structures in SE Asia (Borneo and Sulawesi); Prof Papanikolou and co-workers (the National University of Athens, Greece) on the exhumation of ophiolites Greece; Prof R. Compagnoni and Dr C. Groppo (Torino University, Italy) on the evolution of the evolution of the Cycladic HP belt Greece.

Dr M. Honda, with Dr J. Harris (The University of Glasgow, UK) and Dr T. Matsumoto (Okayama University, Japan), Continuation of collaboration on noble gas studies in diamonds.

Professor T.R. IRELAND, with Prof T.M. Harrison, Department of Earth and Space Sciences, UCLA, USA.

Dr C.H. Lineweaver, with Prof P.C.W. Davies, Beyond Center, Arizona State University and with Prof. C. McKay NASA Ames, on efforts to find alternative or “shadow” life on Earth.

Dr C.H. Lineweaver, with Prof. D. Schwartzman, Geology and Geochemistry, Howard University, on the thermal history of the Earth on a billion year timescale.

Emeritus Professor I. McDougall, with Professor F. Brown, Earth Sciences, University of Utah on the stratigraphy and collection of suitable materials for isotopic dating in the hominin-bearing stratigraphic sequence in the Turkana Basin, northern Kenya and southern Ethiopia.

Mr. Seann McKibbin, with Professor Naoji Sugiura on inter-laboratory reproducibility of determinations of Mn-Cr systematics in angrite meteorites.

Dr R. SALMERON, with Prof. A. Konigl (Department of Astronomy & Astrophysics and Enrico Fermi Institute, The University of Chicago), on wind-driving protostellar disks.

Dr R. SALMERON, with Dr. C. Tassis (Department of Astronomy & Astrophysics, The University of Chicago) on dust dynamics.

Dr R. SALMERON, with Professor C. Dullemond (University of Heidelberg), on radioactive transfer and dust dynamics.

Mr R. Schinteie, with M.M. Pawlowska, Department of Earth Sciences, Cambridge University, UK, on biomarkers of fossil-bearing Mesoproterozoic sedimentary rocks.

Mr A. Stepanov, with Dr A. Korsakov, Institute of Geology and Mineralogy, Novosibirsk, on the study of rocks from the Kokchetav UHP complex.

Dr I.S. WILLIAMS and Prof R.W.R. RUTLAND, with Dr J. Kousa (Geological Survey of Finland). The evolution of the Svecofennian orogen.

Dr I.S. WILLIAMS, with Dr J. Wiszniewska and Dr E. Krzeminska (Polish Geological Institute, Warsaw). The evolution of the basement beneath the East European Platform in Poland.

Dr I.S. WILLIAMS, with Dr S. Mikulski (Polish Geological Institute, Warsaw). Genetic models of gold mineralization in the Sudetes—the geochronology of tectonic processes within the European Variscides.

Dr I.S. WILLIAMS, with Dr J. Nawrocki (Polish Geological Institute, Warsaw). The chronology of Cainozoic mafic magmatism, King George Island, Antarctica.

Dr I.S. WILLIAMS, with Dr M. Kusiak (Polish Geological Institute, Warsaw). Emplacement history of the composite Karkonosze pluton, NE Bohemian Massif.

Dr I.S. WILLIAMS, with Dr Kim Sung Won (Kyungpook National University, Daegu, South Korea). The timing of thermal events in South Korea and South China.

DR I.S. WILLIAMS, with Dr P. Fiannacca and Mr. P. Stella (University of Catania, Sicily). Age, sources and metamorphic history of para- and augen gneisses from the Peloritani Mountains, Sicily.

Earth Environment

Dr M. AUBERT collaborates with Prof Ji Xueping (Yunnan Institute of Cultural Relics and Archaeology), China on the dating of Chinese rock art.

Dr L. K. AYLIFFE collaborates with Dr T.E. Cerling (University of Utah), Dr B. H. Passey (Johns Hopkins University).

Mr. N. DARRENOUGUE collaborates with Dr. C. Payri and Dr. G. Cabioch from the IRD (Institut de Recherche pour le Développement), Nouméa (New Caledonia) who helped with the fieldtrip campaign in Nouméa (October 09).

Prof. P. De Deckker is continuing his collaboration with colleagues from Germany [Dr J.-B. Stuut and Prof K.-U. Hinrichs for the University of Bremen and Drs D. de Beer and R. Abed from the Max Plank Institute of Marine Microbiology] on the geochemical and microbiological fingerprinting of Aeolian dust.

Prof. P. De Deckker collaborates with Ass. Prof. Y. Yokoyama from the University of Tokyo and recently completed a manuscript on micropalaeontological evidence for sea level changes in Bonaparte Gulf.

Prof. P. De Deckker completed a collaborative project with Dr S. Schmidt of the University of Bordeaux on sediment transport in deep-sea canyons.

Prof. P. De Deckker collaborates with Mr T. Russon on a superb record a long deep-sea cores from offshore New Caledonia, and this is in collaboration with Dr G. Cabioch of the IRD in France and Prof. T. Corrège from the University of Bordeaux.

Dr A. DUTTON collaborates with Dr E. Bard, (CEREGE, France), Dr F. Antonioli (ENEA, Italy), on dating submerged speleothems from Argentarola Cave, Italy.

Dr A. DUTTON collaborates with Dr F. Antonioli (ENEA, Italy), Dr C. Monaco (University of Catania), and G. Scicchitano (University of Catania) on dating submerged speleothems from Sicily.

Dr A. DUTTON collaborates with Dr R.M. Leckie, Dr S. Burns, and S. Dameron (University of Massachusetts) on abrupt changes in ocean circulation during the early Eocene climatic optimum.

Dr A. DUTTON collaborates with Dr P. Pearson (Cardiff University, UK) , Dr T. Bralower (Penn State University, USA), and Dr B. Wade (Texas A&M University, USA) on diagenesis in Eocene tropical planktonic foraminfera.

Dr A. DUTTON collaborates with Dr C. Stirling (Otago University, New Zealand) on dating last interglacial corals from the Cape Range Peninsula, WA.

Dr S.M. EGGINS collaborates with Prof. H. Spero, Dr A. Russell and Dr. B. Höenisch, and Ms. K. Allen (LDEO, Columbia University, USA), on the calcification of planktic foraminifers under elevated pCO2 and modified seawater Mg-Ca compositions relevant to ancient and future oceans.

Dr S.M. EGGINS collaborates with Dr. G. Dunbar and Ms. A. Bolton (Victoria University of Wellington, NZ), on the calibration of Mg/Ca seawater thermometers for *Neogloboquadrina pachyderma* and analysis of down-core and core-top records from the southern oceans.

Dr S.M. EGGINS collaborates with Dr A. Sadekov (University of Edinburgh, UK) on the effects of seafloor dissolution and of salinity on foraminiferal Mg/Ca palaeo-seawater thermometry.

Dr S.M. EGGINS collaborates with Prof. J. Bijmé and students (Alfred Wegner Institute, Bremerhaven, Germany) on aspects of Mg and other trace element incorporation into shallow benthic and planktic foraminifers.

Dr S.M. EGGINS, Mr G. NASH and Prof. P DE DECKKER with Prof. A. Rathburn (Indiana State University, USA) on heavy metal uptake by benthic foraminifers.

Dr. S.M. EGGINS, Dr. M.J. ELLWOOD, Dr. M. WILLE, and Ms. A. DE LEON with Dr M. Kelly (NIWA, NZ) on the boron geochemistry of siliceous sponges.

Dr M.J. ELLWOOD collaborates with Dr. Michelle Kelly (NIWA, NZ) on Understanding the growth habits of deep sea sponges, with Dr. Philip Boyd (NIWA, NZ) and Dr. Cliff Law (NIWA, NZ) on Trace element cycling in the Tasman Sea, with Dr Derek Vance (University of Bristol, UK) on isotope fractionation in diatoms and zinc isotopes in oceanic waters.

Dr K.E. FITZSIMMONS collaborates with Dr T.T. Barrows (University of Exeter) on high resolution geochronology and palaeoenvironmental reconstruction in the southeastern Australian highlands and Australian semi-arid zone.

Dr K.E. FITZSIMMONS collaborates with Prof G.A.T. Duller (Aberystwyth University), Dr H.M. Roberts (Aberystwyth University) and Prof A. Wintle (Aberystwyth University) on development of thermally-transferred OSL dating techniques.

Dr K.E. FITZSIMMONS collaborates with Prof. G.H. Miller (University of Colorado, Boulder) on comparison of aridity proxies (with Dr J.W. Magee, ANU), and monsoon influence on the north Australian arid zone.

Prof R. GRÜN collaborated with Prof C. Falgueres, Dr J.J. Bahain and other staff members of the the Département de Préhistoire du Musée National d'Historie Naturelle, Paris, on the further development of dating techniques and he co-supervised Mr M. Duval, who visited the ANU to carry out ESR and isotopic measurements for his PhD work.

Prof R. GRÜN collaborates with Drs D. Grimaud-Hervé and M.H. Moncel on the application of new systems on Neanderthal remains.

Prof R. GRÜN collaborates on isotopic applications with Prof B. Maureille, Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1, on the sites of Les Predelles, La-Chapelle-aux-Saints, La Piage, Les Fieux, and Rescoundudou where Mr. I. Moffat will carry out aspects of his PhD studies. For this collaboration, he was invited as visiting Directeur de recherches at the Institut des Sciences humaines et sociales du CNRS, Bordeaux.

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), Broken Hill, Omo 1, Wadjak, Iwo Eleru (Prof C.B. Stringer, Natural History Museum, London).

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 collaborates with Prof S. Brandt (University of Florida), Prof M. Rodrigo (University of Madrid), Prof J. Richter (Universität zu Köln), Prof G. Barker (University of Cambridge) for the dating work in Africa.

Prof R. Grün collaborates with the Institute of Geology, China Earthquake Administration, Beijing, on the dating of elevated river terraces for the reconstruction of elevation rates in the Himalayas as well as using paramagnetic centres in quartz for the calculation of cooling rates in the Pamir. He was made a Visiting Professor to ensure long term collaboration.

Prof R. Grün continues his collaboration with Dr A. Pike, Department of Archaeology, University of Bristol, on uranium uptake of bones

Prof R. Grün continues his collaboration with 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.

Ms S.C. LEWIS visited Dr A. LeGrande, Dr M. Kelley and Dr G. Schmidt at NASA Goddard Institute for Space Studies, New York, 12 June to 9 September.

Dr J. MALLELA collaborates with Prof. Malcolm McCulloch (UWA), Dr S Hetzinger, Dr J Halfar (Uni. of Toronto, Canada), Dr R Hubbard (the Institute of Marine Affairs, Trinidad) on marine water quality around the islands of Trinidad and Tobago where waters are heavily influenced by runoff from the Amazon and Orinoco Rivers. Cores are being aged and proxy records of past seawater conditions (e.g. temperature, salinity and sediment inputs) will be reconstructed in order to understand how environmental factors have influenced scleractinian carbonate production over the last century in Tobago. Chemical analysis will be conducted at the University of Toronto and ANU.

Mr I. MOFFAT collaborated with Professor Larry Conyers (Denver University) on a project focused on the geophysical detection of heat retainer hearths in Northwest Queensland.

Dr B.N. OPDYKE collaborates with Prof. R Dunbar at Stanford University; Prof. Andre Droxler at Rice University; Prof. K. Calderia at Stanford Universty

Prof B.J. PILLANS with Prof J. Ogg (Purdue University, USA) and Prof P. Gibbard (Cambridge University) on the status of the Quaternary in the International Geological Time Scale.

Prof B.J. PILLANS with Prof A. Netto (Federal University of Rio de Janeiro) on landscape evolution in Brazil.

Prof B.J. PILLANS with Dr Parth Chauhan (Indiana University) and Dr Rajiv Patnaik (Panjab University) on magnetostratigraphy of Pleistocene archeological sites in India

Prof B.J. PILLANS co-editing a new book on Australian geomorphology with Prof P. Bishop (Glasgow University).

Dr S. SOSDIAN collaborates with Dr Y. Rosenthal, Institute of Marine and Coastal Sciences, Rutgers University Dr K. Lawrence, Lafyatte College, USA, Dr E. Grossman at Texas A&M, USA, Dr C. Lear at Cardiff University, Wales.

Ms J SUTTON collaborates with *NIWA from th*e New Zealand Foundation for Research Science and Technology.

Dr. M. WILLE collaborates with Prof. Nicolas Beukes (Department of Geology, University of Johannesburg), Thomas F. Naegler and Prof. Karl Ramseyer (Institute for Geological Sciences, University Bern).

Dr G. YOUNG collaborates with Prof Zhu Min, Prof Chang Meemann and Dr Zhao Wen-Jin at the Institute of Vertebrate Palaeontology & Palaeoanthropology, Academia Sinica, Beijing,

Dr G. YOUNG collaborates with Profs D. Goujet, P. Janvier and H. Lelievre at the Museum nationale d'Histoire naturelle, Paris.

Dr GAVIN YOUNG collaborates with Dr B. Meyer-Berthaud at Montpellier University.

Dr GAVIN YOUNG collaborates with Prof. P. Ahlberg at the University of Uppsala.

Dr GAVIN YOUNG collaborates with Dr Peter Bartsch at Museum fur Naturkunde, Berlin.

Dr GAVIN YOUNG collaborates with Prof. C. Marshall and Prof. I. Schwab, at University of California.

Dr GAVIN YOUNG collaborates with Prof. M. Coates at the University of Chicago,

Dr GAVIN YOUNG collaborates with Prof B. Fritzsch at Creighton University, Nebraska.

Dr GAVIN YOUNG collaborates with Dr J. Maisey at the American Museum of Natural History, New York.

Earth Materials & Processes

Prof R.J. ARCULUS collaborates with Profs J Blundy, M Kendall, and S Sparks, Department of Earth Sciences, University of Bristol, Prof J Davidson, University of Durham, on the petrology of cumulate blocks and crustal architecture of the Lesser Antilles Island Arc; with Prof T Plank, Columbia University, Prof K Kelley, University of Rhode Island, Dr J Lupton of NOAA, volatiles and melts of the Tonga-Lau system; Prof I Wright, National Oceanography Centre, Southampton, Prof I E M Smith, University of Auckland, Prof J Gamble, University of Cork, Petrology of the Kermadec-Tonga Arc.

Dr A.G. CHRISTY collaborated with Dr S.A. Welch (Ohio State University, Ohio, USA) and Dr. D. Kirste (Simon Fraser University, British Columbia, Canada) on geochemistry of acid sulfate soils.

Dr A.G. CHRISTY collaborated with Prof. S.M. Clark (Advanced Light Source, Berkeley, California, USA) on high-pressure studies using the diamond anvil cell.

Dr A.G. CHRISTY is collaborating with Dr G. Zhang, Dr J. Chen, Prof. L. Zhang, Prof. Y. Zhu and others at the School of Earth and Space Sciences, Peking University, Beijing, China, on various metamorphic petrological and mineralogical projects.

Dr A.G. CHRISTY is collaborating with Dr S.J. Mills at the University of British Columbia, Vancouver, Canada, and others on various mineralogical projects.

Prof S F COX and Mr P. Stenhouse commenced a collaboration with Professor Janos Urai (RWTH-Aachen, Germany) on using exceptionally well-exposed vein systems, associated with fault zones in Oman, to explore the distribution of fluid flow during the evolution of the fault system.

Mr R. FARLA collaborated with Assoc. Professor U.H. FAUL (Boston University) on his research on dislocation creep of synthetic (sol-gel) olivine. He received excellent lab support from Dr. M. ZIMMERMAN and Prof.

Dr J.D. FITZ GERALD with Prof I. PARSONS, Grant Institute, University of Edinburgh, natural and laboratory induced microstructures in alkali feldspars and implications for fluid transport in crustal rocks, with Dr A. CAMACHO, University of Manitoba and Dr J.K. LEE, Queens University, Canada, defect microstructures in phlogopites and their effects on diffusion rates for Ar. Joint work also continued into fluid-assisted reactions of feldspars with Prof A. PUTNIS and Dr C.V. PUTNIS, Inst. Mineralogie, WWU Münster and Prof H. Austrheim, Inst. Geosciences/PGP, OSlo and Dr A.K. Engvik, Geological Survey of Norway.

D. L. KOHLSTEDT (University of Minnesota) during his stay in Minneapolis. He received many useful ideas from Prof. S. KARATO (Yale University) and is considering collaboration with him for a future research project.

Dr A. HALFPENNY collaborates with Prof D. Prior, Department of Earth and Ocean Sciences, University of Liverpool, UK, and Dr J. Wheeler, Department of Earth and Ocean Sciences, University of Liverpool, UK, on the recrystallisation and nucleation mechanisms in quartzites and marbles.

Dr A. HALFPENNY collaborates with Prof D. Prior, Department of Earth and Ocean Sciences, University of Liverpool, UK, on the controlling deformation mechanisms of gabbroic shear zones collected on IODP Expedition 304/305.

Dr J. HERMANN collaborates with Prof. M. Scambelluri and Dr N. Malaspina (University of Genova, Italy), and Prof. T. Pettke (University of Berne, Switzerland) on constraints on subduction zone fluids.

Dr J. HERMANN collaborates with Dr Q. Qing (Chinese Academy of Science, Beijing, China) on the formation of high Mg-diorites and the differentiation of the continental crust.

Dr J. HERMANN collaborates with Dr A. Korsakov (Novosibirsk, Russia) on coesite and diamond facies metamorphism in the Kokchetav Massif, Kazakhstan.

Dr J. HERMANN collaborates with Dr M. Marocchi (University of Bologna, Italy), on trace element variations in hydrous minerals in mantle wedge peridotites and implications for mantle metasomatism.

Dr J. HERMANN collaborates with Prof. M. Engi (University of Berne, Switzerland) on Barrovian metamorphism in the Central Alps.

Dr J. HERMANN collaborates with Prof. B. Cesare (University of Padova, Italy), Prof. I. Buick (Stellenbosch University, South Africa) 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 Prof. M.T. Gomez Pugnaire and Mr J.A. Padron (University of Granada, Spain), on dehydration of antigorite in subducted serpentinites.

Dr J. HERMANN collaborates Prof. R. Compagnoni and Dr M. Beltrando (University of Torino, Italy), on formation and evolution of blueschist and eclogite facies rocks in the Western Alps and Corsica.

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 collaborated with D.R. Schmitt and H. Schijns (University of Alberta, Canada), U.H. Faul (Boston University, Y. Aizawa (Japan Manned Space Systems Corporation, Japan), A. Barnhoorn (Utrecht University), J. Kung (National Cheng-Kung University, Taiwan), R.C. Liebermann (Stony Brook University), A.M. Walker (University College, London) and S.J.S. Morris and L.C. Lee (University of California, Berkeley) in the laboratory measurement and modelling of seismic properties.

Mr J. Jones and Prof H. St. C. O'Neill collaborated with Dr A. Berry, Department of Earth Science and Engineering, Imperial College, London, on XANES determination of the coordination state of Ni, Co and W in silicate melts.

Miss H. LI and Dr A. Christy collaborated with L. Zhang, The Key Laboratory of Orogenic and Crustal Evolution, MOE; School of Earth and Space Sciences, Peking University, China, on the paper "The correlation between Raman spectra and the mineral composition of phengite".
Prof G. LISTER collaborated: a) with Prof T. Ahmad at Delhi Universiy, India in developing an AISRF project and in the Himalayan 09 geotransect; b) with Prof J.-P. Burg at ETH Zurich in conducting a PhD project for Mr C. Augenstein in the Swiss Alps.

Dr G. MALLMANN collaborates with Dr R. Fonseca and C. Ballhaus (Universität Bonn, Germany) on the partitioning of Os, Ta and W between metal, sulphide and silicate melts, and with Dr Berry (Imperial College London, UK) on the oxidation state of MORB glasses.

Dr L. MARTIN collaborates with Prof B. Wood (University of Oxford, UK), on element recycling in subduction zones.

Dr L. MARTIN collaborates with Prof M. Ballèvre and Dr P. Bouvais (Université de Rennes, France), on the re-equilibration mechanisms affecting garnet during their metamorphic history.

Dr L. MARTIN collaborates with Prof S. Duchene, Dr E. Deloule and Pr. Vanderhaeghe (CRPG and Université Henri Poincaré, France), on the P-T-time-fluid history of the metamorphic rocks from Ikaria Island (Greece).

Dr L. MARTIN collaborates with Dr M.-A. Kaczmarek (Université de Montpellier, France), on the significance of microstructures in a deformed eclogite from Vendée (France).

Dr D.C. "BEAR" McPHAIL collaborates with Prof K. Kyser of Queen's University (Canada) and Dr Claudine Stirling of Otago University (New Zealand) on a successful ARC Discovery Program proposal to study uranium isotope fractionation; and
Dr D.C. "BEAR" McPHAIL collaborates with Dr C. Oates of Anglo American (London) in the study of hydrogeochemistry for mineral exploration.

Dr. O. NEBEL worked together with Dr. Wim van Westrenen and Dr. Pieter Vroon (both Vrije Universiteit Amsterdam) on the onset of crustal formation and the Hf isotope budget in subduction zones that are associated with sediment subduction.

Mr C. PIRARD collaborates with Dr F. Hatert (Laboratoire de Minéralogie, University of Liège, Belgium) on the mineralogy and ore geology of Katanga Cu-Co-U deposits, D.R. Congo.

Mr C. PIRARD collaborates with Prof A.-M. Fransolet and Dr. F. Hatert (Laboratoire de Minéralogie, University of Liège, Belgium) on the metasomatism in phosphates-bearing pegmatitic systems.

Mr C. PIRARD collaborates with O. Namur, Dr. B. Charlier and Prof. J. Vander Auwera (U.R. Pétrologie & Géochimie endogènes, University of Liège, Belgium) on the differentiation of ferrobasaltic magmas in the Sept-Iles Layered Intrusion, Quebec, Canada.

Dr. R. RAPP collaborates with Professor H. Martin and Dr. D. Laporte, Laboratoire Magmas et Volcans, Universite de Blaise Pascal, Clermont-Ferrand, France, on crust-mantle interactions in the Archean and the origin of Archean granitoid magmatism. He is also involved in collaboration with Professor Tetsuo Irifune and Dr. Norimasa Nishiyama of the Geodynamics Research Center of Ehime University in Matsuyama, Japan, in an experimental study of the physical and chemical properties of deeply subducted crustal rocks at pressures equivalent to the transition zone (~670 km depth) and uppermost lower mantle.

Mr L. T. WHITE collaborates with Prof T. Ahmad (Delhi University) on geochronology in the Indian Himalaya and Shillong Plateau; as well as with Professor J. Aitchison (Hong Kong University) on deformable reconstructions of the Indian and Eurasian plates.

Earth Physics

Mr T. BODIN with Dr K. Gallagher, Geoscience Rennes, Universite de Rennes (France) on non linear regression techniques.

Prof R.W. GRIFFITHS with Prof. C. Kincaid and Ms K. Druken, University of Rhode Island, USA, on modeling of mantle subduction zones.

Prof R.W. GRIFFITHS, Dr G.O. HUGHES and Ms N. MAHER with Prof. C. Kincaid, University of Rhode Island, USA, on circulations in floodplain estuaries.

Dr. A.McC. HOGG and Prof R.W. GRIFFITHS with Prof. W.K. Dewar, Florida State University, USA, and Dr. P.S. Berloff, Imperial College London, UK, on inviscid generation of unbalanced flow.

Dr. A.McC. HOGG with Dr. M. Meredith, British Antarctic Survey, UK, and Dr. A.C. Naveira Garabato, National Oceanography Centre, UK, on the Southern Ocean overturning circulation. Prof KENNETT continues to collaborate with Dr S Fishwick, University of Leicester, UK, and Mr A. Fichtner, University of Munich, Germany, Japan on surface wave tomography.

Prof 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 seismic waves in complex subduction zones and long range propagation in the oceanic lithosphere.

Dr R.C. KERR with Prof. J. Lister, University of Cambridge, UK, and Dr. C. Meriaux, University of Lisbon, Portugal, on mantle plumes.

Dr. A.McC. HOGG and Dr. M.L. WARD with Dr. R. Morrow, LEGOS, France, on Southern Ocean eddy dynamics.

Dr H. MCQUEEN and Prof K. LAMBECK with Dr Y. Tamura (National Astronomical Observatory of Japan, Mizusawa) on operation of Superconducting Gravimeter at Mt Stromlo.

Dr H. MCQUEEN with S. Bonaimé and Dr E. Stutzmann of Progamme Geosccope at the Institut de Physique du Globe de Paris on operation of the Canberra Geoscope Seismic Station as a component of the French and Australian Tsunami Warning Centre networks.

Dr. N. RAWLINSON collborates with the University of Bristol, the University of Leeds, University of Leicester and Victoria University of Wellington.

Dr M.L. RODERICK with Dr S. Schymanski (Max Planck Institute for Biogeochemistry) and Prof M. Sivapalan (University of Illinois at Urbana-Champaign), on the inclusion of vegetation in hydrologic models.

Prof. M. SAMBRIDGE with Prof. R. Snieder (Colorado School of Mines), Coda wave interferometry, Dr. E. Debayle (Univ. of Strasbourg) on mantle imaging with body waves, Prof. K. Gallagher (Univ. of Rennes) on Bayesian partition modelling.

Dr. H TKALČIĆ collaborates with Prof. V Cormier, University of Connecticut, and Dr. Satoru Tanaka, JAMSTEC, Japan, on structure of the inner core and core-mantle boundary, with Prof. M Herak and PhD student J.

Stipcevic, University of Zagreb, on lithospheric structure of Croatia and the Adriatic Sea, with Dr. A Fichtner, Utrecht University and Prof. D Dreger, University of California at Berkeley, on seismic sources, with Dr. Y Chen, 3D Array Technologies, United States, on lithospheric structure of China, with Prof. L. Pekevski, Skopje Seismological Laboratory, on lithospheric structure of Macedonia, with Prof. A Jackson, ETH, on the application of Benford's law in geosciences.

Dr P. TREGONING collaborates with Dr G. Ramillien, Centre Nationale de la Recherche Scientifique, Toulouse, France, on the analysis and interpretation of space gravity data from the GRACE mission, Drs M. Vergnolle and A. Walpersdorf (Universite Joseph Fourier, Grenoble, France) on slow slip events on the Guerrero subduction zone, Mexico. He also collaborates with Prof. T. Herring and Drs R. King and S. McClusky on the development of the GAMIT GPS software.

Dr. M.L. WARD with Prof. W.K. Dewar, Florida State University, USA, on gravity wave and balanced flow interactions.

Integrated Ocean Drilling Program (IODP)

Collaboration occurs with many scientists in America, Japan, Europe, New Zealand and Korea in the IODP context. We provide scientists for various IODP panels and reviews, and AIO is in daily contact with partner scientists and organizations around the world.

PRISE

Dr R.A. ARMSTRONG collaborates with Prof. A. da Silva Filho and Assoc. Prof. I. de Pinho Guimaraes (Federal University of Pernambuco, Recife, Brazil) on the geochronology and crustal growth history of the Borborema province, Brazil; Prof. N. Beukes (University of Johannesburg, South Africa) on the detrital and igneous zircon record and chronology of the western margin of the Kaapvaal Craton; Dr G. de Kock (Council for Geoscience, South Africa) on the geochronology of the Damaran Belt, Namibia; Mr J. Honarpajooh (Kurdistan University, Iran) on copper mineralization in the Tabriz-Zanjan zone, Iran; L. Longridge (University of the Witwatersrand, South Africa) on the age and metamorphic history of the Khan valley region of Namibia; C. Sanchez-Garrido (University of Stellenbosch, South Africa) on the oxygen isotope composition of pebbles in the Moodies Group, Barberton Mountain Belt, South Africa; Dr J. Vry (Victoria University, New Zealand) on the dating of fluid movement in sediments on South Island, New Zealand; Dr H. Mouri (University of Johannesburg) on the geochronology of komatiites from the Limpopo Mobile Belt, South Africa; Dr M. Rigby (University of Pretoria, South Africa) on the timing of granulite metamorphism in titanites from the Limpopo Mobile Belt, South Africa; Dr P.Poprwa (Polish Geological Institute) on geochronology and provenance of zircons from Poland; Professor J. Moore (Rhodes University, South Africa) on provenance of zircons from Palaeoproterozoic diamictites in South Africa; Prof. S. McCourt (University of KwaZulu-Natal, South Africa) on the geochronology and source of the Volcanic rocks of the Tugela Valley, South Africa.

Mr C.M. FANNING continued the collaboration with Prof P.K. Link (Idaho State University) and Dr C. Dehler (Utah State University) on the provenance and time of deposition of Neoproterozoic sequences in Utah and Idaho; Dr J. Goodge (University in Minnesota, Duluth) geochronology and provenance of sequences in the central Transantarctic Mountains and Wilkes Land, Antarctica; 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 Patagonia, Tierra del Fuego and the Antarctic Peninsula; Prof C. Rapela, Universidad Nacional de La Plata, Argentina, and Dr R.J. Pankhurst (British Geological Survey), continuation of collaboration on the geochronological and tectonic evolution of the north Rio de La Plata and adjacent cratons/terrains of Argentina; Dr C. Casquet and Dr C. Galindo (Universidad Complutense, Madrid) on the geochronological and tectonic evolution of the Sierras Pampeanas, NW Argentina and the Arequipamassif of Peru; Dr Christine Siddoway (Colorado College) and Mr Rory McFadden (University of Minnesota) on the tectonic evolution of the Fosdick Mountains, Mary Byrd Land, Antarctica.

Mr S. HUI collaborated with Prof. R. P. Harvey, Case Western Reserve University, Cleveland, USA on analysis of cosmic spherules from the Lewis Cliff, Antarctica.

Ms Ms E. KISEEVA collaborated with Dr. D. Petrov and Prof. Y. Marin, Saint-Petersburg State Mining Institute, Russia on investigations of rare earth elements patterns of zircons from Salmi Granite Pluton, Russia; Dr. K. Litasov, Tohoku University, Sendai, Japan on high pressure (up to 20 GPa) experimental studies of carbonate eclogite.

Dr M.D NORMAN collaborates with Prof. R. Duncan & Mr. J. Huard (Oregon State University), Prof. M. Garcia & J. Taylor (University of Hawai'i), Dr. A. Pietruszka (San Diego State University), Prof. J. Goodge (University of Minnesota), Prof. B. Jolliff (Washington University), and Prof. M. Remus (Universidade Federal do Rio Grande do Sul).

Ms A. ROSENTHAL collaborates with Dr I. Kovacs, Eötvös Lorand Geophysical Institute of Hungary, Budapest, Hungary on ongoing studies of minor amounts of H2O in melts of residual eclogite and H2O in nominally anhydrous minerals; Drs M. Drury, A. Barnhoorn and H. van Roermund, Universiteit Utrecht, The Netherlands on deformation, structure and Norwegian regional petrology/geology; Prof S. F. Foley, University of Mainz, Germany on a) the establishment of near-solidus melts of peridotite in the presence of CO2 and H2O at 40-60kbar using piston-cylinder apparatus, and b) ongoing studies regarding the petrogenesis of East African Rift volcanics; Dr H. E. Höfer and Prof G. Brey, University of Frankfurt am Main, Germany using the electron microprobe "flank method", and Prof A. B. Woodland, University of Frankfurt am Main, using the Mössbauer spectroscopy to study the establishment of the oxidation state of the Norwegian peridotite body and also on the development of standards for $Fe3+/\sum Fe$ in garnets.

Dr G.M. YAXLEY collaborates with Prof S.F. Foley, University of Mainz, Germany and Ms A. ROSENTHAL, RSES on high pressure experimental studies of partial melting of carbonated, hydrous peridotite; Dr H. Höfer and Prof A. Woodland, University of Frankfurt am Main, Germany on the relationships between oxygen fugacity and metasomatism of the cratonic lithosphere recorded in garnet peridotite xenoliths.

Visiting Fellows

Richard Barwick, In an usual form of 'international link' I was invited to be the 'Antarctic History' lecturer on board the ice-ship *Martina Svetlaeva* by Aurora Expeditions. Accordingly, I made two 26-day voyages in January and February of this year and gave a variety of lectures on Antarctic topics. The first voyage was able to land at the Cape Adare and get to Commonwealth Bay region with brief side-visits to Campbell, Auckland and Macquarie Islands. Richard Barwick on the second voyage the ship was able to enter the Ross Sea, visiting Franklin and Beaufort Islands and the major American and New Zealand bases on Ross Island. I was also given the privilege of a brief helicopter visit to The McMurdo Dry Valley region where I had carried out research in 1956-59 when a member of New Zealand party of the Fuchs-Hillary TransAntarctic Expedition and on the third season with Victoria University of Wellington Antarctic Expedition 2.

Dr R. V. Burne collaborates with Prof. Josef Paul, Zentrum f. Geowissenschaften der Universität Göttingen, Germany, Dr Tadeusz Peryt, Polish Geological Institute, Poland, and Dr Tadashi Maruyama, Japan Agency for Marine-Earth Science and Technology, Kanagawa Japan, Mr Gumpei Izuno, Department of Coastal Engineering, University of Tokyo.

Dr E. A. Felton is working with A/Prof. A. Switzer, Nanyang Technological University, Singapore, on cosmogenic age dating of rock coastal geomorphic features.

Dr P.J. JONES collaborates with Dr M. Menning, GeoForschungsZentrum Potsdam (GFZ) on Devonian, Carboniferous and Permian correlation, for the preparation of a high resolution biochronological chart for selected global areas; and Prof. James Ogg (Secretary General, International Stratigraphic Commission) on problems of Carboniferous and Permian global stratigraphy.

Prof K. LAMBECK collaborates with Dr F. Antonioli, ENEA, Rome, and Dr M. Anzidei, INGV, Rome, on sea-level change in the Mediterranean Sea.

Prof K. LAMBECK collaborates with Dr C. Sparrenbom, Swedish Geotechnical Institute, Prof Svante Björck, GeoBiosphere Science Centre, Lund University, and Dr Ole Bennike, Geological Survey of Denmark and Greenland on ice sheet evolution and sea-level changes in southern Greenland.

Prof K. LAMBECK collaborates with Prof G. Bailey, Department of Archaeology, University of York, UK, and Prof C. Vita-Finzi, The Natural History Museum, London, on an EFCHED project relating to archaeology in the Red Sea Basin.

Prof K. LAMBECK, Member of Executive Committee, InterAcademy Panel on international issues.

Prof K. LAMBECK, Board Member, InterAcademy Council.

Prof K. LAMBECK led the Australian delegation to Guangzhou and Xiamen for the sixth annual China-Australia Symposium on Sustainable Coastal and Deltaic Systems, Beijing, 12-15 October 2009.

Dr W. Mayer collaborates with the Muséum national d'histoire naturelle in Paris on the description and interpretation of the geological collections made by various French expeditions to Australia between 1801 and 1841

Dr D.L. STRUSZ collaborated with Dr RONG Jia-yu, Palaeontological Institute, Nanjing, and Dr Rémy GOURVENNEC, Université occidental de Bretagne, Brest, on taxonomic discrimination of early spiriferide brachiopods.

Prof S. R Taylor with Prof. Scott M. Mclennan, State University of New York, stony Brook NY, USA on the geology and geochemistry of planetary crusts.

COOPERATION WITH GOVERNMENT AND INDUSTRY

Earth Chemistry

Dr V. C. Bennett, with Dr. M. Van Kranendonk, Geological Survey of Western Australian, on the determining early Earth environments through geochemical study of chemical sediments of the Pilbara region, Western Australia.

Dr J.J. BROCKS with Dr C. Boreham (Geoscience Australia), Applications of HPLC for the separation of geoporphyrins.

Dr. S.J. FALLON, with Dr. A. McDougall (Dept. Natural Resources & Water, aging of Queensland Lungfish).

Dr M.A. FORSTER, with W. Collins (James Cook University, Townsville), Geoscience Australia and Queensland Geological Survey involved in the Far North Queensland AuScope Seismic Transect - Geochronology of shear zone movement as part of an ARC Linkage project.

Mr R. Schinteie, with J. Cheng, Geoscience Australia, on using the stable isotope facilities.

Dr I.S. WILLIAMS holds a 25% appointment as Chief Scientist at Australian Scientific Instruments Pty. Ltd., a subsidiary of ANU Enterprise, where he works on SHRIMP development, marketing, testing and operator training. SHRIMP technical and scientific advice was provide with Australian Scientific Instruments to the Geological Survey of Canada (Ottawa, Canada), Hiroshima University (Hiroshima, Japan), The National Institute of Polar Research (Tokyo, Japan), The Chinese Academy of Geological Sciences (Beijing, China), the All Russian Geological Research Institute (St. Petersburg, Russia), the Korea Basic Science Institute (Ochang, South Korea) and Geoscience Australia (Canberra). Dr I.S. Williams also provided scientific and technical training in secondary ion mass spectrometry to scientists from laboratories that have purchased SHRIMP ion microprobes. In December 2008 he spent three weeks in Ochang, South Korea, assisting with the installation of the new SHRIMP IIe/mc purchased by the Korea Basic Science Institute and training KBSI SHRIMP operators. He returned to Ochang for a further 3 weeks in July 2009 to lecture and provide additional training in advanced analytical techniques. In April 2009 he spent a month at the National Institute of Polar Research in Tokyo assisting with the retuning of their SHRIMP II after its move to a new laboratory and training NIPR SHRIMP operators in procedures for stable isotope analysis.

Dr I.S. WILLIAMS and Ms Heejin JEON, with Dr P. Blevin (Geological Survey of New South Wales) in a study of the Late Palaeozoic granites of southeastern Australia.

Earth Environment

Dr A. DUTTON collaborates with Dr T. Esat (ANSTO) on last interglacial fossil reefs in Western Australia and on dating submerged speleothems from Argentarola Cave, Italy.

Dr S.M. EGGINS, Mr L. KINSLEY, and Mr D. CORRIGAN with Photon-Machines Inc., laser ablation sampling technology for ICPMS analysis.

Prof R. GRÜN collaborates with the Department of Environment and Conservation, NSW, and the Three Traditional Tribal Groups in the ARC Linkage grant *Environmental Evolution of the Willandra Lakes World Heritage Area.*

Miss T.E. KELLY cooperated with National Parks and Wildlife Service, Department of Environment and Climate Change, Mungo Project.

Mr I. MOFFAT collaborated with David Guilfoyle (Applied Archaeology) and the Albany Heritage Reference Group Aboriginal Corporation on the location of unmarked graves with the Albany Memorial Cemetery using ground penetrating radar.

Prof B.J. PILLANS with Mr J. Wilford (Geoscience Australia) on landscape evolution in the Harden-Young region, N.S.W.

Dr. Martin WILLE collaborates with Dr. Martin J. Van Kranendonk (Geological Survey of Western Australia Department of Mines and Petroleum).

Earth Materials & Processes

Prof R.J. ARCULUS cooperates with Drs P. Crowhurst, R. Angus, L. Baptista (Nautilus Minerals), hydrothermalism, tectonism, and volcanism of the northern Lau Basin; Drs R Mosig, J Ferguson, and Mr T Abraham-James (Platina resources), noble and precious metal ore deposit distribution.

Prof 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".

Prof S. F. Cox and Dr A. Halfpenny are collaborating with geoscientists at the Porgera gold deposit (PNG) on studying the development of fracture-controlled flow systems in this rich and very large, intrusion-related gold system. This collaboration forms part of the activities of the ARC Centre for Excellence in Ore Deposits.

Dr J.D. FITZ GERALD and Prof R.A. EGGLETON with Dr J.L. KEELING, Geological Survey, Dept Primary Industries and Resources, South Australia, microstructures, defects and formation of asbestiform antigorite from Rowland Flat, S.A.

Dr A. HALFPENNY and Professor Stephen Cox collaborate with T. Beardsmore, F. Tulleman and D. Schonfeldt, Porgera Joint Venture, Barrick Gold, on the structural controls and evolution of the Porgera gold deposit, Papua New Guinea.

Dr A. HALFPENNY collaborates with B. Scott and J. Pinder, Rio Tinto on structural controls on the North Parkes copper/gold mine, NSW, AUS.

Dr D.C. "BEAR" McPHAIL, Dr M.D. Norman, and Mr K.N. Horner collaborate with Dr W. McLean (Parsons Brinkerhoff Pty. Ltd.) on characterizing Groundwater Dynamics and Surface Water Interactions in the Lower Murrumbidgee Catchment, New South Wales.

Dr D.C. "BEAR" McPHAIL cooperates with New South Wales Office of Water (formerly Department of Energy and Water) on groundwater in the Lower Murrumbidgee catchment and salinity in the Upper Hunter Valley;

Dr D.C. "BEAR" McPHAIL cooperates with CSIRO Exploration and Mining for regolith geoscience and education (Mr K. Scott of Sydney);

Dr D.C. "BEAR" McPHAIL cooperates with Anglo American (London) for the Anglo American Scholarship in Applied Geochemistry (3rd- and 4th-year scholarship for ANU students);

Dr D.C. "BEAR" McPHAIL cooperates with the Australian Institute of Mining and Metallurgy for scholarships and educational opportunities for ANU undergraduate students; and

Dr D.C. "BEAR" McPHAIL cooperates with the Minerals Council of Australia for Honours and Masters training programs as part of the Minerals Tertiary Education Council initiative.

Dr O. NEBEL worked with Dr. T. Ivanic (Geologic Survey of Western Australia), and Dr. R. Langford (Flinders Mines Ltd.) on the origin and genesis of the Windimurra layered mafic intrusion.

Earth Physics

Dr H. MCQUEEN with R. Tracey and N. Dando (Geoscience Australia) testing and operation of a new absolute and relative gravimeters for establishment of national reference benchmarks and accurate determination of ocean tide loading signals as part of the AuScope funded gravity program.

Dr H. MCQUEEN with Dr L. Hutton of the Geological Survey of Queensland on deployment of the MINQ passive seismic array in North Queensland as part of an AuScope funded project.

Dr H. TKALČIĆ 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 with support from Professor B.L.N. Kennett. The seismic and infrasound arrays have been very ably supported by Scott Savage as station manager at Warramunga. Battery deterioration has reduced the previously high reliability with data transmitted continuously to the International Data Centre in Vienna via satellite link

Dr. N. RAWLINSON cooperates with Kuth Energy Ltd via a linkage project.

Dr M.L. RODERICK consultancy for the Murray Darling Basin Authority titled: "Scientific review on evapotranspiration trends"

Dr M. SALMON and M. SAMBRIDGE collaborating with Geoscience Australia to validate event source parameters and ground motion records from the Flinders Ranges temporary seismic deployment.

Dr M. SALMON collaborated with Department of Primary Industries and Resources SA in the deployment of the Gawler Craton array.

Prof. M. SAMBRIDGE with Dr. P. Cummins of Geoscience Australia on seismological aspects of Tsunami warning.

Prof. M. SAMBRIDGE and Dr. M. Salmon with Drs. T. Allen, D. Burbidge and P. Cummins of Geoscience Australia on validation of event source parameters and ground motion records from the Flinders Ranges temporary seismic deployment.

Dr P. TREGONING with J. Dawson and G. Johnston (Geoscience Australia), AuScope Geospatial.

PRISE

Dr R.A. ARMSTRONG with Dr Hielke Jelsma (De Beers) on the geochronology of Angola and the DRC.

Dr R.A. ARMSTRONG and Dr M.D. NORMAN with Dr S. Matthews of Minera Meridian Limitada, Chile, on sulphur isotope studies of sulphide-bearing veins from the Andes.

Dr R.A. ARMSTRONG and Dr G.M. YAXLEY with various members of the Northern Territory Geological Survey on the geochronology, provenance and history of selected areas of the Northern Territory, using U-Pb, oxygen and Hf isotope studies.

Dr M.D NORMAN with Dr. Wendy McLean (Parsdons Brinkerhoff); Dr. P. Blevin (Geological Survey of New South Wales).

Visiting Fellows

Dr R. V. Burne with Dr Chris Simpson and Dr Alan Kendrick, Department of Environment and Conservation, Western Australia on the scientific monitoring and conservation of Hamelin Pool, part of the World Heritage-listed Shark Bay area; with Ms Ruth Crabb, Commonwealth Department of Environment, Heritage and Conservation on the environmental protection of thrombolite (microbial) community of coastal brackish lakes (Lake Clifton, Western Australia);with Dr Jane Andrews, RIGS, Cornwall Wildlife Trust, on the geological interpretation and conservation of the coastal cliffs of the north Cornish Coast, U.K.

Dr P.J. JONES with Dr P.D. Kruse (Northern Territory Geological Survey), on palaeontological studies of Bradoriida (bivalved Arthropoda) from early Middle Cambrian (Ordian) of the Georgina Basin, central Australia.

Prof K. LAMBECK, as President of the Australian Academy of Science, was a member of the Prime Minister's Science Engineering and Innovation Council.

Prof K. LAMBECK, Expert Panel Member, DIISR Australia India Expert Advisory Group.

Prof K. LAMBECK, Chair, Science Panel, DIISR NCRIS Evaluation.

KEITH SCOTT with Stuart Hutchin (CBH Limited) Characteristics of soils western NSW.

Dr D.L. STRUSZ worked with Dr Ian Percival, Dr L. Sherwin, and Ms L. Deyssing (New South Wales Geological Survey) on the age of Silurian horizons within the Braidwood 1:100,000 sheet area, currently being mapped by the Survey.

Dr D.L. STRUSZ worked with the ACT Planning and Land Authority and the Engineering consultants in assessing and monitoring the effects of bridgework on the Woolshed Creek heritage site.

STAFF ACTIVITIES 2009

CONFERENCES AND OUTSIDE STUDIES

Earth Chemistry

Dr C. Allen attended the Geological Society on America meeting, Portland Oregan, USA to give a talk on the "Distinctive low Lu signature in a data base of U-Pb dated zircons from the World's major rivers."

Dr Y. AMELIN attended the Planet Formation and Evolution: The Solar System and Extrasolar Planets, Tübingen, Germany, 2-6 March and gave an invited presentation entitled "Building a Consistent Timescale of the Early Solar System".

Dr Y. AMELIN attended the 2009 American Geophysical Union Joint Assembly, Toronto, Canada, 24-27 May and gave an invited presentation entitled "Non-traditional isotopic dating: Krogh Revolution beyond U-Pb and zircon" at the special session "Advances in the Measurement of Time: Beyond the Krogh Revolution", dedicated to the memory of Tom Krogh.

Dr Y. AMELIN visited the University of Otago, 7-15 June to complete analytical work (uranium isotope analysis of meteorites) using MC-ICPMS, jointly with Dr. C. Stirling and a PhD student A. Kaltenbach, and a talk entitled "Building a consistent timescale of the early Solar System".

Dr Y. AMELIN attended the 9th Australian Space Science Conference, Sydney, 28-30 September. The paper co-authored by University of Otago PhD student Ms A. Kaltenbach, Dr C.H. Stirling and Dr Y. Amelin entitled "Uranium isotopic composition in meteorites and the origin of the Solar System" was presented by A. Kaltenbach.

Dr Y. AMELIN visited the University of Hawaii, Honolulu, HI USA, 16-29 November to complete analytical work (imaging, mineral identification and 26Al-26Mg dating of meteorites) using electron microprobe and Cameca IMS-1280 ion microprobe, jointly with Dr. A. Krot and Dr. K. Nagashima, and to present an invited talk entitled "Decay rates of radionuclides for use in cosmochronology".

Ms. Janaina N. Ávila, Elizabeth and Frederick White Conference on Nuclear Astrophysics, Canberra, Australia, 24–25 August, presented a paper entitled "*Europium isotopic ratios in stardust SiC grains from AGB stars*".

Dr V.C. Bennett convened a special session on "Chemical Evolution of the Mantle" at the American Geophysical Union Conference, San Francisco, USA, 14-18 December, and presented a paper entitled "Hadean to Modern Mantle Evolution from a 142Nd-143Nd-176Hf Isotopic Perspective".

Dr V.C. Bennett attended the Australian Space Science Conference, Sydney, Australia. 28 September–1 October, and presented a paper entitled "Earth's Oldest Rocks-An Archive of Planetary History."

Dr V.C. Bennett conducted fieldwork in the Anshan region and presented an invited lecture at the Chinese Academy of Geological Sciences, Beijing, P.R. China, entitled "Using isotopic compositions of Archean rocks to determine Hadean Earth history".

Ms K. BOSTON, 9th Workshop on Alpine Geological Studies, Cogne, Italy 16 – 18 September, presented a poster entitled "Evidence for two high pressure metamorphic events in the Sesia Lanzo Zone, Western Alps".

Dr J.J. BROCKS gave an invited lecture, "Molecular fossils, metagenomics and early life on Earth", Macquarie University, "Genes-to-Geoscience" Lecture, 15 April.
Dr J.J. BROCKS attended "Molecular fossils, metagenomics and early life on Earth", ETH Zürich special seminar, 27 May.

Dr J.J. BROCKS – Keynote Lecture "Eukaryote and steroid evolution in the Proterozoic", 19th International Goldschmidt Conference, Davos, Switzerland, 21 – 26 June; and Theme Team 17 member.

Dr J.J. BROCKS with Richard Schinteie (ANU) and Jessica Creveling and Ben Kotrc (Harvard University), Field work in the McDonald Ranges and samples collection in the NTGS drill core store, Alice Springs, Northern Territory.

Dr M.A. FORSTER conducted fieldwork at Mt Kinabalu in Malaysia as part of an argon geochronology study with SE Asia Research Group (Holloway College, University of London), 6 – 13 January.

Dr M.A. FORSTER conducted collaboration at Delhi University and fieldwork in the NW Himalaya to supervise PhD candidate Ms Lee and continue research in the Ladakh region, 18 July – 5 August.

Dr M.A. FORSTER undertook research collaboration and supervision in the field of MSc student E. Moustaka from The National University of Athens. Fieldwork was in the ophiolitic zone of Evia, Greece from 11 September – 3 October.

Dr M.A. FORSTER attended the TANG3O meeting at Curtin University and presented research undertaken at the ANU argon facility, 10 – 11 December.

Dr M. HONDA attended the TANG3O meeting at Curtin University and presented research undertaken at the ANU argon facility, 10 – 11 December.

Professor T.R. IRELAND attended the Institute for Study of the Earth's Interior Steering and Advisory Committee Meeting as an invited panel member, Misasa, Japan, 24 February – 3 March.

Professor T.R. IRELAND conducted fieldwork in the Southern Alps, New Zealand, 9 – 15 March.

Professor T.R. IRELAND attended the Gordon Research Conference 2009, Mount Holyoak College, USA, 5 – 11 July.

Professor T.R. IRELAND gave an invited lecture at Macquarie University, 27 – 29 August.

Professor T.R. IRELAND attended the Australian Space Science Conference, 28 – 30 September, University of Sydney School of Physics.

Professor T.R. IRELAND attended the New Zealand Geological Society Annual Conference, Oamaru, New Zealand, 23 – 27 November.

Professor T.R. IRELAND attended the American Geophysical Union (AGU) Fall Meeting, 15 – 18 December.

Dr. C.H. Lineweaver, Evolution – The Experience, Melbourne, Australia, 8 – 13 February, presented two papers entitled "Is the Origin of Life a Cosmic Imperative or Is it as Unlikely as the Re-evolution of Sulphur-Crested Cockatoos" and "Encephalization, the Planet of the Apes Hypothesis and Evidence that Human-like Intelligence is not a Convergent Feature of Evolution".

Dr. C.H. Lineweaver, Third ANITA Workshop 13 – 14 March, held at Mt Stromlo Observatory, chaired a session and presented a paper entitled "Entropy, Gravity and Life".

Dr. C.H. Lineweaver, Evolution Symposium, 8 May, at the Shine Dome, Canberra, organised by the Australian Academy of Science.

Dr. C.H. Lineweaver, Member, Organizing Committee for 2009 Goldschmidt Conference held in Davos, Switzerland, chaired the Session "Earth, The Early Years, Building a Habitable Planet", 21 – 26 June.

Dr. C.H. Lineweaver, 2009 Goldschmidt Geochemistry Conference, 21 – 26 June, Davos, Switzerland, presented two papers entitled " A Critical Look at the Late Heavy Bombardment Hypothesis" and "Building Habitable Planets: Defining Habitability: The Geochemistry of the Nearest Extrasolar Terrestrial Planets".

Dr. C.H. Lineweaver, Invisible Universe: towards a new cosmological paradigm, Paris, France, 29 June – 3 July, presented a paper entitled "Dark Energy and the Entropy of the Observable Universe".

Dr. C.H. Lineweaver, Nuclear Astrophysics in Australia, Shine Dome, Canberra, 24 – 25 August.

Dr. C.H. Lineweaver, Australian Space Science Conference, 27 – 30 September, University of Sydney, presented an invited lecture entitled "Planetary Science in Australia" and a paper entitled "The Potentially Habitable Planets of the Alpha Centauri System". He was also session chair for one of the planetary science sessions.

Dr X. Zhang attended the TANG3O meeting at Curtin University and presented research undertaken at the ANU argon facility, 10 – 11 December.

Professor I.H. Campbell attended the joint American Geophysical Union-Geological Association of Canada Meeting in Toronto in May where he gave a presentation on "The rise of atmospheric oxygen".

Professor I.H. Campbell attended the Goldschmidt meeting in Davos, Switzerland where he gave a talk on the "Rate of growth of the preserved North American continental crust: Evidence from Hf and O isotopes in Mississippi detrital zircons"

Professor I.H. Campbell visited Professor K. Eriksson at the Virginia Polytech and State University, Professor S. Kay at Cornell University and Professor C. Hawkesworth of Bristol University to discuss collaborative research interests.

Professor I.H. Campbell visited the University of Bonn where he gave a talk on "Superconitnents, Supermountains and the rise of atmospheric oxygen".

Mr A. CHOPRA participated in the 2009 International Summer School of Astrobiology on Earth's Extremophiles and Extraterrestrial Habitability, Santander, Spain, 22-26 June.

Mr A. CHOPRA, 2009 Astrobiology Graduate Conference hosted at the University of Washington, Seattle, USA, 16-22 July, presented a poster entitled "What is Life made of?".

Mr A. CHOPRA, 9th Australian Space Science Conference, Sydney, 28-30 September, presented a talk entitled "Determining elemental abundances in bacteria to 'follow the elements'.".

Mr A. CHOPRA, participated in the Elizabeth and Frederick White Conference on Nuclear Astrophysics, Canberra, 24-25 August.

Mr A. CHOPRA presented a proposal talk for the EARTHRISE (Education and Research Through Interesting Space Experiments) program for graduate students at RSES and RSAA involving balloon borne near-space experiments.

Mr A. CHOPRA, Student Seminars of the Research School of Earth Sciences, 29 April, presented a talk entitled "What is Life made of?".

Mr A. CHOPRA, Research School of Biological Sciences Student Conference, 8-9 October, presented a talk entitled "The Major Elemental Abundance Differences Between Life, the Oceans and the Sun".

Ms T.A. EWING, Goldschmidt 2009, Davos, Switzerland, 21-26 June, presented a paper entitled "*In situ* measurement of Hf isotopes in rutile by LA-MC-ICPMS".

Ms T.A. EWING conducted fieldwork in the Ivrea-Verbano Zone, northern Italy, from 10-17 June.

Dr. S.J. Fallon attended the International Radiocarbon Converence in Kona, Hawaii and presented two papers entitled "Developing robust chronologies of Aboriginal occupation from shell middens along the Kimberley coast of Australia" and "Marine reservoir variability in the Kimberley region, WA"

Ms B. FRASL, 9th Australian Space Science Conference, 28 – 30 September, Sydney.

Ms B. FRASL, Elizabeth and Frederick White conference on Nuclear Astrophysics in Australia, 24 – 25 August, Canberra.

Dr M. HONDA attended the workshop "Developments in Noble Gas Understanding and Expertise (Dingue)" in Nancy, France and the Goldschmidt Conference in Davos, Switzerland, and presented a paper entitled 'Cosmogenic neon exposure dating of young basalt lavas in Australia'.

Ms H. JEON conducted fieldwork in NSW to collect carboniferous granites, 15 –17 February and 7 – 9 March.

Ms J.-U. LEE conducted fieldwork at Mount Kinabalu, Malaysia, 6 – 12 January.

Ms J.-U. LEE conducted fieldwork in NSW to collect samples, 12 – 13 February.

Ms J.-U. LEE conducted fieldwork in the Himalaya, NW India, 8 July – 21 August.

Dr C.H. Lineweaver refereed 14 articles for Astrobiology, International Journal of Astrobiology, Astrophysical Journal, Monthly Notices of the Royal Astron. Society, Astronomy and Astrophysics, Bioinformatics.

Dr. C.H. Lineweaver chaired the Research School of Astronomy and Astrophysics Colloquium Committee, responsible for weekly speakers at Mt Stromlo Observatory.

Dr. C.H. Lineweaver assisted Dr R. Salmeron in organising the fortnightly Planetary Science Institute Seminar Series.

Professor I. McDougall presented an invited paper on Dating Human Evolution to the Evolution-The Experience conference in Melbourne in February 2009.

Mr. Seann McKibbin attended the Elizabeth and Frederick White conference on Nuclear Astrophysics in Australia, 24-25 August 2009, Australian Academy of Sciences Dome, Canberra.

Mr. Seann McKibbin attended the Australian Space Science Conference, 28 – 30 September, University of Sydney School of Physics.

Dr R. SALMERON attended the workshop Dynamics of Discs and Planets, Isaac Newton Institute for Mathematical Sciences, The University of Cambridge. 21 September – 2 October.

Dr R. SALMERON attended the Annual Scientific Meeting, Astronomical Society of Australia, The University of Melbourne. Presented a contributed talk entitled: "Magnetic fields and star formation".

Dr R. SALMERON attended "Evolution of the Universe, the planets, life and thought", Australian Academy of Science.

Dr R. SALMERON attended The Astrophysics of the Magnetorotational Instability and Related Processes, Ringberg. Presented an invited talk entitled "Jets and outflows from stratified protoplanetary disks".

Dr R. SALMERON attended the Third ANITA Workshop, RSAA, ANU. Presented a talk entitled "Jets and winds from young stellar objects".

Mr R. SCHINTEIE attended the 19th V.M Goldschmidt Conference, Davos, Switzerland.

Dr I.S. WILLIAMS attended the 32nd National Symposium of the Australian Academy of Technological Sciences and Engineering, *Future Proofing Australia—Rising to the Challenge of Climate Change*, Brisbane, 15–17 November.

Dr I.S. WILLIAMS attended the 11th Indian Society of Mass Spectrometry TRICON-2009 in Hyderabad, 23-27 November, where he presented an invited talk entitled "Advances in the SHRIMP II Ion Microprobe and its Geological Applications".

Dr I.S. WILLIAMS visited the National Geophysical Research Institute, Hyderabad, 27 November, and gave a lecture on SHRIMP II and its geological applications.

Dr I.S. WILLIAMS visited the Indian Institute of Science, Bangalore, 27–30 November, and gave a lecture on SHRIMP II and its geological applications.

Dr I.S. WILLIAMS visited the Physical Research Laboratory, Ahmedabad, 1 December, and gave a lecture on SHRIMP II and its geological applications.

Dr I.S. WILLIAMS visited the Geological Survey of India, Kolkata, 2 December, and gave a lecture on SHRIMP II and its geological applications.

Earth Environment

Dr M. AUBERT attended the Australian Archaeological Association Conference, Adelaide, Australia, December 2009

Mr. N. DARRENOUGUE, 2nd Marine Sciences Symposium, RSES, ANU, presented his PhD project through a brief talk entitled "Rhodoliths: a potential new biogenic archive of climate change".

Prof. P. De Deckker was a keynote speaker at 3rd the Geologica Belgica Conference in Gent, Belgium.

Prof. P. De Deckker attended the ESF-sponsored Conference on Mechanisms of Quaternary Climate Change held in Australia.

Dr A. DUTTON, Climate and Biotic Events of the Paleogene (CBEP), Wellington, NZ, 12-15 January, presented a paper entitled, "Elemental geochemistry and diagenesis in Eocene tropical planktonic foraminifera: Insights from laser-ablation profiling."

Dr A. DUTTON, COGS Conference, Perth, WA, Australia 6-7 July, presented a paper entitled "Last Interglacial Sea Level Records from the WA coastline: Insights from New Data and Glacio-hydro-isostatic Modeling".

Dr A. DUTTON, The Challenges of Dating Past Interglacials (PALSEA Workshop), Wood's Hole, MA, USA, 21 – 25 September, presented an invited key-note lecture entitled "Glacio-hydro-isostatic modeling of the Last Interglacial."

Dr A. DUTTON, The Challenges of Dating Past Interglacials (PALSEA Workshop), Wood's Hole, MA, USA, 21 – 25 September, presented an invited paper on "Sea Level & Ice Volume During the Last Interglacial."

Dr A. DUTTON, The Challenges of Dating Past Interglacials (PALSEA Workshop), Wood's Hole, MA, USA, 21 – 25 September, presented an invited paper on "Synthesis of Sea Level During the Penultimate Interglacial (MIS 7)."

Dr A. DUTTON, The Challenges of Dating Past Interglacials (PALSEA Workshop), Wood's Hole, MA, USA, 21 – 25 September, co-presented "U-series standard inter-laboratory comparison: A first look at the data."

Dr A. DUTTON conducted field work in the Seychelles in August 2009.

Dr S. EGGINS, 2009 American Geophysical Union Fall Meeting, San Francisco, USA, 14-18 December, co-authored papers entitled "The boron geochemistry of siliceous sponges" and "The boron geochemistry of siliceous sponges", and to assist release of the Photon-machines Inc-ANU laser ablation sampling systems

Dr S. EGGINS, Prof. P. DE DECKKER, Dr M.J. ELLWOOD and Mr G. NASH undertook field sampling programs at Lake Macquarie (NSW) in May and October.

Dr M.J. ELLWOOD, Sutton, J., M. Wille, S. Eggins, W. Maher, P.L., Croot, and M.J. Ellwood 2009. Germanium/Silicon fractionation in Sponges: Implications for Paleo-reconstructions of Oceanic Silicon. Australian Marine Science Association Conference. 5-9 July 2009. Adelaide Convention Centre.

Dr M.J. ELLWOOD, Ellwood, M.J., M. Wille, J. Sutton, W. Maher, S. Eggins, M. Kelly 2009. Silicon isotopic fractionation in marine sponges: A new model for understanding isotope fractionation in sponges and diatoms. Australian Marine Science Association Conference. 5-9 July 2009. Adelaide Convention Centre.

Dr M.J. ELLWOOD, Wille,M., Sutton,J., Ellwood, M., Maher,W., Eggins,S. and Kelly M. 2009. Silicon isotopic fractionation in marine sponges: A new paradigm and model for understanding silicon isotopic variations in sponges and diatoms. pp. A1444-A1444. 19th Annual VM Goldschmidt Conference, Davos, SWITZERLAND.

Dr M.J. ELLWOOD, Andersen,M.B., Vance,D., Archer,C., Archer C, Ellwood,M.J., Allen, C., Hellenbrand,C.D., and Anderson, R.F. 2009. The Zn Isotopic Composition of Diatom Frustules, a Proxy for Zn Availability in Ocean Surface Seawater A40-41. 19th Annual VM Goldschmidt Conference, Davos, SWITZERLAND

Dr M.J. ELLWOOD, Sutton,J.N., Wille,M., Ellwood,M.J., Maher,W.A. 2009. Germanium/Silicon and Silicon Isotope Records of Marine Diatom Opal from a Low Silicon Environment. PP11C-1334 American Geophysical Union Fall Meeting. 14-18 December 2009. San Francisco, California, USA

Dr M.J. ELLWOOD, de Leon, A., Wille,M., Eggins,S.M., Ellwood,M.J.,. The boron geochemistry of siliceous sponges. PP11C-1325. American Geophysical Union Fall Meeting. 14-18 December 2009. San Francisco, California, USA

Dr K.E. FITZSIMMONS attended the 2nd Asia-Pacific Conference on Luminescence and Electron Spin Resonance Dating, Ahmedabad, India, November 2009, and presented a paper entitled "Investigations into the natural luminescence sensitivity of Australian quartz: a diagnostic tool for sediment history?"

Dr K.E. FITZSIMMONS attended the Australian Archaeological Association Conference, Adelaide, Australia, December 2009, and presented a paper entitled "Towards a chronologic framework for human response to environmental change at Lake Mungo."

Prof R. Grün was invited to present *Reconstruction of cooling and denudation rates of the Eldzhurtinskiy Granite, Caucasus, using paramagnetic centres in quartz*. 2nd Asia-Pacific Meeting on Luminescence and ESR Dating. 12-15 November 2009, Ahmedabad, India.

Prof R. Grün gave seminars at Département de Préhistoire du Muséum National d'Histoire Naturelle, Paris, the Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1.

Prof R. Grün gave seminars at the Dept of Geography, Peking University, and the Institute of Geology, China Earthquake Administration, Beijing.

Ms S.C. LEWIS, PAGES YSM and OSM 2009, Corvallis, USA, 6-11 July, presented a paper entitled "Water isotope records of Australian palaeomonsoon dynamics over the last ~30 kyr: integrating speleothem reconstruction and GCM results".

Miss T.E. KELLY, Hong Kong Student Leadership Conference 1 – 6 June 2009, City University of Hong Kong, China SAR.

Miss T.E. KELLY, 7th International Conference on Geomorphology (ANZIAG), 6 – 11 July 2009, Melbourne, VIC, Australia. Presented a paper titled "Research into the Landscape Evolution and Palaeoenvironment of Lake Mulurulu Lunette, Willandra Lakes WHA, NSW".

Miss T.E. KELLY completed the ANZIAG Intensive Course for Young Geomorphologists 12 - 15 July 2009, Melbourne, VIC, Australia.

Miss T.E. KELLY, Cambridge University Summer Program 26 – 31 July 2009, University of Cambridge, UK.

Miss T.E. KELLY, Australian Archaeological Association Annual Conference, 11- 14 December 2009, Flinders University, Adelaide, South Australia. Presented a paper titled "A Preliminary Chronological Framework for the Lake Mulurulu Lunette".

Ms S.C. LEWIS, 9th ICSHMO, Melbourne, Australia, 9-13 July, presented a paper entitled "Speleothem reconstructions of palaeomonsoon dynamics from Flores, Indonesia over the last ~50 kyr".

Dr J. MALLELA attended the ARC Centre of Excellence Postdoc workshop, Brisbane, University of Queensland, 4/8/09.

Dr J. MALLELA was invited to talk at the ARC Centre of Excellence Symposium, Customs House, Brisbane, 6-7/8/09.

Dr J. MALLELA gave a seminar, *Assessing reef health: the managers toolbox,* at the Great Barrier Reef Marine Park Authority (GBRMPA) Townsville, Australia 21/10/09.

Dr J. MALLELA gave a seminar *River runoff and climate change: assessing reef health from the Caribbean to the GBR* at the Australian Institute of Marine Science, Townsville, Australia, 23/10/09.

Ms J. MAZERAT, 9th International Conference on the Southern Hemisphere Meteorology and Oceanography, Melbourne, Australia, 9-13 February.

Ms J. MAZERAT, 8th NCCR International Climate Summer School, Grindelwald, Switzerland, 30 August-4 September, presented a poster entitled "Coral and Speleothem Reconstruction of Ocean-Atmosphere Dynamics in Southern Insonesia during the 8.2ka event".

Ms J. MAZERAT, fieldwork on the islands of Sumbawa and Flores, Indonesia from 31 May - 6 July.

Mr I. MOFFAT, Wallis, L.A., Keys, B., MOFFAT, I. and Fallon, S., 2009, *Gledswood 1 Shelter: initial radiocarbon dates from a Pleistocene aged rockshelter site in north Queensland,* Australian Archaeology Conference, Adelaide, Australia.

Mr I. MOFFAT, Moffat, I., Wallis, L.A., Keys, B., Koch, R., Hounslow, M., Beale, A., Domett, K. and Holt, L., 2009, *Magnetism and Prehistory in Australia: Possibilities and Problems*, Australian Archaeology Conference, Adelaide, Australia.

Mr I. MOFFAT, Moffat, I., Grün, R., Kelly, T.E. and Pappin, D., 2009, *Detailed Geoarchaeological Investigations of the Northern Mungo Lunette*, Australian Archaeology Conference, Adelaide, Australia.

Mr I. MOFFAT, Kelly, T.E., Grün, R., Moffat, I., Fizsimmons, K.E., Pappin, D. and Doyle, C., 2009, *A Preliminary Chronological Framework for the Lake Mulurulu Lunette*, Australian Archaeology Conference, Adelaide, Australia.

Mr I. MOFFAT, Hasiotis, S.T., Moffat, I. and Reiley, M., 2009, *Preliminary Report on the Burrows and Behavior of the Bardi Grub (Insecta: Lepidotera: Hepialidae) from Pointbar and Levee Deposits of the Darling River, Bindora Station, near Pooncarie, New South Wales, Australia*, Geological Society of America Conference, Portland.

Mr I. MOFFAT, Moffat, I. and Grün, R., 2009, *Strontium Isotope Tracing of Human Migrations in the Levant*, Research School of Earth Sciences, Australian National University Student Conference, Canberra, Australia.

Mr I. MOFFAT, Kelly, T.E., Grün, R., Moffat, I., Aubert, M. and Fitzimmons, K., 2009, *Archaeometry at Lake Mulurulu,* Research School of Earth Sciences, Australian National University Student Conference, Canberra, Australia.

Dr B. OPDYKE, CBEP 2009 Wellington, New Zealand 6-21 January 2009

Dr B. OPDYKE , COGS Meeting, Perth WA, July 2009

Dr B. OPDYKE , Geological Society of America Meeting, Portland USA, October 2009.

Prof B.J. PILLANS conducted fieldwork in India from 23rd-29th March to collect samples for paleomagnetic dating of archeological sites.

Prof B.J. PILLANS attended the 7th International Conference on Geomorphology in Melbourne from 6-11th July 2009 and gave an invited oral presentation: "Permo-Carboniferous inheritance in Australian Landscapes". He was also the after Dinner Speaker at the conference dinner, speaking on the topic: "Geomorphology Downunder".

Prof B.J. PILLANS attended the Geosciences'09 conference in Oamaru, New Zealand, from 23rd-27th November 2009 and gave an oral presentation: "The Gravestone Project: Weathering rates from the dead".

Dr S. Sosdian conducted field work along Dr Mike Gagan in Nias, Sumbawa, and Flores, Indonesia from May 10-June 10;

Ms J. SUTTON, Sutton,J., Wille,M. Ellwood,M. and Maher,W. (2009) Germanium/Silicon and Silicon Isotope Records of Marine Diatom Opal from a Low Silicon Environment. AGU Fall meeting, San Francisco.

Ms J. SUTTON, Sutton,J., Wille,M. Ellwood,M., Maher,W., Kelly, M., Eggins,S. and Croot,P. (2009) Germanium/Silicon fractionation in Sponges: Implications for Paleo-reconstructions of Oceanic Silicon. AMSA2009 "Connectivity" conference, Adelaide.

Miss C.M THOMPSON attended the ANU Marine Symposium and presented a seminar entitled "Chemical and Textural Evidence for Diagenetic Overgrowth in Planktonic Foraminiferal Carbonate"

Dr M. WILLE, Goldschmidt Conference 2009, Davos, Switzerland, 21-26 July, presented a paper entitled "Silicon isotopic fractionation in marine sponges: A new paradigm and model for understanding silicon isotopic variations in sponges and diatoms".

Earth Materials & Processes

Prof R.J. ARCULUS held a Benjamin Meaker Fellowship at the University of Bristol from February 1st to April 30th; and an Institute of Advanced Studies Distinguished Fellowship at the University of Durham, September 20th to December 20th; Was Chief Scientist of Research Voyage SS02/2009 of the Marine National Facility May 1st to June 30th.

Dr A.G. CHRISTY attended the 8th International Eclogite Conference, Xining, Qinghai, China,25 Aug - 3 Sept., and gave a talk "Pressure dependence of the Zr-in-rutile thermometer: demonstration using Western Chinese eclogites." He also attended pre- and post-conference field trips.

Dr A.G. CHRISTY was a co-author on a talk presented by Ms. K.R. Adena, "Geochemistry of volcanic and impact glasses from the Taurus-Littrow area on the Moon", at the Australia Space Science Conference, Sydney, 28-30 Sept.

Dr A.G. CHRISTY attended the Biennial conference of the Specialist Group for Geochemistry, Mineralogy and Petrology of the Geological Society of Australia, Kangaroo Island, South Australia, 8-13 Nov., with associated field stops on the Fleurieu Peninsula and Kangaroo Island, and presented a poster "Improved bond valence parameters for Sb(III) and Sb(V), demonstrating coordination number independence of parameters."

Dr A.G. CHRISTY attended the Digital Core Consortium Annual Meeting, Australian Academy of Sciences, Canberra, 17-18 Nov., and was a co-author on the poster "Elastic anisotropy at the pore/grain scale", presented by Mr. Alon Arad.

Prof S. COX presented an invited lecture at the Geological Society of New Zealand annual conference in Oamaru in November. He also presented a lecture at the 2009 Euroconference on Rock Physics and Geomechanics in Ascona, Switzerland in September. He also presented a lecture at the University of British Columbia in January.

Mr R. FARLA attended the international conference Deformation, Rheology and Tectonics (DRT) in early September 09 and gave a presentation of his research in front of the 300 most important Earth scientists interested in rock deformation. His talk was titled: presented

"Dislocations in deformed fine-grained olivine: recovery kinetics and seismic attenuation." Received a distinction for the top three student talks.

Dr J.D. FITZ GERALD visited the Institut für Mineralogie, Westfalisches Wilhems-Universität, Münster, a reseach stay funded by the Deutscher Akademischer Austausch Dienst, in June-July.

Dr A. HALFPENNY attended the Society for Geology Applied to Mineral Deposits (SGA) 10th Biennial Meeting, Townsville, Australia, 15th-21st August and presented a talk entitled "Development and Evolution of Fracture-Controlled Flow Regimes and Gold Mineralisation, Porgera Gold Deposit, PNG."

Dr A. HALFPENNY attended the Deformation, Rheology and Tectonics Conference (DRT), Liverpool, England, 7th-9th September 2009 and presented a poster entitled "Development and evolution of fracture-controlled flow regimes and gold mineralisation, Porgera gold deposit, PNG" and presented a second poster entitled "Comparison of Dynamically recrystallised Quartz Rich Microstructures utilising Electron Backscatter Diffraction."

Dr A. HALFPENNY conducted field work at the Porgera Gold Mine, Papua New Guinea from 10th-20th June 2009.

Dr A. HALFPENNY conducted field work at the North Parkes copper/gold mine, NSW, Australia from 4th-8th May 2009, 25th-29th May 2009 and 26th October -6th November 2009.

Dr J. HERMANN, 19th annual V.M. Goldschmidt Conference, Davos, Switzerland, 20-26 August, presented a paper "Experimental constraints on carbonate and silicate melts and CO2 release during subduction of sediments" and was co-author on 6 other contributions.

Dr J. HERMANN, Biennial conference of the Specialist Group for Geochemistry, Mineralogy and Petrology, Kangaroo Island, Australia, 8-13 November, presented a paper "Trapping high pressure fluids in piston cylinder experiments: implications for trace element recycling in subduction zones" and was co-author on 2 other contributions.

Dr J. HERMANN, EURISPET (international PhD summer school), Granada, Spain, 21-27 June, presented two lectures.

Dr J. HERMANN conducted fieldwork in the Dora Maira Massif (Italy) from 1-2 July.

Dr J. HERMANN visited Dr Qing Qian at the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China, from 12-23 October and gave two invited seminars as well as an invited seminar at the School of Earth and Space Sciences, Peking University, Beijing, China.

Dr J. HERMANN presented invited seminars at the James Cook University, Townsville, on the 22 April, and at Adelaide University on the 22 May.

Mr K.N. HORNER, attended the 10th Australasian Environmental Isotope Conference & 3rd Australasian Hydrogeology Research Conference, Perth, Australia, 1-3 December, presented a paper titled "Environmental Tracers in Silicate Aquifers: Lower Murrumbidgee Groundwater Management Area, New South Wales"

Mr K.N. HORNER conducted field work in the Lower Murrumbidgee River Catchment of the Murray Basin from 16-28 March and 13-19 September 2009.

Prof I. JACKSON attended and presented papers at the General Assembly of the International Association for Seismology and Physics of the Earth's Interior (Cape Town, January), the Final Stagnant Slab Symposium (Kyoto, February), and the Fall Annual Meeting of the American

Geophysical Union (San Francisco, December), and lectured at the Deep Earth Mineralogy Centre of Excellence (Ehime University, Matsuyama, Japan, March).

Miss H. LI, Fourth International School "European Intensive Seminars of Petrology" (EURISPET) on "HIGH-PRESSURE METAMORPHISM AND SUBDUCTION ZONES", Granada, Spain, June 27 to July 5th, 2009, presented a poster and talk entitled "Experimental constraints on chlorine behavior in subducted sediments", conducted one day of practical sessions in the laboratory and 3 days of field work in the high-pressure, prograde peridotite and serpentinites of Cerro del Almirez (Sierra Nevada), and the Ronda Peridotite.

Miss S. McALPINE, attended the Biennial Conference of the Specialist Group for Geochemistry, Mineralogy and Petrology, Kangaroo Island, Australia, 8 – 13 November, presented a poster entitled "Mantle peridotites from the active New Britain-West Bismarck Arc front."

Dr L. MARTIN attendedBiennial conference of the Specialist Group for Geochemistry, Mineralogy and Petrology, Kangaroo Island, Australia, 8-13 November, presented a poster "Carbon recycling in subduction zones: insight from partial melting experiments on altered oceanic crust".

Dr. O. NEBEL attended the Goldschmidt conference, Davos, Zwitzerland 21-26 June, presented a paper entitled: Lu-Hf isotope inheritance from subducting detrital zircons during crustal formation.

Prof H. St.C. O'Neill attended the meeting of the Geological Society of Australia Special Group on Geochemistry, Petrology and Mineralogy held on Kangaroo Island where he presented papers on "The oxidation state of Uranium in silicate melts and its implications for U crystal/liquid partition coefficients".

Prof H. St.C. O'Neill visited Prof Xi Liu in Peking University, Beijing, in April and gave talks at Peking University, the Institute of Geology and Geophysics, Chinese Academy of Sciences, and the China University of Geosciences.

Prof H. St.C. O'Neill conducted experiments using synchrotron X-rays at the Advanced Photon Source, Chicago and the Photon Factory, Japan, in April, and the Australian Synchrotron in May.

Mr C. PIRARD attended the 19th V.M. Goldschmidt Conference, Davos, Switzerland, 21-26 June 2009 presented a talk entitled "Melt transport in the mantle: transition from dunite channels to pyroxenite dykes in the upper mantle section of New Caledonia".

Dr R. RAPP, 2009 Fall Meeting of the American Geophysical Union (AGU) in San Francisco, California, USA, December 13-18th, presented an invited paper entitled "Origin of primitive andesites by melt-rock reaction in the sub-arc mantle".

Earth Physics

Prof R.W. GRIFFITHS, the Ninth International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, February, presented a paper entitled "Processes for adjustment of the global overturning circulation to changing surface boundary conditions".

Prof R.W. GRIFFITHS, the ANU Marine Science Symposium, keynote lecture, "Mixing in the oceans", Canberra, 30 September

Dr A.McC. HOGG, the Ninth International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, February, presented a paper entitled "Wind stress forcing of the Southern Ocean".

Dr G.O. HUGHES, the Ninth International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, February, presented a paper entitled "The role of available potential energy in the ocean overturning circulation".

Prof B.L.N. KENNETT made a short visit to Taiwan in February for collaborative work on seismic wave propagation in subduction zones and presented a set of lectures on "Imaging the Earth". In July he spent a week in Tokyo working with Prof. T. Furumura on the nature of the bend in slab structure between Honshu and Hokkaido and then attended a workshop on Eaquations of State of materials at high temperatures and pressures at Ehime University. in Japan and gave a set of lectures and two seminars, he then engaged in collaborative work at the Earthquake Research Institute, University of Tokyo where he also presented a seminar. In September he spent a period of study leave at the University of Munich working on problems relating to the deep Earth.

Dr R.C. KERR, American Geophysical Union Meeting, San Francisco, USA, 14-18 December, presented a paper entitled "Thermal erosion of felsic ground by the laminar flow of a basaltic lava, with application to the Cave Basalt, Mount St. Helens, Washington".

Dr. N. RAWLINSON, IASPEI General Assembly, Cape Town South Africa, 10-16 January 2009, presented a paper entitled "WOMBAT:A high density rolling array experiment for passive seismic imaging in Australia".

Dr. N. RAWLINSON conducted fieldwork in New South Wales from 5-13 May; 1-11 June and 5-17 August.

Mr J. ROBERTSON, American Geophysical Union Meeting, San Francisco, USA, 14-18 December, presented a paper entitled "Cooling and solidification of channelized viscoplastic lava flows".

Dr M.L. RODERICK, American Geophysical Union Conference, San Francisco, USA, 14-18 December, convened a session titled "Evaporation and Water Transport Dynamics in the ABL", presented an invited paper titled "Projecting changes in catchment water availability using a Budyko framework".

Dr. M. SALMON, American Geophysical Union Conference, San Francisco, USA, 14-19 December, presented a poster entitled "AusMoho: A new Moho map of continental Australia".

Prof. M. SAMBRIDGE visited the Univ. of Victoria, BC, Canada, in February where he gave several student lectures on aspects of nonlinear inversion.

Prof. M. SAMBRIDGE attended the Joint European and National Astronomy Meeting (JENAM) as part of the European week of Astronomy in April at the Univ. of Hertfordshire, UK.

Prof. M. SAMBRIDGE visited and gave seminars at Univ. of Tasmania

Dr H TKALČIĆ chaired a special session entitled "Moho, lithosphere and upper mantle structure beneath Europe: What have we learned in 100 years" at the AGU Fall Meetingin San Francisco, December 2009.

Dr H TKALČIĆ gave an invited presentation entitled "Seismological Portrait of the Anomalous 1996 Bardarbunga Volcano, Iceland, Earthquake" at the AGU Fall Meetingin San Francisco, December 2009.

Dr H TKALČIĆ coauthored 12 presentations and gave a talk entitled "Earthquakes and Stations of the Southern Hemisphere: Keys to the Inner Core Anisotropy Puzzle?" in the special session on the Earth's core at the AGU Fall Meetingin San Francisco, December 2009.

Dr H TKALČIĆ gave two talks on the Earth's inner core in the geodynamics and seismology sessions of the EGU Annual Meetingin Vienna, May 2009.

Dr H TKALČIĆ gave an invited talk entitled "Inner core boundary properties from PcP and PKiKP waves" at the I*ASPEI General Assembly*, Capetown, South Africa, January 2009.

Dr H TKALČIĆ spent 1 month at JAMSTEC in Japan, collaborating with Dr. S. Tanaka on the structure of the Earth's core and interacting with a number of Japanese seismologists on other topics in seismology.

Dr P. TREGONING, American Geophysical Union Conference, San Francisco, USA, 13-18 December, co-authored a paper entitled "Assessment of 3D hydrologic deformation using GRACE and GPS".

Dr P. TREGONING, American Geophysical Union Conference, San Francisco, USA, 13-18 December, co-authored a paper entitled "Regional deformation from the 2004 Macquarie Ridge great earthquake, Australia-Pacific plate boundary zone".

Dr P. TREGONING, American Geophysical Union Conference, San Francisco, USA, 13-18 December, co-authored a paper entitled "Estimation of hydrological loading effects to correct VLBI analysis".

Dr P. TREGONING, American Geophysical Union Conference, San Francisco, USA, 13-18 December, co-authored a paper entitled "New Geodetic Infrastructure for Australia: The NCRIS / AuScope Geospatial Component".

Dr P. TREGONING, European Geophysical Union Conference, Vienna, Austria, 19-24 April, presented a paper entitled "Atmospheric effects in GPS analyses".

Dr M.L. WARD, European Geophysical Union Meeting, Vienna, Austria, 19-24 April, presented a paper entitled "Eddy response to variable atmospheric forcing in the Southern Ocean" and a poster entitled "Forcing of gravity waves by potential vorticity in a shallow water model".

Dr E. VANACORE conducted fieldwork in Central Australia in September 2009 for servicing the broadband stations of BILBY project.

Dr E. VANACORE conducted fieldwork in South Australia in late October and early November to assist with the Curnamona array pull out.

Dr M.L. WARD, Workshop on Mesoscale Eddies, Exeter, UK, 27-29 April, presented a poster entitled "The influence of standard modes of variability in an eddy-resolving Southern Ocean model".

Dr M.L. WARD, Australian Defense Force Academy, Canberra, 22 May, presented a paper entitled "Resonant scattering of oceanic gravity waves by balanced mesoscale eddies".

Integrated Ocean Drilling Program (IODP)

Neville Exon helped organize and chair a session at a Marine Geoscience Meeting of the Committee for Ocean Geosciences (COGS) in Perth in July, and presented two papers there, both related to IODP.

PRISE

Dr R.A. ARMSTRONG, AGU Fall Meeting, San Francisco, USA, 14-18 December.

Mr C.M. FANNING, Spring AGU Joint Assembly, Toronto, Canada, 24-27 May.

Mr C.M. FANNING, Geological Society of America Annual meeting, Portland, USA 18-21 October and Rocky Mountain section meeting, Orem, Utah 11-13 May.

Mr C.M. FANNING, The Geological Society Fermor Meeting "Rodinia: Supercontinents, Superplumes & Scotland", Edinburgh, Scotland, 6-9 September and field trip to the Scottish Highlands, 9-13 September.

Mr C.M. FANNING, Chilean Geological Congress, Santiago, Chile, 22-26 November.

Mr C.M. FANNING conducted fieldwork in the Flinders Ranges, South Australia 23-29 March.

Mr C.M. FANNING conducted fieldwork in the Sheeprock Mountains, Utah, USA, 13-17 May and the Portneuff gap area, Pocatello, Idaho, USA on 14 October.

Mr C.M. FANNING conducted fieldwork in the coastal regions of southern Chile, Puerto Montt to Santiago, 28 November - 4 December.

Mr S. HUI, 9th Australian Space Science Conference, Sydney, 28–30 September, presented a talk entitled "Geochemistry of Apollo 16 Lunar Impact Glasses: Tracking Formation and Transport through Chemistry and Age Dating".

Ms E. KISEEVA, The Deep Carbon Cycle (workshop), Zurich, Switzerland, 18–20 June.

Ms E. KISEEVA, Goldschmidt 2009, Davos, Switzerland, 21–26 June.

Ms E. KISEEVA, EURISPET, Granada, Spain, 27 June – 5 July.

Ms E. KISEEVA, internship at Tohoku University, Sendai, Japan, 10 Aug – 5 Nov 2009 to conduct high pressure (up to 20 GPa) experimental studies of carbonate eclogite phase relations, supervised by Prof E. Ohtani and Dr K. Litasov.

Mr J. McDONALD, 10th Australasian Environmental Isotope and 3rd Australasian Hydrogeology Conference, Perth, 1-3 December, presented a poster entitled "Strontium Isotope Composition Variations in the Lower Murrumbidgee Groundwater System, NSW".

Dr. M.D. NORMAN, Lunar Reconnaissance Orbiter Targeting Workshop, Tempe, USA, 6-9 June.

Dr. M.D. NORMAN, 9th Australian Space Science Conference, Sydney, 28-30 September, presented a paper entitled "Lunar Anorthosites as Targets for Exploration".

Dr M.D. NORMAN, AGU Fall Meeting, San Francisco, USA, 14-18 December.

Dr G.M. YAXLEY, The Deep Carbon Cycle (workshop), ETH, Zürich 18-20 June.

Dr G.M. YAXLEY, Goldschmidt 2009, Davos, Switzerland, 21-26 June, presented a paper entitled "Melting and melt-peridotite interactions in heterogeneous upper mantle sources of primitive volcanics".

Dr G.M. YAXLEY, CODES – the first 20 years (symposium), Hobart, 3-5 December.

Visiting Fellows

Dr R. V. Burne conducted fieldwork in England and Ireland in June-July 2009 comparing the environmental setting of the Carboniferous Bude Formation, North Cornwall, with the Carboniferous rocks of Loop Head, County Claire, Ireland.".

Dr R. V. Burne undertook fieldwork with Prof. Josef Paul of Gottingen University on the Bundsanstein oolitic limestones and stromatolites on the margins of the Harz Mountains, Germany in July 2009.

Dr E. A. Felton attended Sapphire Coast Marine Discovery Centre's **Marine Science Forum** in Eden on 21-22 March.

Dr E. A. Felton attended the NSW Department of Environment, Climate Change and Water's **Marine Habitat Mapping Information Session** at Sydney on 26 August.

Dr E. A. Felton attended the **Selwyn Symposium** "Origin of the Eastern Highlands" in Melbourne on 24 September.

Dr E. A. Felton co-authored a poster at the **7th International Conference on Geomorphology** in Melbourne, July 2009. Switzer, A. D., Felton, E. A., Fink, D. M., Crook, K. A. W. The age of the coastal cliff-top platform and boulders at Little Beecroft Head, southeast Australia.

Prof K. LAMBECK, Climate Change Congress, Copenhagen, Denmark, 10-12 March, presented a paper entitled "Sea level change as an indicator of cryosphere instabilities".

Prof K. LAMBECK, Magellan IODP Workshop, Copenhagen, Denmark, 13-15 March, presented a paper entitled "The Scandinavian ice sheet: into and out of the Last Glacial Maximum".

Prof K. LAMBECK, 'Il bacino del Tevere', Accademia Nazionale dei Lincei, Rome, Italy, 23 March, presented a paper entitled "Sea level change along the Thyrrenean Coast: past and future".

Prof K. LAMBECK, GIA Modelling Training School, Gävle, Sweden, 1-5 June, presented a lecture entitled "Sea level changes".

Prof K. LAMBECK, Indian National Science Academy Platinum Jubilee Concluding Function, Kolkata, India, 7-10 December, presented a paper entitled "The role of national academies in education, research and science policy: the Australian experience

Dr W. Mayer, XXIII International Congress of the History of Science and Technology, Budapest, Hungary, 28 July-2 August, presented a paper entitled "Voyages of scientific discovery in times of war: The Baudin and Flinders expeditions to Australia (1801-1803)".

Dr W. Mayer, Colloque, Portés par l'air du temps: la vie et les voyages du capitaine Baudin, Brussels, Belgium, 2-5 September, presented a paper entitled « L'accueil en Europe des résultats géologiques de l'expédition Baudin en Australie ».

KEITH SCOTT, 24th International Applied Geochemistry Symposium, Fredericton, New Brunswick, Canada, 1-4 July 2009, presented a paper entitled "Exploration for Zn-rich mineralisation in semi-arid environments: an example from the Cobar region, NSW, Australia" and a poster "Exploration for deeply buried gold deposits in the Bendigo region, Victoria, Australia: regolith geochemistry of the Lockington area".

KEITH SCOTT, 5th Australian and New Zealand Aerosol Seminar,Auckland,New Zealand, 22-24 July 2009, presented a paper entitled "Dust and terrestrial salt (NaCl) in SE Ausralia: Implications for Aeolian co-transport and co-deposition".

KEITH SCOTT wrote report "Characteristics of soils of the ELura district and their implications for base metal exploration in western NSW" (CSIRO EM Report P2009/1754) for CBH Limited (October 2009).

EDITORIAL RESPONSIBILITIES

Earth Chemistry

Dr Y. AMELIN, Associate Editor, Geochimica et Cosmochimica Acta.

Dr Y. AMELIN, Member of the editorial board, Chemical Geology.

Dr M.A. FORSTER, reviewer for Journal of Geophysical Research (Solid Earth) and Lithos.

Dr. M. Honda, Associate Editor, Geochemical Journal.

Earth Environment

Prof. P. De Deckker editorial board of Journal of Paleolimnology, Marine Micropaleontology.

Prof. P. De Deckker editorial board of Journal Palaeogeography, Palaeoclimatology, Palaeoecology.

Dr K.E. FITZSIMMONS, Editor, Quaternary Australasia.

Dr S.M. EGGINS, Editorial Board, Quaternary Geochronology.

Prof. R. GRÜN Editor-in-Chief of *Quaternary Geochronology*, associate editor of the *Journal of Archaeological and Anthropological Sciences* and member of the Editorial Boards *of Quaternary Science Reviews* and *Radiation Measurements*.

Mr I. MOFFAT, Associate Editor, Exploration Geophysics

Dr B.N. OPDYKE is one of the four primary Science Editors at **Geology** (Geological Society of America Publication)

Prof. B.J. PILLANS, Editorial Board, Quaternary Science Reviews.

Dr G YOUNG, Editorial Board, Alcheringa; Guest editor, Palaeoworld (IGCP 491 special issue).

Earth Materials & Processes

Prof R.J. ARCULUS, Editor, Journal of Geophysical Research, Solid Earth.

Dr A.G. CHRISTY, Editorial Board, Mineralogical Magazine (UK).

Dr A.G. CHRISTY, Editorial Board, Central European Journal of Geosciences.

Dr A.G. CHRISTY, reviewed manuscripts for Mineralogical Magazine, Journal of Petrology, Journal of Metamorphic Geology.

Prof S F Cox continued as a member of the Editorial Advisory Boards of Journal of Structural Geology and Geofluids.

Dr J.D. FITZ GERALD, Editorial Board, Physics and Chemistry of Minerals.

Dr J. HERMANN, Editor, Journal of Petrology.

Dr J. HERMANN, Associate Editor, LITHOS.

Prof I. JACKSON, Member Editorial Board, Physics of the Earth and Planetary Interiors, Earth and Planetary Science Letters.

Prof G. LISTER, Associate Editor, Journal of Geophysical Research, American Geophysical Union.

Prof H. St.C. O'Neill, Editorial Board, Chemical Geology.

Earth Physics

Prof R.W. GRIFFITHS, Associate Editor, Journal of Fluid Mechanics.

Prof B.L.N. KENNETT, Member of Advisory Editorial board for *Physics of the Earth and Planetary Interiors* and *Earth and Planetary Science Letters.*

Dr. N. RAWLINSON, editorial board, Tectonophysics

Dr. N. RAWLINSON, guest editor on special volume "Convergent plate margin dynamics: new perspectives from structural geology, geophysics and geodynamic modelling" Rawlinson and Schellart (eds), Tectonophysics

Dr. M.L. RODERICK, Associate Editor, Water Resources Research (American Geophysical Union).

Dr P. TREGONING, Associate Editor, Journal of Geophysical Research (solid Earth).

PRISE

Dr R.A. ARMSTRONG, Editorial Board, Journal of African Earth Sciences.

Dr M.D NORMAN, Editorial Board, Australian Journal of Earth Sciences.

Visiting Fellows

Richard Barwick designed the cover for the journal *Aboriginal History* and is currently editing the 40 figures for a forthcoming monograph on Victorian Aborigines by Dr Marie Fels. of Melbourne.

Dr R. V. Burne was invited to adjudicate in the case of a disputed review process for the Proceedings of the National Academy of Science, USA.

Dr E. A. Felton serves on the Editorial Board, *Marine Geology*.

Dr E. A. Felton reviewed several papers on aspects of rocky shoreline geology and tsunami research for the journal *Geology*.

Dr C.T. Klootwijk, Guest Editor Special Volume on Paleomagnetism and Rock Magnetism for the Australian Journal of Earth Sciences.

KEITH SCOTT, Editorial Board for proposed book "Shaping a continent, Building a nation: A geology of Australia" for 34th International Geological Congress 2012.

OUTREACH AND WORKSHOPS

Earth Chemistry

Dr J.J. BROCKS was interviewed by the *Sydney Morning Herald*, the *BBC* and by *Science News* about the appearance of the earliest animals in the geological record.

Dr J.J. BROCKS gave a radio interview on local and national news (*World Today* on ABC) about the earliest evidence of animals and Charles Darwin's conundrum of the Cambrian Explosion.

Dr J.J. BROCKS gave an interview for *ABC Science Online* (interviewer D. Cooper) about the first appearance of life on Earth.

Mr A. CHOPRA was an invited speaker at an ANU residence's (Bruce Hall) 2009 High Table event on 9 September themed 'Are we alone? An exploration into life and the universe'. C.H. Lineweaver (RSES & RSAA) and P. Francis (RSAA) were the other invited speakers.

Mr A. CHOPRA presented invited astrobiology oriented public talk entitled 'In the Shadow of the Moon' at two residential halls at ANU (27 May at UniLodge and 3 June at Burgmann College) to approximately 100 residents in 2009. The talk celebrated the 40th anniversary of the Apollo 11 Moon landings and considered connections between the origin of the Moon and the life on Earth.

Mr A. CHOPRA assisted with other RSES staff and students in organising hands-on astronomy and planetary science based activities at the 2009 National Science Week event hosted at CSIRO Discovery Centre on 21-22 August.

Mr A. CHOPRA participated and presented in a 'Dance your PhD' workshop at the 2009 Stromlo Christmas Seminars at RSAA on 26 November 2009.

Mr A. CHOPRA completed the ANU Graduate Short Course Award in Science Communication 26-28 October 2009.

Mr A. CHOPRA presented an invited lecture to approximately 200 first year chemistry undergraduate students at the University Of Western Australia on the process of modern scientific research on 31 March 2009.

Ms T.A. EWING participated in outreach activites at the "Canberra Science Spectacular", held at the CSIRO Discovery Centre on 21 August as part of National Science Week.

Dr. M.A. FORSTER was tour leader for the Penrose Conference "Lithospheric Extension" post-conference field trip "Core Complexes of the Central Aegean", for 22 international academics participants.

Dr. M.A. FORSTER provided tours of the Argon Facility and Microscope Facility to the Earth Chemistry Review Panel, for the Applicants for the Directorship, and various visiting academics.

Dr. C.H. Lineweaver appeared on the ABC "Catalyst" science show, interviewed by Graham Philips about Space Weather. Broadcast Australia-wide on 7 March, approximately one-minute segment (recorded March, 2007).

Dr. C.H. Lineweaver appeared live on Channel 7, "Sunrise" program, interviewed by D. Kosh and N. Barr about the new water recovery system on the International Space Station, 22 May.

Dr. C.H. Lineweaver appeared on the ABC "Catalyst" science show, interviewed by Graham Philips about Lineweaver's research on the lunar impact record. Recorded 1 June at Mt

Stromlo, broadcast 16 July.
Dr C.H. Lineweaver appeared live on Sky News Australia, interviewed by Leigh Hatcher about the relaunch of NASA's Space Shuttle. Approximately three-minute interview broadcast 26 July.

Dr. C.H. Lineweaver appeared on the ABC "Compass" lead-in to the retrial of Galileo, interviewed by Deborah Boerne. Excerpts of this interview were shown as part of the UNSW retrial of Galileo on Oct 26 (filmed at Mt Stromlo, 24 September).

Dr. C.H. Lineweaver appeared live on Channel 10, "Project 7", interviewed about the Oct 6, 2009 10-meter asteroid that burnt up over southern Sulawesi, 28 October.

Dr. C.H. Lineweaver will appear in the role of Christopher Clavius, the Pope's astronomer, on the ABC "Compass" documentary retrial of Galileo, filmed during the UNSW production at Clancy Auditorium, 26 October. One-hour documentary to be broadcast in early 2010.

Dr. C.H. Lineweaver was interviewed live about "Big Questions" every other Tuesday afternoon for 10 or 15 minutes by Genevieve Jacobs for her Canberra ABC 666 radio show on the following dates and times:

> 21 April, about Stephen Hawking's illness and contribution to cosmology;
> 5 May, about the origin of the universe;
> 19 May, about the origin of the Earth;
> 2 June, about the origin of life;
> 16 June about Richard Dawkins, Paul Davies and the relationship between science and religion;
> 21 July, about the exploration of the Moon on the occasion of the 40th anniversary of Apollo 11, as part of a 2 hour special. Rebroadcast 21 July on ABC Northern Tasmania (Launceston), on the Drive Program with Hillary Burden, ABC 666 Canberra, on the Drive Program with Louise Maher, and on ABC 936 Hobart, Tasmania Drive Program with Louise Saunders;
> 18 August, about the human race and phylogenetic trees; and
> 1 September, about the future of the Earth.

Dr C.H. Lineweaver was interviewed live on 21 April by Lindy Burns, "Drive" show in Melbourne, 5:20-5-45 pm, Melbourne radio, about Gliese 581d, the discovery of a 2-Earth-mass planet around an M star.

Dr C.H. Lineweaver was interviewed live by Lindy Burns, "Drive" show in Melbourne, 774 Melbourne, 12 May, about the Space Shuttle Atlantis launch and repair mission to the Hubble Space Telescope.

Dr C.H. Lineweaver was interviewed and participated in a panel discussion on 24 May, with Marcus Chown and Paul Willis (ABC, Catalyst program) as part of Sydney Writer's Festival, Cafe Scientifique on the topic "The Science of Parallel Universes", to be broadcast on ABC radio, 27 December.

Dr C.H. Lineweaver was interviewed on 12 August by Jennifer Macey (ABC) about the Tidbinbilla Cosmos-Magazine-sponsored Kim Carr message to Gliese 581d. Broadcast Australia-wide on ABC at noon on "The World Today", in Canberra on ABC 666, and on Radio National.

Dr. C.H. Lineweaver was interviewed live on 17 August, by Catherine McLernon for the Brekky Show on Radio MAMA in Geraldton WA, about "Is there more than one universe?"

Dr C.H. Lineweaver was interviewed live on 19 August, by Damien Smith of Perth Radio (ABC), (arranged by Peter Barr), about "Is there more than one universe?"

Dr C.H. Lineweaver was interviewed live on 24 September by Shane McLeod (Radio National) on the discovery of water on the Moon. Also broadcast on ABC Canberra 666.

Dr C.H. Lineweaver was interviewed live on 9 October, by John Barron (ABC National Radio Drivetime host), about the impact of the LCROSS satellite into the Moon.

Dr C.H. Lineweaver was interviewed live on 16 October by Jenny Bates/Jenny McMahon of ABC Radio Newcastle, about a new paper in Science magazine on the asteroid 2 Pallas.

Dr C.H. Lineweaver was interviewed by Nicole Steinke of 360 ABC Radio National, broadcast 17 October, documentary about the motivations of amateur and professional astronomers. Rebroadcast on Wednesday, 21 Oct. Brent Clough (interview recorded 19 June).

Dr C.H. Lineweaver was interviewed live on 20 October by Christopher Lawrence of ABC 936 Hobart, about the multiverse and Lineweaver's lecture at the University of Tasmania.

Dr C.H. Lineweaver gave a series of lectures to the National Youth Science Students, RSAA, 9, 15 and 29 January.

DR. C.H. Lineweaver gave a lecture "Astrobiology" to the RSAA Summer Scholars, 4 February.

Dr. C.H. Lineweaver gave a lecture answering the ten most important scientific questions posed by Year 10 science students at Melrose High School, organised by Geoff McNamara, 21 May.

Dr. C.H. Lineweaver gave a lecture at Wiruna, NSW to the Astronomical Society of New South Wales, entitled "How did our Universe Begin?", 23 May.

Dr. C.H. Lineweaver participated in the Sydney Writer's Festival. He gave a presentation and was part of a panel discussion on "The Science of Parallel Universes", 24 May; Master of Ceremonies was ABC's Science Journalist Paul Willis and the other participant was science writer Marcus Chown.

Dr. C.H. Lineweaver gave a lecture "Cherries and Cosmology" in Young, NSW at the Young Services Club, to high school students, 2 June, 2009 as part of ANU's effort to attract rural students to ANU.

Dr. C.H. Lineweaver participated in, and gave a lecture "Cosmobiology: Our Place in the Universe", at the 35th annual Prof. Henry Messel Science School at the University of Sydney, 23 – 24 July.

Dr. C.H. Lineweaver gave the Annual Paul deLaeter Physics Lecture "Are We Alone?" to ~ 400 high school students at the University of Western Australia, 20 August.

Dr. C.H. Lineweaver participated in a panel discussion at ABC Studios, Ultimo, Sydney, for Science Week on Extraterrestrial Life, with Fred Watson, Paul Willis and Graham Phillips, 29 August.

Dr. C.H. Lineweaver gave a lecture "Are We Alone?" to high school students at Don College, Devonport, Tasmania, 19 October, host Stephen Crocker.

Dr. C.H. Lineweaver gave a lecture "Are We Alone?" to high school students at Launceston College, Launceston, Tasmania, 20 October, host Jason Dicker.

Dr R. SALMERON is a Member of the Gemini Planet Finding Science Working Group.

Dr R. SALMERON is a Visiting Fellow, Centre for Astrophysics & Supercomputing, Swinburne University of Technology. Presented a talk entitled "Magnetic fields and protoplanetary disk dynamics".

Dr R. SALMERON is a Visiting Fellow, Centre for Stellar and Planetary Astrophysics, Monash University. Presented a talk entitled "Magnetic fields in protoplanetary disks".

Dr R. SALMERON is a Visiting Fellow, Max Planck Institute fur Astronomie, The University of Heidelberg. Presented a talk entitled "Magnetic activity in protoplanetary disks".

Ms J. Thorne attended the SIMS student workshop 2009, at the University of California, Los Angeles, USA, 17-20 February 2009.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students attending the National Youth Science Forum, 15 and 29 January.

Dr I.S. WILLIAMS was a guest on the radio 2XX Fuzzy Logic Science Show, 15 February.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students from the Department of Earth Sciences, Tokyo University, 11 March.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by ANU Anthropology students, 30 July.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students and staff from Dickson College, 16 September.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by Year 6 students and staff from Blaxland Public School, 30 September.

Earth Environment

Mr. N. DARRENOUGUE was interviewed by ANU communication officer Mrs. M. Bannister-Tyrrel, to appear in the 2010 Science, Medicine and Health Graduate prospectus.

Prof. P. De Deckker gave several radio interviews during several dust storm events in September-October this year.

Dr A. DUTTON was interviewed live on ABC Radio 666 on 7 April about her research to reconstruct sea level using submerged speleothems in Italy.

Dr A. DUTTON was interviewed by numerous national newspapers (e.g., The Australian, The Sydney Morning Herald) and ABC Science (online) amongst other news publications that ran articles on her research to reconstruct sea level using submerged speleothems in Italy and was asked to comment on the significance of the break-up of the Wilkins Ice Bridge in Antarctica.

Dr A. DUTTON gave a lecture at University House on 13 May entitled "Lessons from the Past: Sea level change during previous warm interglacial periods."

Dr A. DUTTON gave a lecture to the ACT division of the Geological Society of Australia entitled, "Lessons from the past: Sea level change during the Last Interglacial."

Dr S.M. EGGINS is a member of the Research Advisory Group of the Sapphire Coast Marine Discovery Centre, Eden, NSW.

Dr M.J. ELLWOOD was interviewed on radio about the a first year field trip to Eden. Approximately 3 minute interview with, ABC Radio, broadcast at 6.50 am 22 September.

Dr K.E. FITZSIMMONS was interviewed by ABC Mildura-Swan Hill radio about human-environment interactions in the distant past in the Willandra Lakes World Heritage Area, 2 November 2009.

Dr K.E. FITZSIMMONS was guest lecturer at Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany.

Dr K.E. FITZSIMMONS was invited to attend the OZ-INTIMATE (Australian Integration of Ice, Marine and Terrestrial records of the Last Glacial Maximum and Termination – a core programme of the International Union for Quaternary Research palaeoclimate commission) workshop at Lucas Heights (ANSTO), Sydney.

Dr K.E. FITZSIMMONS was guest lecturer at the Department of Physical, Environmental and Mathematical Sciences, University of New South Wales at Australian Defence Force Academy, Canberra.

Dr K.E. FITZSIMMONS gave seminars at the ANU Quaternary Forum and RSES Earth Environment Group meetings.

Dr K.E. FITZSIMMONS is a regular contributor on the Fuzzy Logic Popular Science radio show, 2XX FM.

Miss T.E. KELLY had her research reported in the Canberra Times, 22 March 2009, in an article titled "Fastening on to the Future".

Miss T.E. KELLY prepared and presented an interactive display based on her research, for the National Science Week Science Spectacular at CSIRO Discovery, Canberra.

Miss T.E. KELLY was interviewed and podcast regarding her Willandra Lakes research, by a student from the ANU Centre for the Public Awareness of Science.

Dr J MALLELA was interviewed on Weather channel broadcast television about her recent publication 25/7/09. The interview was on hurricanes, cyclones and coral recruitment.

Mr I. MOFFAT presented a paper entitled The Application of Geophysical Techniques to Archaeological Sites in Australia to the Australian Society of Exploration Geophysics meeting in Canberra, ACT.

Mr I. MOFFAT presented a paper entitled Geophysical Prospection at the Meadows' Wesleyan Cemetery to the Quaternary forum meeting in Canberra, ACT.

Mr I. MOFFAT presented a public lecture entitled Seeing Beneath the Soil: Locating Historic Burials with Geophysical Techniques to the Western Australian Museum in Albany, WA.

Mr I. MOFFAT presented at public lecture entitledArchaeology of Meadows' Wesleyan Cemetery as part of the Meadows 150 Celebrations in Meadows, SA.

Mr I. MOFFAT presented a paper entitled The Geophysical Detection of Historic Graves within the Department of Archaeology Seminar Series, Flinders University, SA.

Mr I. MOFFAT presented a paper entitled Applications of Geophysical Techniques to Archaeology to a meeting of the Canberra Archaeology Society, Canberra, ACT.

Mr I. MOFFAT co-authored a paper entitled Archaeological geophysics at Flinders University for issue 143 of the Australian Society of Exploration Geophysics magazine, Preview in December.

Mr I. MOFFAT appeared on the cover of issue 141 of the Australian Society of Exploration Geophysics magazine, Preview in August.

Mr I. MOFFAT was featured in an article discussing his research entitled Digging up history for families in the Albany Advertiser, 16/04/09

Mr I. MOFFAT gave a radio interview discussing his research, 100.9FM, Albany, 16/04/09

Mr I. MOFFAT gave a television interview discussing his research, WIN News, 14/04/09

Mr I. MOFFAT featured in a magazine article discussing his research, Australian Geographic, April 2009.

Dr B.N. OPDYKE gave Monthly Radio interviews on Local Radio 2xx on Environmental matters. Outreach talks on Global Change at Melrose High School, Campbell High School, and Girls Grammer.

Dr S. SOSDIAN was interviewed on ABC radio news about her findings of a recent publication on paleoclimate. The interview was with Clarissa Thorpe, ABC radio news on Thu Jul 23, 2009 12:28pm.

Ms J. SUTTON contributed to CSIRO Discovery Centre, National Science Week Outreach.

Miss C.M. THOMPSON attended the ANU Sponge Taxonomy Workshop 23 November.

Dr G. YOUNG conducted daily geology walks demonstrating the Permian geology and palaeontology at Merry Beach for members of the public during the ANU Open Week at Kioloa Field Station in January, 2009.

Dr G. YOUNG gave an evening public lecture on '2008 Discovery – giant Devonian fossil fish from coastal platform S of Eden, NSW'.

Dr G. YOUNG gave two lectures to the Geological Society of Australia on 21 April and 18 August,

Dr G. YOUNG gave a presentation on 'Charles Darwin the geologist' at the Evolution Conference in Melbourne in Februar.

Dr G. YOUNG gave a presentation at the Conference on Australian Vertebrate Evolution, Palaeontology and Systematics at University of NSW in June.

Dr G. YOUNG's fieldwork and fossil discoveries near Eden on the south coast were featured in local newspapers (Eden, 14 May; Merimbula, 8 July) and was interviewed for ABC southeast on 25 May.

Dr G. YOUNG gave a televised report shown on WIN News 1 May.

Dr G. YOUNG was interviewed and photographed for an article on research funding at ANU in *The Canberra Times* on 27 October.

Earth Materials & Processes

Prof R.J. ARCULUS participated in the EURISPET workshop in Granada, Spain, in July, 2009.
Prof S F COX presented a 3 day workshop in Lima (Peru) for geoscientists of VALE Exploration. The workshop dealt with aspects of structural controls on permeability and fluid flow in ore systems. Professor Cox also contributed to an industry-based workshop in Vancouver in January.

Dr A. HALFPENNY gave a talk and discussion session at the Porgera mine site on structural geology

Dr J. HERMANN coordinated the Earth Science presentation for NATIONAL SCIENCE WEEK at the CSIRO Discovery (21-22 August).

Dr J. HERMANN coordinated visits of students and delegations at RSES: 2 groups participating at the National Youth Science Forum (15 and 29 January), one day visit of students from the Department of Earth Sciences at Tokyo University (11 March) one afternoon visit of school students from Baxland Public School (NSW; 30 Sept) and a visit of a delegation from the Chinese University of Geosciences (11 Dec).

Mr K.N. HORNER, ANU National Water Week Seminar Series hosted by RSES, 21 October, presented a paper titled "How Connected is Connected: Geochemical Techniques for Assessing Groundwater/Surface Water Interaction".

Dr D.C. "BEAR" McPHAIL organised a workshop on geochemical modelling using Geochemist's Workbench, presented by Tom Meuzelaar of Rockware (Colorado, USA) 22-25 June 2009.

Dr D.C. "BEAR" McPHAIL provided expert advice on geological monument/display at Questacon, ACT.

Dr D.C. "BEAR" McPHAIL provided independent expert commentary to the Alice Springs News on possible environmental impacts of uranium mining and transport.

Dr. NEBEL visited a workshop on analytical geochemistry in Davos, Switzerland.

Earth Physics

Throughout the year, members of the GFD Group presented tours and demonstrations during visits of high school and undergraduate students to the GFD Laboratory, including for the National Youth Science Forum and for Graduate Students from Tokyo University.

Prof R.W. GRIFFITHS, DR A. McC. Hogg, Dr G.O. HUGHES and DR A. Dutton made a submission to Senate Select Committee on Climate Policy regarding the proposed Carbon Pollution Reduction Scheme.

Prof R.W. GRIFFITHS participated, as a representative of the Australian Academy of Science, in a workshop on development of the scheme Excellence for Research in Australia (ERA), Joint Academies Forum and the Australian Research council.

DR A. McC. HOGG gave an after dinner speech at the Singapore-Australia Solar Energy Workshop, ANU, entitled "Climate Change: Developments since AR4".

Prof B.L.N. KENNETT gave a number of radio interviews on issues related to earthquakes and tsunamis.

Dr M.L. RODERICK was interviewed on television, radio and for newspaper articles about the launch of the new ANU Global Water Atlas, 4 August.

Dr M.L. RODERICK presented an invited lecture called 'Dynamic Terrestrial Surfaces for Earth System Modelling' at the ARC Network for Earth System Science Winter School at UNSW, 9 September.

Dr M.L. RODERICK taught Year 11 biology students at Radford College about climate change and human ecologic impacts as part of the federal "Scientist-in-Schools" program, 6 November.

Dr M.L. RODERICK presented a web-based seminar on climate change to school teachers from remote communities throughout Queensland with the assistance of the Queensland Resources Council, 16 November.

Dr M. SALMON helped present an interactive earthquake hazard seminar to students at Radford college 16 October

Throughout the year, members of Seismology and Mathematical Geophysics group presented tours and demonstrations during visits of high school and undergraduate students to the ANSIR seismic instrument Laboratory and TerraWulf computational facility, including for the National Youth Science Forum, Radford College, and Graduate Students from Tokyo University.

In November members of the Seismology and Mathematical Geophysics group presented a series of talks and demonstrations at Radford College Yr 6 to coincide with a study unit on Natural Hazards. Prof. SAMBRIDGE also demonstrated seismic equipment at Lyneham Primary School, ACT, during Science week.

Dr M. SALMON helped present and interactive display at CSIRO for National Science week August 22

Dr M. SALMON introduced students to our seismic imaging facility for National Youth Science Forum January 29

Dr M. SALMON introduced graduate students visiting from Tokyo University to our seismic imaging facility March 11

Dr. E. SAYGIN participated as a volunteer at the RSES booth at CSIRO as part of the National Science Week activities. (August 2009)

Dr E. SAYGIN volunteered at Radford College for two outreach events to help teach the basics of seismology, basics about volcanoes, and the hazards associated with these phenomena. (October 2009)

Dr H TKALČIĆ gave a keynote lecture on the Earth's inner core at the workshop entitled "From Core to Crust: Towards an Integrated Vision of Earth's Interior" held at the International Centre for Theoretical Physics (ICTP), Trieste, Italy.

Dr H TKALČIĆ gave invited seminar talks to University of Melbourne, University of Zagreb, University of Tokyo/Earthquake Research Institute, Tokyo, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, and National Research Institute for Earth Science and Disaster Prevention (NIED), Tsukuba.

Dr P. TREGONING was interviewed on ABC and SBS news and also gave around 10 radio interviews about the drought in the Murray-Darling Basin. He gave an invited presentation at the National Water Commission on measuring groundwater using space gravity, was an invited scientist at the Café Scientifique at the Alliance Française de Canberra and gave an invited presentation at Parliament House as part of the "Run for a Safe Climate". He gave a presentation to year 6 students at Telopea Park School on observing the effects of climate change.

Dr. E. VANACORE participated as a volunteer at the RSES booth at CSIRO as part of the National Science Week activities (August 2009)

Dr E. VANACORE volunteered at Radford College for two outreach events to help teach the basics of seismology, basics about volcanoes, and the hazards associated with these phenomena. (October 2009)

DR. M. WARD, Ms A. MORRISON and Mr. K.D. STEWART attended the Australian Research Council Research Network for Earth System Science (ARCNESS) winter school on Earth System Modelling.

Integrated Ocean Drilling Program (IODP)

Three eminent European IODP scientists, Peter Clift, John Parkes and Achim Kopf gave seminars at RSES and elsewhere in Australia, with considerable funding from AIO.

Neville Exon helped organize and chair two meetings in Pusan, Korea in April. One was on the potential formation of an Asia Pacific IODP Consortium and the other on potential Marine Geoscience Cooperation in the South West Pacific. He gave several papers at those meetings. He is joint chair of the Marine Geology & Geophysics Consultative Group for the Marine National Facility Future Research Vessel, which reported in December (report is on www.iodp.org.au under News and Events). He is also a member of the higher level Technical Advisory Group for the new vessel, which will continue to deal with new vessel matters for at least a year.He reviewed several research papers during the year and also an application for a full Professorship at Curtin University.

He gave a talk in the RSES Seminar Series entitled "Mass transport on the continental slope between Grafton and Noosa – could it generate tsunamis?"

PRISE

Dr R.A. ARMSTRONG participated in a Workshop on U-Pb dating by LA-ICP-MS in San Francisco, USA, 12 – 13 December.

Mr S. HUI demonstrated at the CSIRO Discovery Centre for National Science Week.

Dr M.D NORMAN was interviewed on ABC regional radio, and newspapers in Sydney, Perth, and Melbourne about water on the Moon and meteorites from Mars.

Visiting Fellows

Dr R. V. Burne gave presentations to community organizations in Lake Preston and Mandurah, WA, on the scientific significance and conservation strategies for the Yalgorup Lakes National Park, WA, and to community organizations and the Queanbeyan Council, NSW, on the geology, geomorphology and hydrology of Googong.

Dr E. A. Felton serves on the Executive Board of the Sapphire Coast Marine Discovery Centre, Eden NSW.

Dr E. A. FELTON is providing NSW National Parks with accurate geological information for signage in coastal national parks on the NSW South Coast.

Dr E. A. FELTON provided advice to NSW National Parks concerning geotechnical stability of cliffs used for beach access in coastal national parks on the NSW South Coast.

Dr C. Klootwijk prepared a report on greenhouse gas reduction targets for the Standing Committee on Climate Change, Environment and Water of the ACT Legislative Assembly.

Prof K. LAMBECK, as President of the Academy of Science, has provided a number of interviews on radio and print during 2009. This included the televised National Press Club address on 9 September 2009 entitled "Internationalisation of Australian Science" (http://www.science.org.au/events/lectures-and-speeches/npc2009.htm), an Australian

National Library oral history interview, an opinion piece 'Comments on *Heaven and Earth: Global Warming: The Missing Science*' (presented on ABC Radio National show, Ockham's Razor, broadcast at 8.45am on 7 June 2009 http://www.abc.net.au/rn/ockhamsrazor/stories/2009 /2589206.htm#transcript), and an interview on the internationalisation of Australian Science on the ABC-TV 7.30 Report on 8 September 2009 (http://www.abc.net.au/7.30/content/2009/s2680254.htm).

As President of the Australian Academy of Science, Prof K. LAMBECK participated in several Conferences and Symposia including the International Conference on Science and Technology for Sustainability 2009: Global Food Security and Sustainability, Tokyo, Japan, 17-18 September 2009, and the High Flyers Think Tank on Agricultural Productivity and Climate Change, Melbourne, 22-23 October 2009.

Prof K. LAMBECK, Great Barrier Reef Foundation Chairman's Panel Workshop, Sydney, New South Wales, 28 July 2009, guest speaker on the topic of Climate Change Science.

Prof K. LAMBECK, 2009 Clarke Memorial Lecture, Sydney, New South Wales, 30 October 2009, entitled "Climate Change through the lens of the geological record: the example of sea level".

Prof S. R. Taylor took part in a Questacon celebration of the 40th anniversary of the Apollo 11 lunar landing as well as appearing on NZ TV.

Prof S. R. Taylor gave a seminar on The Moon at the University of New South Wales, Oct 12.

TEACHING ACTIVITIES

Earth Chemistry

Dr J.J. BROCKS taught 'Early evolution of life on Earth (and other planets?)' in Geol3022 Planetary Science.

Dr J.J. BROCKS taught the 'Carbon Cycle' as part of the 'Global Cycles' course EMSC3027.

Dr J.J. BROCKS taught 'The Origin of Banded Iron Formations' as part of the 'Economic Geology' course EMSC3007.

Dr M.A. FORSTER taught the 3rd year Mapping Course at Broken Hill, 16-24 June.

Professor T.R. IRELAND taught the Planetary Science Course (EMSC3022) in Semester 2, July – November, with Dr C.H. Lineweaver.

Dr C.H. Lineweaver team-taught with Prof. T.R. Ireland, the EMSC 3022, Planetary Science Course, July – November.

Dr C.H. Lineweaver gave a guest lecture on gravity and entropy in Astronomy 1001 (convenor Dr Paul Francis), 9 September.

Dr C.H. Lineweaver gave an invited lecture to ANU students of Bruce Hall on "Are We Alone?", 6-8 pm, 9 September.

Dr C.H. Lineweaver gave a lecture "Astrobiology" to the RSAA Summer Scholars, Duffield Lecture Theatre, 8 December.

Dr C.H. Lineweaver gave a research seminar on "Entropy and Life" to the Research School of Biological Sciences (organized by Roderick Dewar), Robertson Seminar Room, 22 April.

Dr C.H. Lineweaver gave a seminar "Viruses and the Origin of Sex", to the virology research group of the John Curtin School of Medical Research, ANU, Finkel Theatre, 15 September.

Dr C.H. Lineweaver gave a seminar in the Department of Physics, University of Queensland, 22 September, on "Gravity, Life and the Second Law of Thermodynamics"

Dr. C.H. Lineweaver gave an RSES Earth Chemistry Mass Spectroscopy seminar "Review of the Latest Exoplanet Data and the Potato Radius", 4 December, D.H. Green Room.

Earth Environment

Dr L.K. AYLIFFE gave a lecture on "Reconstructing past environments and ecologies using stable isotopes preserved in animal tissues" as part of the Chemistry of the Earth and Oceans undergraduate course (EMSC2015).

Prof. P. De Deckker taught course EMSC2019 Marine Micropalaeontology and History of Life

Prof. P. De Deckker taught course EMSC3019 Carbonate Reef Platforms [held in New Caledonia]

Prof. P. De Deckker taught coordinated EMSC2016 Resources and Environments

Prof. P. De Deckker taught one week in EMSC 1004 The Blue Planet.

Dr. A. DUTTON taught a lecture in Chemistry of the Earth and Oceans on Cenozoic Paleoclimate.

Dr. A. DUTTON taught a lecture in Surficial Processes on secular change in seawater chemistry during the Phanerozoic.

Dr S.M. EGGINS co-taught the 3rd year Earth and Marine Science course Marine Biogeochemistry (EMSC 3023).

Dr. S.M. Eggins lectured and demonstrated for the field-based component of the 3rd year Earth and Marine Science course Coral Reef Ecology (EMSC 3019)

Dr. S.M. Eggins demonstrated for laboratory and field-practical components of the 1st year Earth and Marine Science course The Blue Planet (EMSC 1006)

Dr M.J. ELLWOOD coordinated and co-taught the third year course Marine Biogeochemistry (EMSC 3023).

Dr M.J. ELLWOOD taught the third year course Special Topics (EMSC 3050).

Dr M.J. ELLWOOD taught in the second year course Chemistry of the Earth and Oceans (EMSC 2015).

Dr M.J. ELLWOOD coordinated and taught in the first year course The Blue Planet (EMSC 1006).

Dr M.J. Ellwood taught in the second year course Analytical Chemistry (CHEM 2207).

Dr M.J. Ellwood taught in the third year course Climate Change Science & Policy (ENVS 3020)

Dr K.E. FITZSIMMONS taught part (4 weeks) of Stable isotope analysis and Quaternary geochronology (BIAN3010).

Prof. R. GRÜN taught a 6 unit course *Scientific dating techniques and isotope analysis for archaeology and palaeoanthropology* (BIAN 3010/6510) at the Dept. of Archaeology and Anthropology, ANU.

Miss T.E. KELLY taught as a lab and field demonstrator in SRES1004, Australia's Environment.

Mr I. MOFFAT taught the graduate subject ARCH8307 "Introductory Archaeological Geophysics" within the Department of Archaeology at Flinders University.

Mr I. MOFFAT taught a short course entitled "Geophysics for Archaeologists" to students within the Department of Land Information Management, TAFESA.

Mr I. MOFFAT taught a short course entitled "Geophysics for Archaeologists" as part of the Australian Archaeology conference.

Dr B.N. OPDYKE taught EMSC 2014 Surficial Processes; Taught and coordinated EMSC3027 Global Cycles; Taught the field component of EMSC2012; Taught part of EMSC2016, Resources. Helped with EMSC1007.

Prof. B. PILLANS gave 9 lectures in EMSC2016 "Environmental and Regolith Geoscience" (second year undergraduate course, second semester)

Dr G. YOUNG taught the vertebrate palaeontology part of the 'Marine Palaeontology and Evolution' course (EMSC 2019).

Dr G. YOUNG participated in south coast student excursions for EMSC 2014 in April, and EMSC 1006 in September.

Earth Materials & Processes

Prof R.J. ARCULUS taught parts of: EMSC1006 The Blue Planet; EMSC2016 Resources and the Environment; EMSC2020 The Lithosphere; EMSC3024 Magmatism and Metamorphism
Dr. A.G. CHRISTY co-convened (with Prof. D.J. Ellis) and delivered most of EMSC2017 (Mineralogy).

Dr. A.G. CHRISTY delivered some lectures and a tutorial on Atomic Spectroscopy for CHEM2207 (Analytical Chemistry).

Dr. A.G. CHRISTY demonstrated on ENVS 1004 "Australia's Environment" field trip to Snowy Mountains.

Prof S F COX taught EMSC2012 Introduction to Structural and Field Geology, EMSC3002 Structural Geology and Tectonics, and portions of EMSC1007 and EMSC 3005 as part of the RSES Earth and Marine Science Education program.

Dr J.D. FITZ GERALD participated in final year projects and theses of three students from the ANU Department of Engineering.

Dr J. HERMANN was convener of the course "Magmatism and Metamorphism" (EMSC 3024) and taught 15 hours of lectures, 30 hours of practicum and one day of excursion.

Dr J. HERMANN taught one hour at the course "Chemistry of Earth and Oceans" (EMSC 2019).

Dr J. HERMANN taught one day at the course "Introduction to Earth Science in the field" (EMSC 1007).

Dr J. HERMANN co-supervised two students for a special research topic (EMSC 3050).

Mr K.N HORNER provided tutoring support for the Introduction to Hydrogeology (EMSC 3025) and Environmental Geochemistry (CHEM 2204) courses (Semester 2).

Prof. I. JACKSON coordinated and co-taught PHYS3070 Physics of the Earth (with Drs. H.

TKALČIĆ and P. TREGONING), and supervised the 4th-year engineering project of J. MU.
Prof G. LISTER taught third year Geology Field Camp (GEOL 3001), and supervised five PhD candidates.

Dr L. MARTIN co-supervised Craig Couper for its special research topic (EMSC 3050).

Dr D.C. "BEAR" McPHAIL coordinated and/or taught EMSC3025 Groundwater (100%; coordinated and taught) in second semester

Dr D.C. "BEAR" McPHAIL coordinated and/or taught CHEM2204 Environmental Chemistry (50%; coordinated and taught) in second semester with Edie Sevick and Ron Pace of RSC

Dr D.C. "BEAR" McPHAIL coordinated and/or taught EMSC2016 Resources and the Environment (16%; taught 2 weeks) in second semester; and

Dr D.C. "BEAR" McPHAIL coordinated and/or taught MTEC Honours course Regolith Geoscience and Mineral Exploration (1 week; coordinated 75% and taught 20%) in first semester break (20-24 April).

Dr. NEBEL participated in first year field courses to the Kosciusko National Park and the Coastal field Camp in Kioloa. He further assisted in the second year petrology course.

Mr L. T. WHITE was a course demonstrator on EMSC 3001 (Field Geology) and assisted during the field trip for EMSC 1006 (The Blue Planet: An Introduction to Earth System Science). He was also contracted by UNSW as a course demonstrator for their second-year course GEOS2171 (Earth Structures).

Earth Physics

Mr T. BODIN taught for 9 hours 2 year students for the lab course : *Introduction to geophysics.*

Dr G.F. DAVIES taught the Masters in Geophysics course Plate Tectonics and Mantle Dynamics (EMSC 8016).

Drs G.O. HUGHES, A.McC. HOGG and R.C. KERR, and Prof R.W. GRIFFITHS taught Physics of Fluid Flows (PHYS3034).

Drs A.McC. HOGG and Dr M.L. RODERICK taught 3rd year course, Ocean Atmosphere Modelling (EMSC3029).

Dr A.McC. HOGG taught The Blue Planet (EMSC1006).

Dr A.McC. HOGG supervised the Special Topic project undertaken by Ms N. Maher (EMSC3051).

Prof B.L.N. KENNETT – Introductory lectures in EMSC2018 "Geophysics", contribution to EMSC1007 "Earth Sciences in the Field" and guest lecture on Geothermal Energy to ENGN4516.

Prof B.L.N. KENNETT presented a set of lectures on "Imaging the Earth" at the National Taiwan Normal University in May.

Dr. N. RAWLINSON assisted with lecturing the course PHYS3070

Dr. N. RAWLINSON is convener of Earth Physics honours.

Dr M.L. RODERICK taught part of the third year course, Global Cycles and Paleooceanography (EMSC3027).

Dr M.L. RODERICK taught part of the first year field course at Kioloa, Introduction to Earth Science in the Field (EMSC1007).

Dr M. SALMON – Co-coordinator and lecturer for Geophysics EMSC2018 (first semester)

Prof. M. SAMBRIDGE taught a graduate course on geophysical inversion as part of the Master's program in Physics of the Earth (EMSC8012).

Prof. SAMBRIDGE and Dr. Salmon were joint convenors of the second year Introduction to Geophysics course (EMSC2018).

Prof. M. SAMBRIDGE supervised Mr. D. Leykam an Advanced Studies Course (Ph.B.) student on a research project on projective methods for the solution of inverse problems, in second semester 2009.

Dr H TKALČIĆ taught an undergraduate course "Physics of the Earth" with Prof I. Jackson and Dr P. Tregoning (PHYS 3070), Faculty of Science.

Dr H TKALČIĆ took a share in teaching EMSC 2018 coordinated by Prof. M. Sambridge and Dr. M. Salmon.

Dr P. TREGONING taught 1/3 of the undergraduate physics course Physics of the Earth (PHYS3070) and was the convener of the RSES Masters program.

Dr. E. SAYGIN taught practicals the for Earth Physics component of Introduction to Earth Science in the Field (EMSC1007). (December 2009)

Dr E. VANACORE assisted with teaching a single lab class for PHYS3070 dealing with locating earthquakes. (September 2009)

Visiting Fellows

Dr R. V. BURNE is a member of the advisory committee for Richard Schinteie's doctoral research project, and offered advice to several other masters and Doctoral students on aspects of their research.

Dr R. V. BURNE was employed as a Sessional Academic by the Fenner School to act as course tutor for EMSC 1006 "the Blue Planet" which is jointly run with RSES in the second semester 2009.

KEN CAMPBELL Undergraduate Teaching contributed three lectures to EMSC 2019x and one practical class on Echinoderms. In addition I also helped with several practical classes on the Geology of the Permian on the South Coast and on Vertebrate Palaeontology.

KEN CAMPBELL Ms, Alice Clement is now working on Dipnoans from Gogo, Western Australia.

KEITH SCOTT taught part of the Minerals Tertiary Education Council Honours course "Regolith Geoscience and Mineral Exploration"

HONOURS AND MASTERS SUPERVISION

Earth Chemistry

Dr J.J. BROCKS supervised the honours project of Carina Lee, Dia- and catagenesis of beta-carotene and bacterioruberin.

Dr. C.H. Lineweaver supervised two undergraduate physics research projects of Graham S.L. Stock and Jo M. Hancox "Evaluating the independence of Elemental Abundance Estimates of Solar System Bodies", March – July, 2009.

Dr. C.H. Lineweaver supervised 4th year physics 2-semester research project of Iliriana Kerim, "The Search for Life on Titan", March – June and July – November 2009.

Dr C.H. Lineweaver supervised 2nd year ANU Physics PhB student Yanjun "George" Zhou on a research project "Exoplanet Statistics", July – November 2009.

Dr C.H. Lineweaver is supervising RSAA Summer Scholar Elysse Shinella on the research project: "Finding the Largest and Oldest Basins on the Moon", November 2009 to February 2010.

Earth Environment

Prof. P. De Deckker co-supervised Ms Natalie Lim, an Honours student in Microbiology.
Dr. A. DUTTON supervised the Honours project of Ms C. Thompson on diagenesis in Eocene planktonic foraminifera.

Dr S.M. EGGINS supervised the Honours project of Ms. A. Komugabe on the dating, determination of growth rates and metal incorporation into Antipatharian black corals

Prof R. GRÜN supervised the Honours project of Ms K. Boljkovac on *In situ SHRIMP δ18O and laser ablation ICP-MS Sr/Ca and 87Sr/86Sr measurements in fossil otoliths for palaeoclimate reconstructions at the Willandra Lakes World Heritage Area*

Prof R. GRÜN supervised the Masters project of Ms W. Lees on *Sr isotope tracing of human migration in Vanuatu.*

Mr I. MOFFAT supervised the honours project of Mr B. Keys entitled Engrained in the Past: Using Geoarchaeology to Understand Site Formation Processes at the Gledswood Shelter 1 Site, Northwest Queensland within the Department of Archaeology at Flinders University.

Dr B. OPDYKE supervised Anthony David on a part time Honours project modeling the Glacial to Interglacial Carbon cycle.

Dr B. OPDYKE supervised the masters project of Ms Merinda Nash on the impacts of "ocean acidification" on sediments of Great Barrier Reef.

Prof. B. PILLANS supervised Ms Kiralee Beavis for her Honours thesis "Comparison of weathering profiles in the Marra Mamba and Brockman Iron Formations, Hamersley Iron Province, Western Australia".

Dr M. WILLE co-supervised the Honours project of Kelly M. James on nutrient cycle of a phytoplankton bloom.

Dr G. YOUNG supervised M.Sc student James Hunt, M.Phil student Greg Bell.

Earth Materials & Processes

Prof R.J. ARCULUS supervised the honours projects of Mr N. Dyriw on the Geochemistry of northern Lau Basin, and Ms A Bradney on the Ongoing eruption of Rabaul Volcano
Dr A.G. CHRISTY and Dr M.D. Norman supervised Ms Katherine Adena's Honours project "Geochemistry of Impact and Volcanic Glasses at Taurus-Littrow Region on the Moon." (submitted November 2009).

Dr A.G. CHRISTY and Prof. D.J. Ellis supervised Mr. A. Maulana's M. Phil project "Petrology of basement complexes in S.W. Sulawesi" (submitted July 2009).

Prof S Cox supervised the project of Mr Kent Inverarity on the structure and folding mechanisms in the Taemas area, NSW.

Dr D.C. "BEAR" McPHAIL supervised the honours project of Mr J. Knight on Aquifer interactions in the Lower Murrumbidgee (mid-year start in 2009).

PRISE

Dr M.D. NORMAN supervised the honours project of Ms K. Adena on the petrology and geochemistry of lunar impact and volcanic glasses from the Apollo 17 landing site.

Visiting Fellows

KEN CAMPBELL supervises Mr Greg Bell PhD candidate working on material from West of Forbes, NSW.

DR C. KLOOTWIJK assisted Ms R. Mann with her honours project on the regolith characteristics of the Tomingly area, NSW.

KEITH SCOTT supervises the honours project of Lance Karlson on the characterization of dust in NW Australia.

OTHER MATTERS

Earth Chemistry

Dr Y. AMELIN oversaw setting up and testing the new clean chemistry laboratory in the Jaeger 5 building. The MAT-261 thermal ionisation mass spectrometer, previously located at the Earth Environments, was moved to a new location in the Jaeger 3 building, and is fully functional again, with an upgrade planned next year. Procedures for high-precision U-Pb dating of accessory minerals (zircon etc.) and meteorites are set up and tested. One project in cosmochemistry, which includes combined U-Pb chronology and uranium isotopic study, is completed and the manuscript is in preparation.

Dr V.C. Bennett, Program Committee Member and Early Earth Theme Coordinator, Goldschmidt Conference 2010.

Dr V.C. Bennett sits on the Board of Directors, Geochemical Society.

Dr V.C. Bennett is on the Goldschmidt Medal selection committee, Geochemical Society.

Dr V.C. Bennett continues as a member of the ANU Major Equipment Committee.

Professor I.H. Campbell was elected General of the Commission for the Evolution of the Solid Earth, a sub-commission of the International Mineralogical Association; and is co-leader of the Commission for Large Igneous Provinces (LIP).

Mr A. CHOPRA mentored 3rd Year Physics research student Ms I. Kerim (supervised by Dr C.H. Lineweaver) on a project examining thermodynamic requirements of possible biochemical reactions that could be used by life on Saturn's moon Titan.

Dr M.A. FORSTER served as a member of the RSES OH&S Committee and became Chair of this committee in Sept 2009.

Dr M.A. FORSTER runs the RSES Argon Facility and supervisors students using this facility.

Dr M.A. FORSTER manages and runs the RSES Microscope Facility and supervisors students using this facility.

Dr. C.H. Lineweaver received a $15,000 grant to support the Planetary Science Institute's Distinguished Visitor Prof Phil Nicholson August (visit planned for March – July 2010).Dr. C.H. Lineweaver gave a presentation and participated in a panel discussion organized by ANU Media office "Hot Tips from the Experts on How to Get One's Message out most Effectively to Print, Radio and Other Media", Manning Clark Theatre, 21 April.

Dr C.H. Lineweaver was one of 6 researchers chosen by the Astronomical Society of Australia and sponsored by local chapters of the Australian Institute of Physics to give public lectures around the country to celebrate the International Year of Astronomy. He gave the lecture "Is there more than one Universe?" in Perth (University of Western Australia, 19 August), Geraldton (Universities Centre, 17 August), Canberra (ANU, 2 September), Brisbane (Regatta Hotel, 21 September) and Hobart (Univ of Tasmania, 20 October).

Mr. Seann McKibbin is serving as RSES student facilitator (June 2009- present).

Dr R. SALMERON served as Reviewer, Astrophysical Journal, Monthly Notices of the Royal Astronomical Society, Astrophysics & Space Science.

Earth Environment

Prof. P. De Deckker was the chair of the Archaeology and Geoscience Committee of AINSE

Prof. P. De Deckker is a member of the IODP [ANZIC] Council.

Dr. A. DUTTON organized the Consortium for Ocean Geosciences (COGS) conference in Perth, July 2009.

Dr. A. DUTTON served as a member of the PALSEA working group which aims to provide empirical constraints on future sea level rise and co-coordinated an international U-series dating interlaboratory comparison study as part of this initiative.

Dr A. DUTTON served as a member of the MARGO committee to promote Marine Geoscience in Australia.

Dr A. DUTTON is the treasurer for the Sedimentary Division of the Geological Society of Australia.

Dr S. EGGINS is a member of the board of the ANU Climate Change Institute.

Dr K.E. FITZSIMMONS was nominated as representative for the Australasian Quaternary Association at the Federation of Australian Science and Technology Societies Women in Science Workshop, Parliament House, Canberra.

Dr K.E. FITZSIMMONS was joint organiser of the International Association of Geomorphologists (IAG) Conference field trip to central Australia (with Professor Gerald Nanson, University of Wollongong, Dr Gresley Wakelin-King, Dr Tim Cohen, Macquarie University).

Miss T.E. KELLY, President, ANU Postgraduate and Research Student Association.

Miss T.E. KELLY, Chair, ANU Postgraduate Representative Council (PRC).

Dr J. MALLELA was elected to the postdoctoral committee for the Australian Research Council (ARC) Centre of Excellence for Coral Reef Studies, Australia, as the ANU representative.

Dr B. OPDYKE chaired the Australian Geological Societies ACT Branch.

Dr B. OPDYKE chaired the Australian Sedimentologists Group of the Australian Geological Society

Dr B. OPDYKE as on the planning committee tor the Australian Earth Science convention in Canberra in 2010

Prof B.J. PILLANS, President, Stratigraphy & Chronology Commission, International Union for Quaternary Research.

Prof B.J. PILLANS, Vice President, Geological Society of Australia

Prof B.J. PILLANS, President, Australian & New Zealand Geomorphology Group

Prof B.J. PILLANS, Chair, Working Group on Lower/Middle Pleistocene Boundary, International Commission on Stratigraphy

Dr GAVIN YOUNG is a Titular Member of the International Union of Geosciences Subcommission on Devonian Stratigraphy, and co-leader (with Prof ZHU MIN, Beijing) of IGCP Project 491 ('Middle Palaeozoic Vertebrate Biogeography, Palaeogeography and Climate').

Earth Materials & Processes

Dr A.G. CHRISTY is Australian National Representative on the Commission for New Minerals and Mineral Classification of the International Mineralogical Association.

Dr A.G. CHRISTY is a member of the Pyrochlore Group Nomenclature subcommittee of the Commission for New Minerals and Mineral Classification.

Dr A.G. CHRISTY is co-ordinator for the Ph.B. program in the Earth Sciences disciplinary area, exclusive of Geophysics.

Professor S Cox continued in the position of Associate Director (Education) for RSES.

Dr J. HERMANN presented a seminar at RSES on the 19. March.

Mr K.H. HORNER was appointed as a Postgraduate Student Representative on the committee of the ACT division of the Geological Society of Australia.

Prof I. JACKSON served as Executive Committee member and Vice-President, International Association for Seismology and Physics of the Earth's Interior, and as co-convenor of Symposium L1 Structure and dynamics of the lithosphere: observations, modelling and laboratory constraints, IASPEI General Assembly Cape Town, South Africa 10-16 January 2009, and as a member of the Scientific Program Committee for the 2011 IUGG General Assembly in Melbourne.

Dr D.C. "BEAR" McPHAIL served on the Australian Institute of Mining and Metallurgy Branch Committee for Canberra and Central West NSW; and

Dr D.C. "BEAR" McPHAIL served on the Minerals Council of Australia Minerals Tertiary Education Council Committee.

Dr D.C. "BEAR" McPHAIL reviewed manuscripts for international journals, e.g., Geochimica et Cosmochimica Acta, Geology, Chemical Geology

Dr D.C. "BEAR" McPHAIL reviewed research proposals: ARC Discovery and Luxembourg Research Foundation

Dr. O. NEBEL partly supervised the honors project of Mr. N. Dyriw on the genesis of Lau Basin back arc basalts.

Prof H. St.C. O'Neill serves on the Program Advisory Committee of the Bragg Institute, for the new OPAL Reactor at Lucas Heights, NSW

Mr L. WHITE, a member of Mapping and Planning Support (MAPS) assisted the Victorian Police with GIS support for one week during the 2009 Victorian bushfires.

Earth Physics

Prof R.W. GRIFFITHS was appointed to the Australian Research Council College of Experts, and served on the Physics, Chemistry, Geoscience panel.

Prof B.L.N. KENNETT, Chair National Committee for Earth Sciences and Chair of Working Party on National Geotransects.

Dr. N. RAWLINSON is chair of the Specialist Group in Solid Earth Geophysics, Geological Society of Australia.

Dr. N. RAWLINSON is on the organizing committee of Seismix2010, a conference on seismic profiling of continents and their margins, to be held in 2010.

Dr E. SAYGIN conducted fieldwork in Central Australia 2009 for servicing the broadband stations of BILBY project. (September 2009)

Dr H TKALČIĆ is responsible for the managing of the Seismic and Infrasonic facility in Warramunga, Northern Territory.

Dr H TKALČIĆ conducted field-work in NSW with Dr. Rawlinson (EAL1 seismic deployment installation) and coordinated RSES seismic data conversion, storage and acquisition.

Dr H TKALČIĆ is a liaison for the PhB program in the Earth Sciences for geophysics.

Dr P. TREGONING, National delegate to the International Association of Geodesy. He is a member of the AuScope Geospatial Steering Committee and chair of the AuScope Gravity Subcommittee and was a member of the AAS/ATSE Working Group who developed "An Australian Strategic Plan for Earth observations from space".

PRISE

Dr. M.D. NORMAN served on the National Executive Committee of the Geological Society of Australia, the Organising Committee of the 2010 Australian Earth Science Convention, the Steering Committee of the First Australian Decadal Plan for Space Science National Committee for Space Sciences), and as Chair of the geochemistry group of the NASA Lunar Advanced Science and Exploration Research (LASER) proposal review panel.

Visiting Fellows

Ken Campbell Raised funds to support the curation of fossil specimens in the ANU. This is critical as our material is of world-wide significance. At present we have in hand $35,000 plus a written guarantee of another $10,000, and another $ 5,000 has been offered.

Ken Campbell Obituary for Prof. D.A. Brown. I was asked by the Emeritus Professoriate to prepare an obituary for Emeritus Prof D.A.Brown, the first Professor of Geology at ANU. I have also done the same for the Geological Society of Australia.

Dr P.J. JONES, Corresponding member of the Subcommission on Carboniferous Stratigraphy of the International Stratigraphic Commission, International Union of Geological Sciences

Prof K. LAMBECK, President, Australian Academy of Science.

Prof K. LAMBECK, President Elect, Federation of Asian Scientific Academies and Societies.

Dr W. Mayer served as Councillor of the History of Earth Sciences Society (HESS) from 2006 to 2009.

Dr D.L.STRUSZ continued as a Corresponding Member of the IUGS Subcommission on Silurian Stratigraphy.

Prof S. R. Taylor is Chair of the House Committee, Australian Academy of Science.