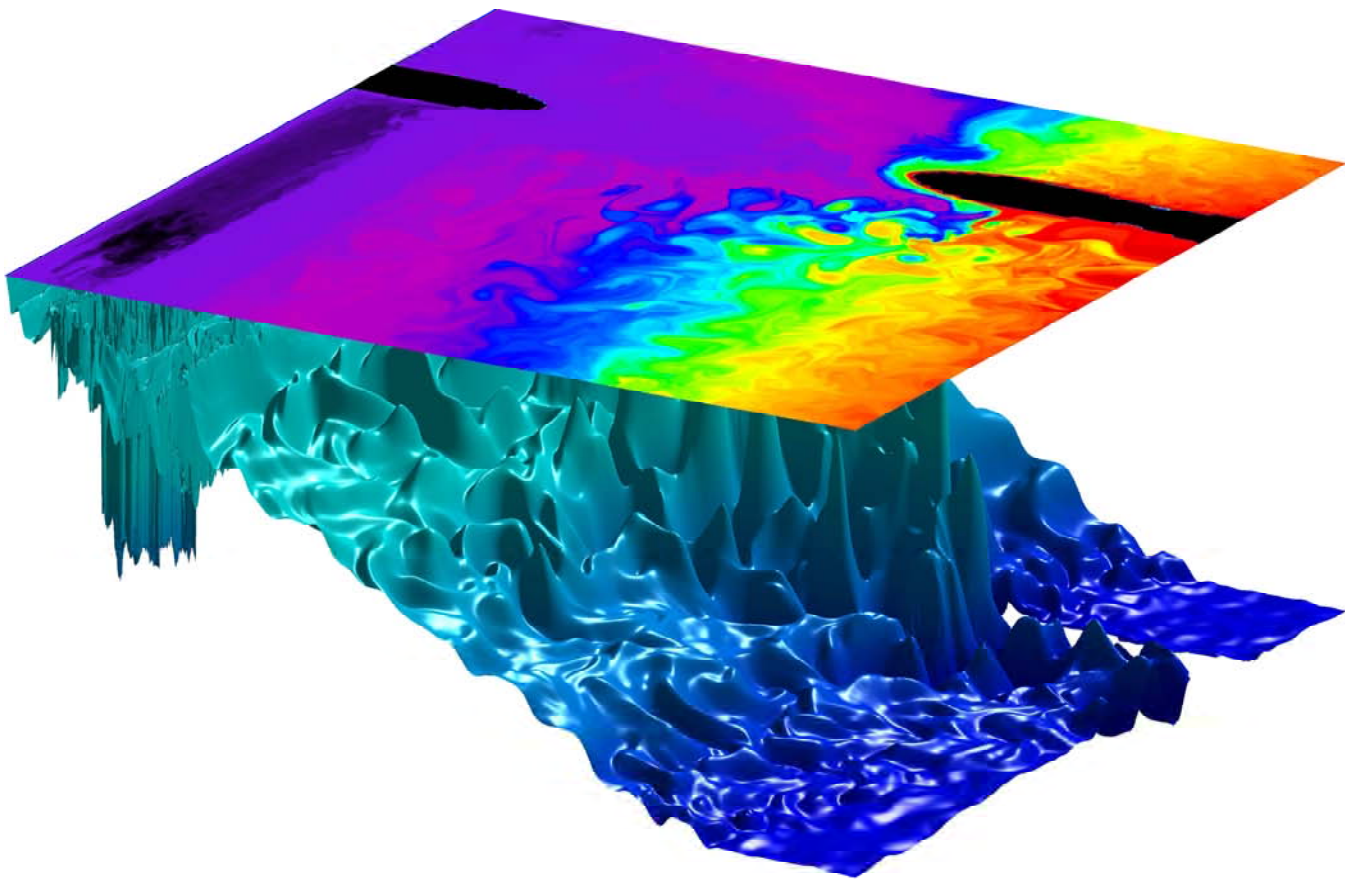


Research School Of Earth Sciences Annual Report 2010



*Idealised numerical model of the Southern Ocean overturning,
at 1/16th degree resolution.*

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Director's Review of 2010

It has been a real pleasure for me to assume the Directorship of the Research School of Earth Sciences (RSES) on February 1, 2010, and to have the opportunity to work with and lead such an outstanding group of people. Whenever I travel or talk to people outside of RSES, I am constantly reminded of the esteem with which our School and colleagues are held within the University, throughout Australia and the rest of the world. The number of major prizes, fellowships of learned societies, publications, citations of publications and grant funding successes during 2010, and the ongoing achievements of our education programs, only serve to reinforce my view of the exceptional quality of activity within the RSES.

The biggest strategic challenge that I face as Director of RSES is to maintain and enhance the reputation of the School. Over the next 5-10 years, we are likely to see significant staff turnover with the impending retirement of some of the School's most distinguished scientists. Performance benchmarks within RSES are exceptionally high and these standards will only be maintained or enhanced if we can attract scientists of outstanding promise to the RSES. To this end, we have embarked upon a recruitment process to attract high-calibre early career individuals to the School. The aim is to renew our staffing profile and to give our new recruits the freedom and opportunity to establish their research activities within the School to enable a smooth transition during this phase of anticipated staff turnover.

This year has been a demanding one in many ways. I have had to rapidly familiarize myself with new names, faces and activities of not only RSES colleagues, but also of the major players within the University and the broader Australian science and policy landscape. In addition, one of my priorities is to consolidate all of the research and teaching activities of the recently merged School so that all staff are co-located within the Jaeger complex rather than being separately housed in two major sites across the ANU campus. The Vice-Chancellor has provided funding for a new 3-storey building that will enable co-location of colleagues and students from Building 47, provide significant teaching space, house much of the School's administrative functions, and that will also provide a clear front entrance to the School for the first time in its history. Progressing to preliminary sketch plans and through the various subsequent design and approval stages has been a major activity during 2010. Tangible evidence of progress was achieved at the end of 2010 with demolition of the former Old Hospital Building (B Block) and preparation of the site for excavation and construction early in 2011. The new building is scheduled for completion by the end of 2011 with occupancy in time for the beginning of the 2012 academic year. Construction of an environmentally sustainable, attractive and modern building will significantly enhance the Jaeger complex, and will benefit the full range of School activities.

Other significant developments have started in 2010, and will continue into 2011. We have embarked upon a curriculum review with the intention of developing an undergraduate Earth science program with a stronger emphasis on quantitative skills and with broader scientific underpinning in addition to the excellent Earth science training that we already provide. We are also continuing to involve more academic staff in the undergraduate program, which is helping to spread teaching loads across the merged School and is exposing our students to a wider range of people and their expertise. Colleagues are also working hard to diversify their sources of research funding, which is providing more opportunities to carry out world-leading research and is supporting the training of PhD students and post-doctoral researchers. In 2011, we also intend to engage more actively with our alumni as we head toward the School's 40th anniversary celebrations in 2013.

In closing, I extend my thanks to all RSES colleagues for their efforts during 2010. Much hard work has gone into the many outstanding successes that have been earned and enjoyed this year. I am also grateful for the assistance provided to me by so many during my first year as Director of RSES. I look forward to seeing the School progress from strength to strength during the term of my Directorship.

Prof. Andrew P. Roberts
Director, RSES

HONOURS & AWARDS

Mr. A. CHOPRA was awarded the 2nd prize for a poster presented at the ANU 2010 ResearchFest (\$350).

Mr A. CHOPRA was awarded a \$3600 grant from the organising committee and RSES to present an invited talk at the 2010 Astrobiology Graduate Conference in Tällberg, Sweden.

Mr A. CHOPRA was awarded an \$800 grant from the NASA Astrobiology Institute and a \$1500 grant from the ANU Vice-Chancellor's HDR travel grant to present a talk and poster at the 2010 Astrobiology Science Conference in Texas, USA.

Mr A. CHOPRA was awarded a \$2000 grant from the organising committee to present a poster at the 2010 Gordon Research Conference and Seminars on the Origin of Life in Galveston, USA.

Ms B. FRASL received financial support for students from the Geological Society of Australia to attend the AESC 2010.

Dr C.H. LINEWEAVER was given a "Top PhD Supervisor Award" by Prof M. Thomas (ANU), November 10, 2010.

Dr C.H. LINEWEAVER was chosen as one of ANU's top lecturers to give one of a dozen lectures at "ANU for a Day" organized by L. Cram at the Hyatt Hotel, Canberra, Lecture title: "Our Place in the Universe" July 25, 2010.

Mr S. McKIBBIN was awarded 2nd prize in the Australian Space Science Conference Student Poster Session.

Dr D. RUBATTO was awarded a 2011 Queen Elisabeth II Fellowship from the Australian Research Council.

Dr D. RUBATTO was supported by the Herbette Foundation, Lausanne, for a sabbatical visit at the University of Lausanne.

Mr R. SCHINTEIE received the Graduate Short Course Award in Scientific Communication.

Dr I.S. WILLIAMS was nominated for the 2010 ANU Top Supervisor Award.

Dr I.S. WILLIAMS, Australian Scientific Instruments Pty. Ltd., at which Dr I.S. Williams is Chief Scientist, won the 2010 Chief Minister's Award for ACT Exporter of the Year.

Mr. N. DARRENOUGUE was awarded one of the two 2011 Australian-French Association for Science & Technology (AFAS, ACT) fellowships in order to undertake two fieldtrips in New Caledonia this coming year.

Ms J. MAZERAT was awarded a travel/conference support by IMAGES to attend the 10th International conference on paleoceanography, San Diego, USA.

Prof. A.P. ROBERTS, Japan Society for the Promotion of Science Senior Invited Fellow.

Prof. A.P. ROBERTS, Exceptional Reviewer Award, *Geology*.

Prof R.J. ARCULUS was elected as a Fellow of the American Geophysical Union.

Mr C. AUGENSTEIN got awarded the VC travel grant (\$1500) and the International Alliance of Research Universities (IARU) travel allowance (\$3000) for a cross institutional visit at the Department of Earth Sciences at ETH Zurich, Switzerland.

Prof S. COX received the Bruce Hobbs Medal from the Geological Society of Australia's Specialist Group in Tectonics and Structural Geology.

Dr J.D. FITZ GERALD was awarded a John Sanders medal in July by the Australian Society for Microscopy and Microanalysis, and a Vice Chancellor's Career Achievement Award at the 2010 ANU Staff Awards ceremony.

Mr K.N. HORNER was awarded the 2009 D.A. Brown Travel Scholarship, which funded his attendance at the 2010 International Association of Hydrogeologists Annual Congress in Krakow, Poland, 12-17 September.

Mr K.N. HORNER was awarded an ANU Vice-Chancellor's HDR Travel Grant for Cross-Institutional study in the Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, CANADA from 27 September to 17 December.

Ms K. KISEEVA received an ANU travel grant for attending the IMA conference, in Budapest, Hungary, 2010.

Prof G. LISTER has been successful in being awarded an ARC LIEF grant LE110100047. *Events through time: eruptions, extinctions, impacts, orebodies and orogenies. Upgrading the national argon geochronology network.* (key personnel LISTER, G., Jourdan, F., Forster, M. and McInnes, B.).

Prof G. LISTER was awarded an AINSE grant for use of the UWS SIMS facility by PhD candidate Ms I. Stenhouse.

Ms I. STENHOUSE, PhD Candidate, won AMMRF TAP grant and Vice-chancellor HDR travel grant.

Miss D. TANNER was awarded a Graduate Student Fellowship from the Society of Economic Geologist's Foundation.

Dr G.M. YAXLEY commenced an ARC Future Fellowship in the Earth Materials and Processes Research Area from January 2010.

Dr G.M. YAXLEY received a "Top Supervisor Award 2010" from ANU.

Mr. R. BRODIE - Ph.D. student - was awarded the inaugural ASEG prize for best student paper in the journal *Exploration geophysics* for his paper entitled, "*Holistic inversion of frequency-domain airborne electromagnetic data with minimal prior information*" with Prof. M. SAMBRIDGE.

Prof P. CUMMINS was awarded the Stillwell Award by the Geological Society of Australia for the best paper of the year in the *Australian Journal of Earth Science* in 2008.

Mr T. BODIN received the AGU 2009 Fall meeting Outstanding Student Paper Award.

The paper was: "*Seismic Tomography with The Reversible Jump Algorithm*" - Bodin. T. and Sambridge, M. (2009) AGU Fall Meeting, San Francisco.

Prof. P. CUMMINS was awarded the Stillwell Award by the Geological Society of Australia for the best paper of the year in the Australian Journal of Earth Science in 2008.

Dr. G.F. DAVIES was honoured upon his retirement with a special session at the American Geophysical Union Fall Annual Meeting, at San Francisco in December, entitled Dynamic Earth: Plates, Plumes and Mantle Convection.

Prof R.W. GRIFFITHS presented a Plenary Lecture at the American Physical Society – Division of Fluid Dynamics conference at Longbeach, California in November.

Prof R.W. GRIFFITHS was elected an inaugural Fellow of the Australasian Fluid Mechanics Society.

Prof B.L.N. KENNETT will receive the Flinders Medal, the highest award in the Physical Sciences, from the Australian Academy of Science in May 2011 and deliver the associated Finders Lecture.

Prof. M. SAMBRIDGE was elected a Fellow of the American Geophysical Union.

Dr H TKALČIĆ was awarded JSPS Fellowship from Japanese Government for a collaborative work with his Japanese colleagues, and to tour Japan and give lectures on his research in 2011.

Visiting Fellows

Dr K. A. W. CROOK was accorded Honorary Life Membership of the Australian Marine Sciences Association in July 2010.

Stuart Ross Taylor, Emeritus Professor

The winner of the 2010 of the Mary B. Ansari Best Reference Work award of the Geoscience Information Society was

"Planetary Crusts: Their Composition, Origin and Evolution" by S. Ross Taylor and Scott McLennan, published by Cambridge University Press. This work received high scores for its uniqueness in subject coverage, the quality of the work, and the authoritativeness of the authors.

Scott McLennan, currently Professor at the State University of New York, Stony Brook, USA, was a former student and staff member of RSES

The award was presented at the Geological Society of America Conference in October in Denver, Colorado.

ACADEMIC STAFF

Director and Professor

B.L.N Kennett, MA PhD ScD Cambridge, FAA, FRS (to 31 January 2010)

A.P Roberts, BSc Massey, BSc (Hon) PhD, DS Victoria University (from 1 February 2010)

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

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 (to 5 August 2010)

S. Eggins, BSc UNSW, PhD Tasmania

C.M. Fanning, BSc Adelaide

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

J. Hermann, Dip PhD ETH Zürich

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, BSc - Tennessee Technological University, MSc Tennessee, PhD Rice

M Roderick, BAppSc QUT, PGDipGIS Qld, PhD Curtin

D. Rubatto, BSc MSc Turin, PhD ETH

P. Tregoning, BSurv PhD UNSW

I.S. Williams, BSc PhD ANU

G.C. Young BSc (Hons) ANU, PhD London (to 30 June 2010)

Fellows

C. Alibert MS Paris VII, first thesis ENS Paris, State thesis, CRPG, Nancy

Y. Amelin, MSc, PhD Leningrad State University

R. Armstrong, BSc MSc Natal, PhD Witwatersrand

J.J. Brocks, Dip Freiburg, PhD Sydney

M. Ellwood, BSc (Hons) PhD Otago

A.M. Hogg, BSc ANU, PhD UWA

G. Hughes, BE ME Auckland, PhD Cambridge
S McClusky BSurv, PhD NSW (from 8 July 2010)
B.N. Opdyke, AB Columbia, MS PhD Michigan
N. Rawlinson, BSc PhD Monash
M.L. Roderick BAppSc QUT, PGDipGIS Qld, PhD Curtin
H. Tkalcic, Dip Engineering in Physics, Zagreb, PhD California
G. Yaxley, BSc PhD Tasmania (ARC Future Fellow)

Research Fellows

L. Ayliffe, BSc (Hons) Flinders, Graduate Diploma (Oenology) Adelaide, PhD ANU
A.L. Dutton, BA (Mus) Massachusetts, MSc PhD Michigan (to 25 December 2010)
S. Fallon, BA MS San Diego, PhD ANU
M. Forster, BSc MSc PhD Monash
G. Iaffaldano, BSc (Physics) Rome, PhD Munich (from 1 February 2010)
O. Nebel, Diplom Geologie Dr. rer. nat. Munster
E-K Potter, BSc Wollongong, BSc (Hon) PhD ANU
A Purcell, BSc (Hons) PhD ANU (from 6 April 2010)

Postdoctoral Fellows:

M. Aubert, PhD, Université du Québec, Institut National de la Recherche Scientifique
(to 1 January 2010)
K. Fitzsimmons, BSc (Hons), Dip Modern Languages Melbourne, PhD ANU (to 27
February 2010)
A. Halfpenny, M.E.Sc PhD Liverpool
T. Iizuka, BSc (Geology), MSc (Geology), PhD, Tokyo Institute of Technology (from 1
February 2010)
J. Mallela BSc (Hons) Leeds, MSc Heriot-Watt, PhD Manchester Metropolitan
L Martin BSc (Hon) MSc Paris XI, PhD Henri Poincare University
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
E. Vanacore BS Geological Sciences Virginia Tech , PhD Rice
M. Ward, BSc (Hons) Florida, C.A.S Cambridge, PhD Florida State
M.H. Wille, Dimp Geosciences, Muenster, PhD Bern (to 8 August 2010)

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

S Bonnefoy, B.Sc. (Hons) (University Paris-IX), DiplMaths DEA University Paris Sud
A.G. Christy, BA(Hon) MA PhD Cambridge (to 1 June 2010)
J.D. Fitz Gerald, BSc James Cook, PhD Monash
S. Hart BSc (Hons) Melbourne
P. Holden, BSc Lancaster, PhD St. Andrews
J. Kurtz, BSc MSc Louisiana State, PhD Arizona State (to 24 September 2010)
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)
Rensselaer Polytechnic Institute
J.Shelley, BSc, MSc (Geology), University of Canterbury NZ
S Sosdian, B.Sc.Monmouth, Ph.D. (2008) Rutgers

Research Assistants

A. Arcidiaco, BAppSc GradDip SAInst
B.J. Armstrong, BSc UNISA
S. Hart BSc (Hons) Melbourne

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 – (Withdrawn July)
T. Bodin, MSc Louis Pasteur University
K. Boston, BSc (Hons) ANU
L. Brentegani, BSc (Biological) Bologna, MSc Ancona
J. Brownlow, BSc (App Geology), UNSW
C. Chapman, BSc(Adv), BE(Hons), Syd, Grad Dipl BMTC
A. Chopra, BSc Univeristy of WA, BSc (Hons) ANU
A. Clement, BSc (Hons) Melbourne University
M. Crawford, BSc (Hons) UQ
N. Darrenougue, BSc MSc University of Bordeaux
A. De Leon, BSc (Hons) University of Melbourne
J.P. D'Olivo Cordero, MSc UABC Mexico
T. Ewing, BSc (Hons), MSc University of Canterbury
R. Farla, Doctoraal Degree Utrecht University
B. Frasl, BSc MSc Univeristy of Leoben
E.Gowan, BSc(Geophysics)(Hons)- Uni Manitoba, MSc Vict Uni, Canada
B. Hanger, BEng (Chem)(Hons), BSc – Monash. (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
M. Huyskens, BSc, MSc, Westfallische Wilhelms-Universität Münster
K. James, BSc (Adv) (Hons) – ANU
A. Jarrett, BSc Hons – ANU
H. Jeon, MSc Seoul National University
J. Jones, Dip Gemmology GAGTL, London, BSc (Hons) Auckland University
B. Kallenberg, BSc & MSc – Freie Uni, Berlin
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
A. Komugabe, BBiotech/BBus – UTS, Hons – ANU
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
A. McCoy-West, BSc, MSc (Hons) BCA Victoria Univ Wellington
I. McCulloch, BSc UNSW, GradDip ANU
J. McDonald, BSc ANU
S. McKibbin, BSc University of Newcastle
N. Mikkelson, BSc (Hons), ANU BArts, ANU
P. Millstead, Dip 1 cert in Gemmology ACT Institute of Technology, BSc UC
I. Moffat, BA BSc (Hons) University of Queensland
G. Nash BA/BSc (Hons), ANU
M. O'Byrne, BSc (Hons) Grad Dip ANU

T. O'Kane, BSc (Hons) ANU
 R. Owens, BSc (Hons)- ANU
 A. Papuc, BSc (Hons) Australian National University
 J. Park, BSc MSc Korea University
 S. Pilia, B Exploration & App Geophysics - Cagliari & MSc (Expl & Geoph)- Pisa
 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
 R. Schinteie, Cert Arts MSc BSc GripDip University of Auckland
 N. Scropton, M.Earth Sc - Oxford, UK
 N. Sinclair, BA/BSc Deakin University, BSc (Hons) 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
 D. Tanner, BSc Hons-ANU
 C. Thompson, BSc(REM), Hons (Geology) - ANU
 J. Thorne, BSc (Hons) ANU
 S. Tynan, BA/BSc (Hons) ANU
 L. White, BSc (Hons) University of New South Wales
 J. Wykes, BSc (Hons) MPhil ANU
 Y. Xue, BSc - China Uni, MSc - Peking Uni
 M. Young, BA Physics, Hendrix College
 S. Yuguru, B. Env Sci (HIA Honours Monash University, MSc University of Papua New Guinea
 I. Zhukova - B. Geology & M. Geology - Novosibirsk, Russia

MPhil Candidates

M. Nash, B.Comm UC, BSc ANU

Honours Students

Honours Geology

Jason Bennett (MY)
 Mitchell Bouma (MY)
 Anna Bradney (MY)
 Nicholas Claydon
 Timothy Curran
 Anthony David (PT)
 Matthew Jason Doull
 Rebecca Garner
 Leigh Gibson, (MY)
 Lisa Howat (MY)
 Paige Kennedy
 Jonathon Knight
 Peter Le Roux
 Alex Lukomskyj
 Rebecca Norman
 Nicola Power

Matthew Valetich (MY)
Tarun Whan
Carl Zimmermann

Honours Physics of the Earth

Nicola Maher
Mark Llewellyn Pittard
PT part time
MY mid year start

Masters Students

Master of Natural Hazards (7512)

Tim Anderson
Christina Griffin
Neni Marlina
Robbie Morris

Masters Physics of the Earth (7903)

Ross Costelloe
Ashraf Hanna
Matthew Knafl
Daniel Jaksa
Marco Maldoni
Md. Sakawat Hossain
Jackson Tan, Boon Sze
Yang Li

Masters (other)

Marija Dojchinov
Jingming Duan
Russell Jack
Erdinc Saygin
Liam Sturgess
Steve Tatham

PHD THESES COMPLETIONS

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

Ross Brodie - Holistic Inversion of Airborne Electromagnetic Data. Supervisor: Prof Malcolm Sambridge. Advisors: Dr N Rawlinson, Prof. B Kennett, Dr B Drummond.

Brian Choo - Revision and Description of the Actinopterygian Fishes of Devonian Eastern Gondwana. Supervisor: Dr Gavin Young. Advisors: Dr B Opdyke, Dr J Long.

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

Ryan Ickert - U-Pb, Lu-Hf, and O Isotope Systematics of Zircon from Southeastern Australian Siluro-Devonian Granites. Supervisor: Prof. Ian Williams, Advisors: Dr B. Chappell, Dr V. Bennett, Dr S Eggins

Julia Jasonsmith - Origins of Salinity and Salinisation Processes in the Wybong Creek Catchment, New South Wales, Australia. Supervisor: Derry McPhail, Dr Ben McDonald. Advisors: Dr S Beavis, Dr I Roach, Dr R Creswell.

Renaud Joannes-Boyau - Direct Dating of Human Remains. Supervisor: Dr Rainer Grun. Advisors: Prof I. Jackson, Dr S. Eggins

David Robinson - Studies on Earthquake Location and Source Determination Using Coda Waves. Supervisor: Prof. Malcolm Sambridge. Advisors: Dr N Rawlinson, Dr P Cummins, Prof B Kennett.

Gregory Shirtliff - The Waste and Low Grade Ore Stockpiles of Ranger Uranium Mine: A System Approach. Supervisor: Prof. Tony Eggleton

Heather Sparks - Sulfide Melting at Broken Hill, Australia: Geochemical and Experimental Investigations. Supervisor: Dr John Mavrogenes. Advisors: Dr J Hermann, Dr A Berry, Dr C McFarlane.

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 J Hermann, Prof H O'Neill, Prof R Arculus.

Luke Wallace - Biogeochemistry of Acid Sulphate Soils. Supervisors: Dr Derry McPhail, Dr R Fitzpatrick. Advisors: Dr S Welch, Dr D Kirste, Dr S Beavis, S Rogers, S Lamontagne

MASTERS SUB-THESES COMPLETIONS

Muksin- Understanding the Seismic Structure Beneath Sumatera and its Surrounding Regions. Supervisor: Prof. Brian Kennett. Advisors: Dr Michelle Salmon, Dr Nicholas Rawlinson, Dr Sara Pozgay, Prof. Ian Jackson.

RSES Student Awards

A.L. Hales Honours Year Scholarship: Nicola Maher

Mervyn and Katalin Paterson Travel Fellowship: Alice Clement (to be taken up in 2011).

D.A. Brown Travel Scholarship: Magdalena Huyskens (to be taken up in 2011).

Robert Hill Memorial Prize: Not awarded

A.E. Ringwood Scholarship: Yunxing Xue

John Conrad Jaeger Scholarship: Alexander McCoy-West

Summer Research Scholarships

Mr Neil Berry (University of Canterbury, New Zealand) under the supervision of Stewart Fallon

Mr Nathan Coleman (Australian National University, Canberra) under the supervision of Steve Eggins

Ms Bianca Das (Lincoln University, New Zealand) under the supervision of Bradley Opdyke

Ms Lyndsay Dean (Australian National University, Canberra) under the supervision of Patrick De Deckker

Ms Michaela Flanigan (Australian National University, Canberra) under the supervision of John Mavrogenes

Ms Eleanor Peterson (Australian National University, Canberra) under the supervision of Oliver Nebel

Ms Aimee Robinson (Lincoln University, New Zealand) under the supervision of Michael Ellwood

Mr Michael Short (Flinders University, South Australia) under the supervision of Bear McPhail

National Alliance SRS

Ms Kym Rogers (Charles Darwin University, Darwin) under the supervision of Stewart Fallon

Student Internships

Ms Penelope Baker of Australian National University; Supervisor: Dr Andrew Hogg and Dr Graham Hughes

Ms Clare Connolly of Australian National University; Supervisor: Dr Greg Yaxley

Ms Bronwyn Dixon of Australian National University; Supervisor: Dr Michael Gagan

Ms Anna Haiblen of Australian National University; Supervisor: Dr John Mavrogenes

Ms Micaela Hartley of Australian National University; Supervisor: Prof. Malcolm Sambridge

Mr Ryan Holmes of Australian National University; Supervisor: Prof Ross Griffiths

Ms Sharmila Sane of Australian National University; Supervisor: Dr Andrew Hogg

Mr Yan Zhao 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

Student Officer

Maree Coldrick

School Student Assistant

Joy McDermid (from 18 November 2010)

Information Technology Manager

Paul Davidson, BSc, MSc, Auckland, PhD, ANU

Information Technology Officer

Duncan Bolt, BSc Sydney

Brian Harrold, BSc ANU

Hashantha Mendis, BInfTec Deakin

Receptionist

Josephine Margo (to 1 September 2010)

Shannon Avalos (from 2 September 2010)

Area Administrators

Earth Chemistry –

Robyn Petch (to 10 October 2010)

Josephine Margo (from 18 October 2010)

Earth Environment –

Susanne Hutchinson, BA, La Trobe University (to 15 January 2010)

Robyn Petch (from 18 October 2010)

Earth Materials – 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 (to 10 July 2010)

IODP Administrator

Sarah Howgego

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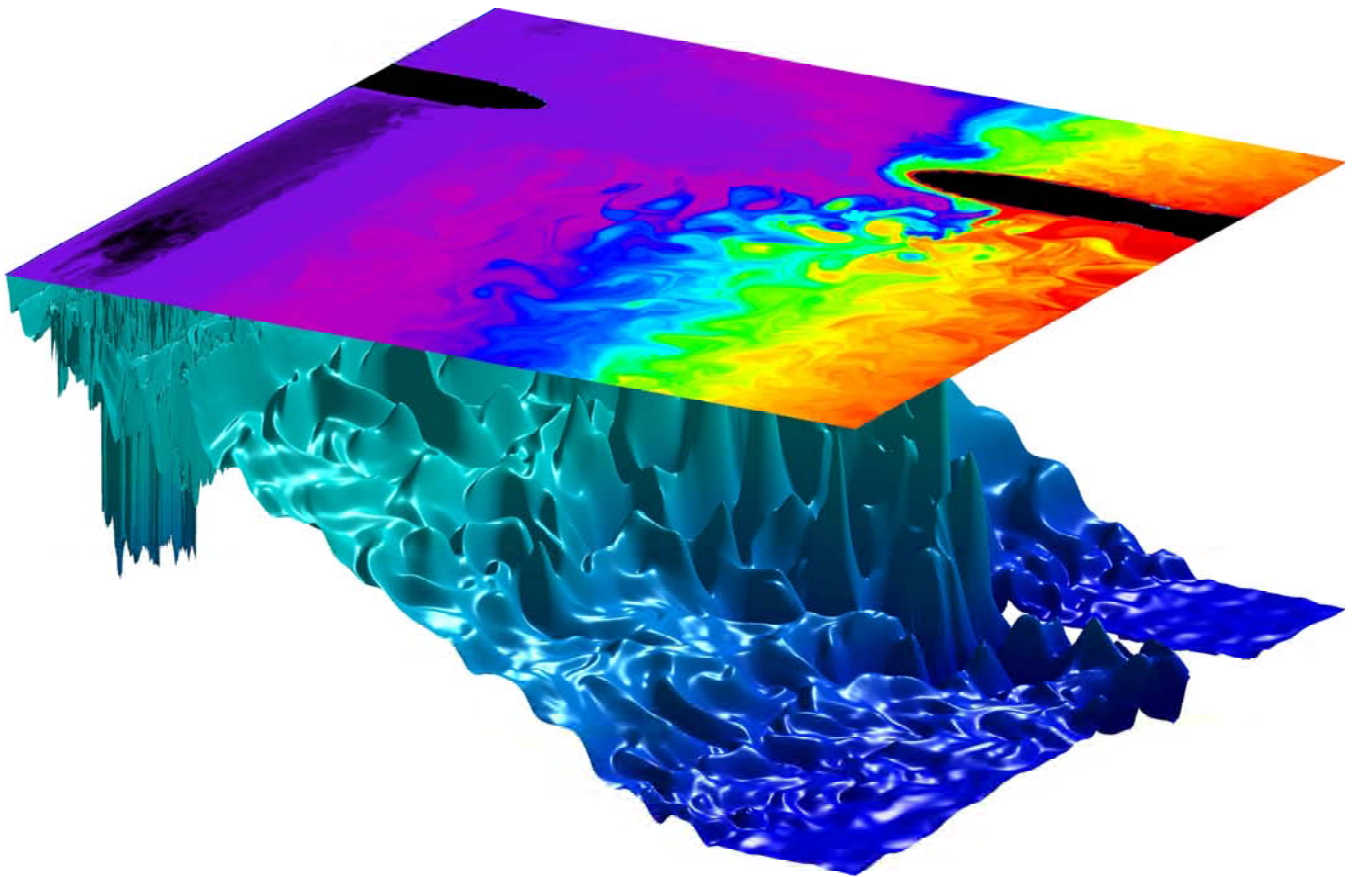
Charlotte Allen, AB Princeton MSc Oregon , PhD VirginiaTech
Anthony Beasley, AssocDip CIT
Brent Butler, Cert III Mechanical Engineering Sydney Institute
Joseph Cali, BAppSc QIT
David Cassar, Adv. Dip of Engineering (Electronics), CIT
David Clark, Cert III Metal Fabrication, CIT, Adv. Dip Engineering (Mechanical) CIT
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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 Kregge, MSc Australian Defence Force Academy, BSc Charles Stuart University, BE University of Canberra (to 10 January 2010)
Andrew Latimore, Bachelor of Engineering (Electronics) and Communications Engineering, University of Canberra
Qi Li
Emma Mathews (to 29 October 2010)
Linda McMorrow, AssocDip Science NTU
Graham Mortimer, BSc PhD Adelaide
Hayden Miller, Advanced Diploma in Mechanical Engineering, CIT
Samuel Mertens, BA (Hons) (to 10 January 2009)
Shane Paxton
Anthony Percival
Sisounthon (Tony) Phimphisane
Tristan Redman – Trainee
Eva Reynolds BSc (Hon) ANU (to 30 June 2010)
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
Ben Tranter, Cert II in Automotive Radiator Services John Batman Institute of TAFE, Automotive Climate Control / Air conditioning Casey Institute of TAFE (from 10 April 2010)
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 (to 9 April 2010)

Research School Of Earth Sciences (Earth Chemistry)

Research Activities 2010



Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.

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 processes at all time scales. Much of our analytical work involves detailed in situ analysis on the microscale, or chemically concentrating trace elements from larger samples for high precision analysis. As highlighted in this year's research contributions, a range of analytical approaches has been applied to answering key research questions in tectonics, petrology, solar system studies, paleoclimatology, and paleoecology.

2011 has been a year of transitions and of exciting analytical developments for Earth Chemistry. In June, after 9 highly successful years for the group, Prof. Trevor Ireland has stepped aside from the administrative role of area coordinator, with Dr. Vickie Bennett taking up this position and becoming an Associate Director. Congratulations to four members of Earth Chemistry on their successful applications in the 2010 promotions round, with Dr. Jochen Brocks and Dr. Yuri Amelin moving to Senior Fellow and Dr. Stewart Fallon and Dr. Marnie Forster promoted to Fellows. We welcome new staff members Ms. Susan Alford and Dr. Rachel Wood, who will be part of the Radiocarbon lab team under the direction of Dr. S. Fallon. Dr. Igor Iatsevitch, after many years in the Noble Gas area, will now be providing technical expertise to the argon dating facility. We acknowledge the highly competent services of long-time Area Administrator Ms. Robyn Petch, who in June moved to a similar position within Earth Environment; Ms. Josephine Magro has now capably taken up the administrative duties within Earth Chemistry. New PhD students enrolled this year are Mr. Alex McCoy-West (2010 Jaeger Scholarship awardee; supervisor V. Bennett), Ms. Magdalena Huyskens (Y. Amelin) and Ms. Kelly James and Ms. Aimee Komugabe (S. Fallon). Dr. Andrew Cross and Dr. Ryan Ickert were awarded their PhD degrees and Ms. J. Avila submitted her thesis.

Dr. D. Rubatto and Dr. J. Brocks were both awarded highly prestigious Queen Elizabeth II Fellowships by the Australian Research Council in the 2010 Discovery round. Following on from a successful 2010 ARC LIEF grant, a new Thermo Triton Plus thermal ionization mass spectrometer was delivered to the TIMS lab in November, with instrument acceptance testing and commissioning being overseen by Drs. Y. Amelin and V. Bennett. The acquisition of this equipment fulfills recommendations of the 2009 Geochemistry and Petrology Review and will facilitate new types of isotopic measurements, complementing the in situ microanalytical capabilities of the SHRIMPs as well as enabling new research directions. In-house construction of the ARC funded, next generation SHRIMP SI, which will be used exclusively for stable isotopic investigations, has now been completed and this instrument has moved into the testing phase. A new SEM, funded by a 2010 ANU Major Equipment proposal led by Dr. D. Rubatto, was delivered and accepted in December. Loss of several labs and workrooms owing to the space reorganization resulting from start of construction of new building J8, accompanied by destruction of OHB-A, resulted in periods of disruption for many Earth Chemistry staff, but with all necessary functions now accommodated, at least temporarily, in other spaces.

Earth Chemistry postgraduate students and academic staff were prominent at national and international conferences, including conference presentations at the Goldschmidt Conference, held in Knoxville in June, the Australian Earth Science Convention, held in Canberra in July, the Lunar and Planetary Science Conference at Houston in March and the American Geophysical Union meeting in December in San Francisco. Academic staff increasingly took on formal undergraduate teaching commitments this year. PhD candidates Ms. Tanya Ewing and Mr. Sasha Stepanov, in turn, organized our well-attended, weekly mass spectrometry seminar series.

The link between ocean-continent transition zones and (ultra-)high pressure metamorphism: a geochronology study

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Rifted margins comprise wide zones of exhumed crustal and mantle rocks that separate 'typical' continental and oceanic crust. These zones, referred to as Ocean Continent Transitions (OCT), may extend over more than 50% of the present-day rifted margins. Because of their extension and complex architecture, OCT may exert significant influence on the subsequent evolution of the margins when they become compressional and enter orogenies. Lithological associations compatible with distal continental margins are found in high-pressure (HP) and ultra-high-pressure (UHP) terranes.

We investigated the origin of such a lithological association in the Etnol-Levaz unit of the Western Alps, and its role in the dynamic of the deep subduction of the margin. This unit records HP metamorphism and crops out close to the UHP terrane of Lago di Cignana. Because of the intense reworking of this unit during subduction, we used zircon, a highly retentive geochronometer, to trace its rift-related, pre-subduction history.

Zircons from a mafic eclogite and a mylonitic gneiss were dated. The age of the zircon cores in both samples confirm the Permian intrusion of mafic and felsic magmatic protoliths, respectively. Age and chemical composition of zircon rims indicate limited melt infiltration in the continental basement during the Mesozoic. We attribute such melting to the intrusion of mafic magmas in the oceanic crust during the Jurassic. In turn, this implies that at 150-165 Ma the continental basement was resting upon oceanic crust. Subsequent zircon overgrowths in the gneiss and eclogite constrain possible Cretaceous hydrothermal circulation on the ocean floor and subduction to HP conditions in the Eocene.

We conclude that the investigated HP and UHP units were part of a Mesozoic OCT and suggest that OCT's are placed in a favorable position to reach (U)HP conditions, following negatively buoyant oceanic lithosphere into subduction. Such zones are then accreted to the orogen, in response to the arrival of more buoyant continental lithosphere, resisting subduction. The preservation of original relationships between rock units that underwent subduction to (U)HP conditions also suggests that the process of tectonic burial and exhumation need not be chaotic, but large, coherent bodies can behave relatively rigidly, while well-defined movement zones accommodate most of the deformation.

Relevant publication

<http://geology.gsapubs.org/content/38/6/559.abstract>

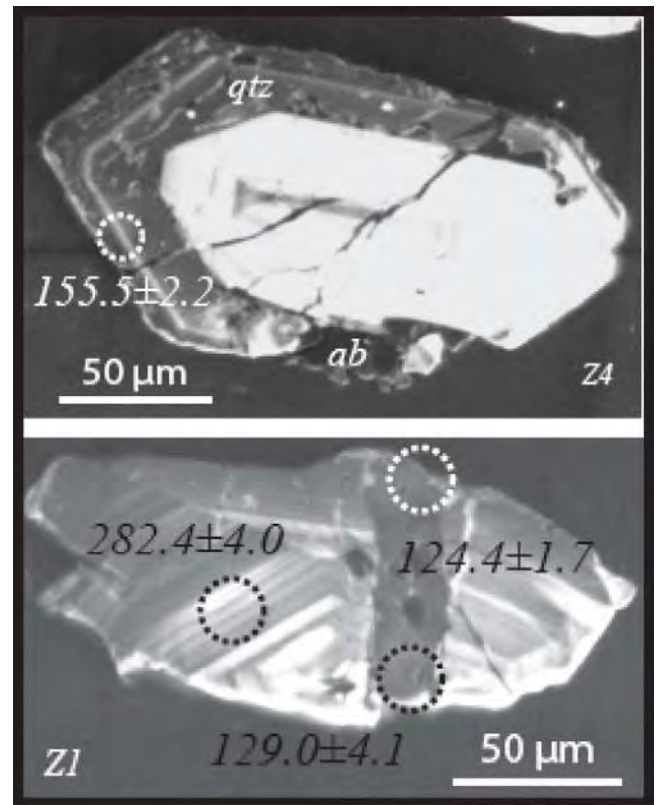


Figure 1. Cathodoluminescence images of representative zircons from the gneiss. SHRIMP U-Pb ages constrain the Permian crystallization of the protolith and Jurassic to Cretaceous ages attest to melt and fluid infiltration in the sample.

Figure 2. Jurassic palaeogeography of the European margin of the Western Tethys. Star indicates position of the Etnol-Levaz continental slice.

Zircon and monazite can really stand the heat

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³ Division of Evolution of Earth Environments, Kyushu University, Fukuoka, Japan

Radioisotope geochronology involves far more than simply measuring the ages of rocks. Different isotopic systems record different stages in the thermal history of a rock depending upon the chemical stability of the host mineral and the closure temperatures of each isotopic system in that mineral. One of the most robust isotopic systems is the U-Th-Pb system in zircon and monazite. In suitable environments, both these minerals are chemically stable at temperatures up to at least 900°C, and experimental studies indicate that their U-Th-Pb closure temperatures are at least as high at that. A question that remains unresolved, however, is whether the closure temperatures measured experimentally are the same as the closure temperatures under natural geological conditions.

The rocks of the central Highland Complex in Sri Lanka have been subject to some of the highest peak temperatures of crustal metamorphism known, over 1050°C. At such temperatures most crustal rocks would develop sufficient partial melt to mobilise, but the metasediments of the Highland Complex were unusually dry, and hence have remained intact. Rocks metamorphosed under such extreme conditions provide a rare opportunity to study zircon and monazite growth, and the behaviour of their U-Th-Pb isotopic systems, at ultra-high temperatures.

Two sapphirine-bearing metasediments from near Kandy were chosen for our study (Sajeew et al., 2010), one quartz-saturated (containing remnants of the peak metamorphic mineral assemblage) and the other quartz undersaturated (containing only retrograde assemblages). The quartz-saturated granulite contained both zircon and monazite, the quartz-undersaturated granulite contained zircon only.

By analysing the various growth zones in the zircon and monazite crystals using the ANU SHRIMP II ion microprobe, we identified and dated zircon and monazite formed at different times in the geological history of these rocks. The zircon crystals in the quartz-saturated rock mostly consisted of three growth layers: protolith detrital zircon, prograde metamorphic zircon and retrograde metamorphic zircon. Remarkably, each layer preserved an accurate U-Pb record of its crystallisation age, proving that under suitable geological conditions, the closure temperature of the zircon U-Th-Pb isotopic system exceeds 1050°C, higher than has been demonstrated by any experimental study. Most of the monazite preserved only the age of retrogression, but one older core was identified (Figure 1), demonstrating that monazite also has a U-Th-Pb closure temperature in excess of 1050°C. The metamorphic zircon overgrowths in the quartz-undersaturated granulite recorded only the age of retrogression.

The rocks near Kandy were originally sediments derived from sources ranging in age from 2.5 to 0.83 Ga. The sediments were heated to over 1050°C at a depth of about 25 km at about 570 Ma, then rapidly decompressed isothermally at about 550 Ma. These Sri Lankan metasediments were trapped in an ultra-hot collisional orogen during the final amalgamation of Gondwana, locally superheated, possibly by basaltic underplating, then rapidly uplifted, a cycle that we now know lasted about 20 million years.

Reference:

Sajeew, K., Williams, I.S. & Osanai, Y., 2010: Sensitive high-resolution ion microprobe U-Pb dating of prograde and retrograde ultrahigh-temperature metamorphism as exemplified by Sri Lankan granulites. *Geology*, **38**, 971–974.

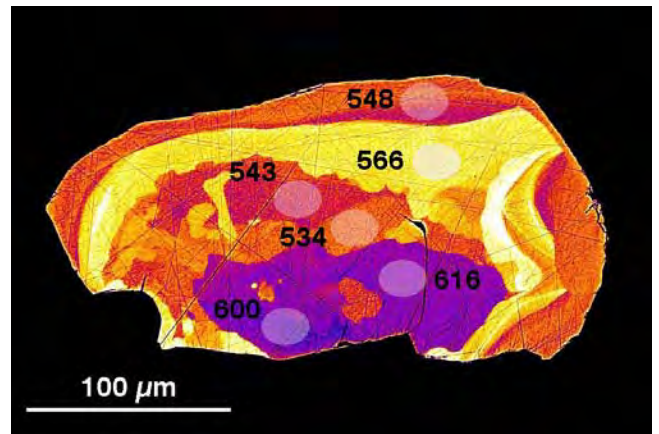


Figure 1. False colour backscattered electron image of a monazite crystal from a Kandy ultra-high temperature granulite showing spots analysed by SHRIMP II with their U-Pb dates (Ma). The purple core is at least 50 million years older than the retrograde metamorphic monazite surrounding it.

A new protocol for in situ measurement of the hafnium isotope composition of rutile

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Hafnium (Hf) isotope signatures can differentiate between important reservoirs within the Earth, such as the crust and mantle. Measurement of Hf isotopes thus allows fingerprinting of which reservoirs have had input to the source of a rock. Hf isotope analysis has most commonly been applied to the mineral zircon, but recently it has also been applied to rutile (Choukroun et al., 2005; Aulbach et al., 2008). Rutile (TiO_2) is a mineral that occurs in many metamorphic and sedimentary lithologies. It is appealing for isotopic analysis in metamorphic samples as it is more easily linked to major reactions than zircon. However, it contains relatively low levels of Hf (<300 ppm) and therefore requires careful analysis to obtain accurate Hf isotope measurements.

We have developed a new analytical protocol to measure the Hf isotope composition of rutile by laser ablation multicollector inductively coupled mass spectrometer (LA-MC-ICPMS) as accurately and precisely as possible. This technique allows an area of rutile ~200 nm in diameter to be analysed in situ. The new protocol produces excellent results. Rutile from a New Caledonian trondhjemite has been analysed by solution MC-ICPMS to provide an independent constraint on its Hf isotope composition. 95 LA-MC-ICPMS analyses of rutile from the same sample are in excellent agreement with the solution result, demonstrating the accuracy and long-term reproducibility of our technique (Fig. 2).

A case study on the Duria garnet peridotite demonstrates the usefulness of Hf isotope analysis of rutile for investigating the evolution of metamorphic rocks. This sample contains both zircon and rutile. Hermann et al. (2006) showed that rutile formed as part of the peak metamorphic assemblage with a depleted mantle signature, whereas zircon formed later during retrogression and the influx of crustal fluids (Fig. 1). We analysed both rutile and zircon for Hf isotopes by LA-MC-ICPMS. Rutile has a Hf isotope composition that indicates a depleted mantle origin. In contrast, the Hf isotope signature of zircon records input from a crustal source. These results are consistent with the findings of Hermann et al. (2006). Furthermore, they emphasise that when rutile and zircon form at different times they can record isotopic information about different events. This example demonstrates that Hf isotope analysis of rutile is a powerful tool for understanding metamorphic histories, as it can unlock information that zircon may not record.

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- Choukroun M, O'Reilly SY, Griffin WL, Pearson NJ, Dawson JB (2005) Hf isotopes of MARID (mica-amphibole-rutile-ilmenite-diopside) rutile trace metasomatic processes in the lithospheric mantle. *Geology* **33**(1): 45-48.

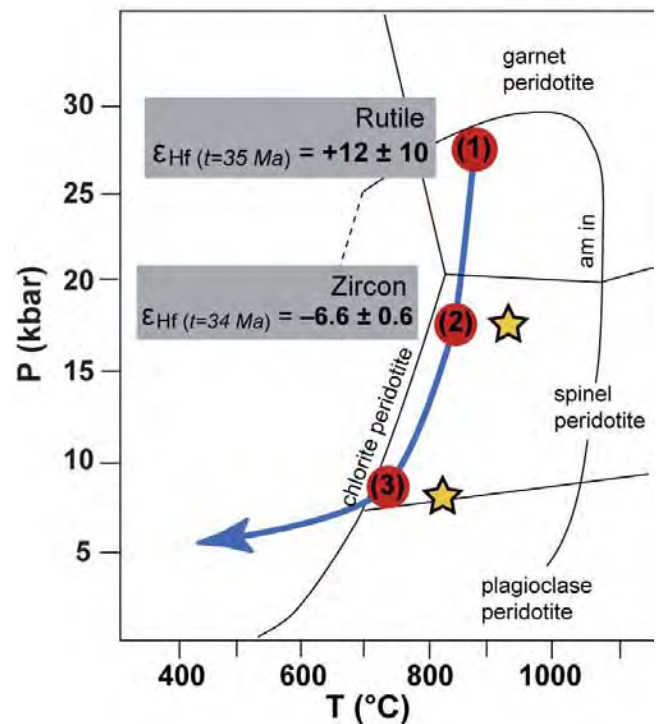
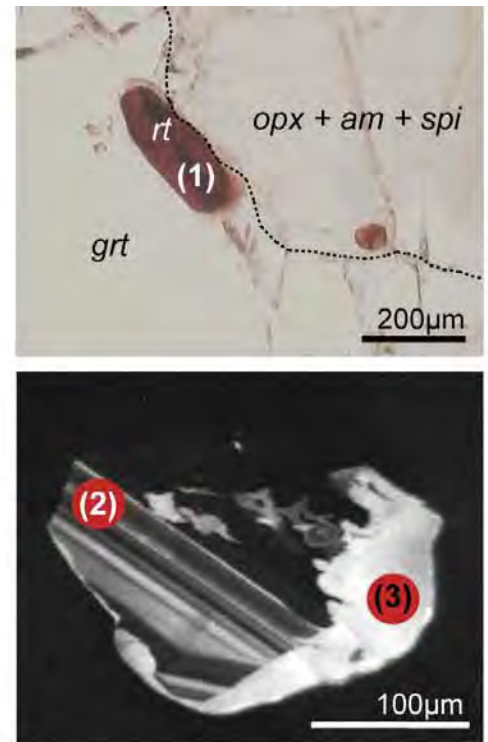


Figure 1. Pressure-temperature-time path for the Duria garnet peridotite, modified after Hermann et al. (2006). Stars indicate crustal fluid influx events. Rutile from the Duria peridotite is shown in transmitted light (top), and zircon in cathodoluminescence (centre).

Hermann J, Rubatto D, Trommsdorff V (2006) Sub-solidus Oligocene zircon formation in garnet peridotite during fast decompression and fluid infiltration (Duria, Central Alps). *Mineralogy and Petrology* **88**(1-2): 181-206.

Full details in the online article in Chemical Geology (in press):
<http://dx.doi.org/10.1016/j.chemgeo.2010.11.029>

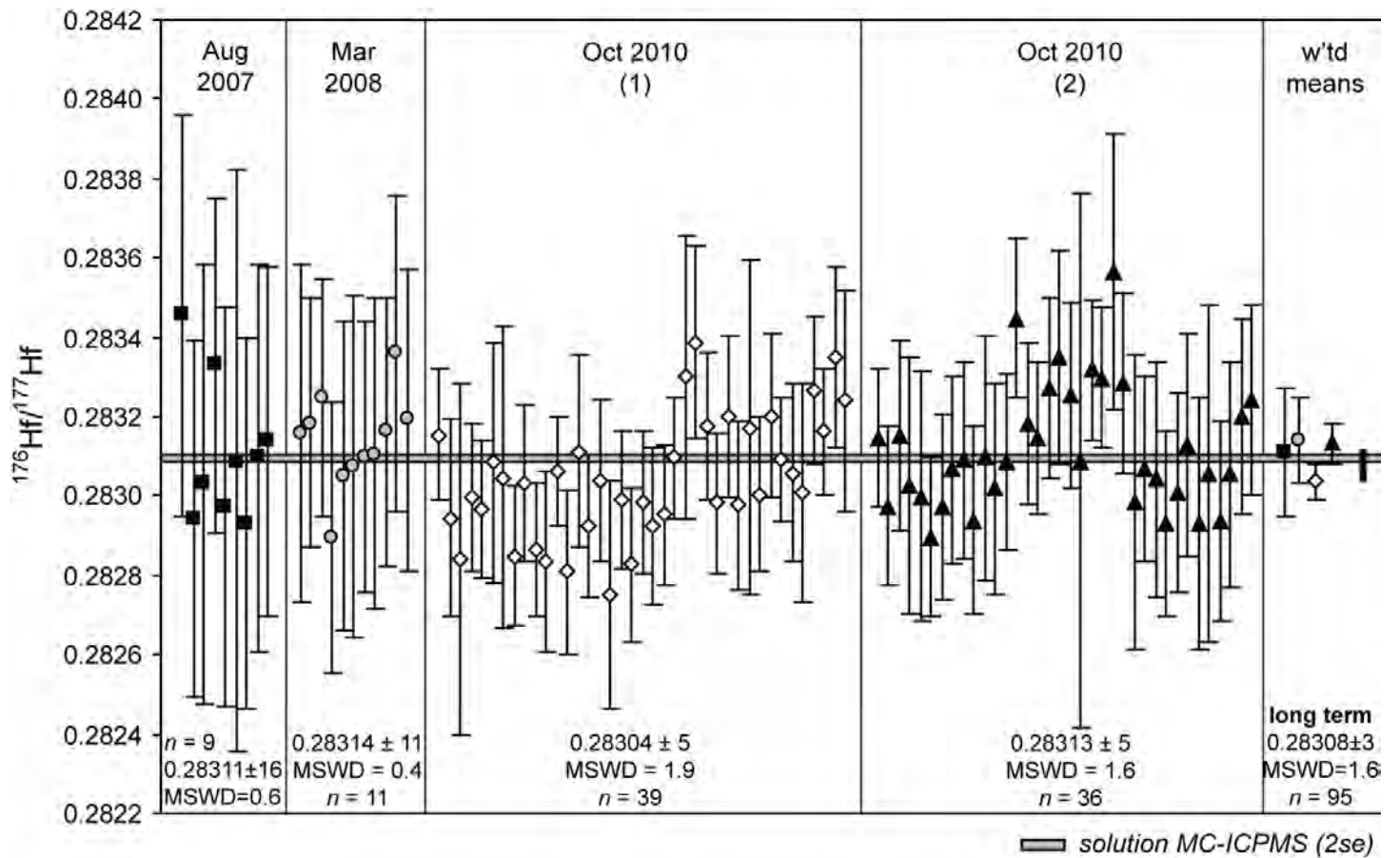


Figure 2. Measured Hf isotope composition ($^{176}\text{Hf}/^{177}\text{Hf}$) of rutile from a New Caledonian trondhjemite in four sessions across three years. Note excellent agreement with the $^{176}\text{Hf}/^{177}\text{Hf}$ determined independently by solution MC-ICPMS.

Early crustal evolution deduced from a combined U-Pb and Sm-Nd isotopic study of Mt. Narryer and Jack Hills monazites

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Knowledge of early crustal evolution is central to deciphering the evolution of the young Earth. Metasedimentary rocks from the Mt. Narryer region in the Yilgarn Craton of Western Australia are of particular importance, because they yield Hadean (>4.03 Ga) detrital zircons, that contribute to our understanding of early crustal evolution (e.g., Froude et al., 1983; Compston and Pidgeon, 1986). Despite the geological significance of the Hadean crustal fragments, other detrital mineral phases in the metasedimentary rocks are just beginning to receive some attention and little is yet known. Characterization of different detrital phases is crucial for the robust provenance analysis.

Monazite, a LREE phosphate mineral, is ubiquitous as an igneous accessory phase in low-Ca felsic rocks and as a secondary accessory phase in a wide range of metamorphic rocks. Monazite can be precisely dated by the U-Th-Pb system, thereby providing timing constraints on igneous and metamorphic events. In addition, its ¹⁴⁷Sm-¹⁴³Nd systematics provide constraints on whether the source magma is of juvenile 'mantle' origin or reflects a more extensive crustal reworking history. In this study, we have conducted in situ U-Pb isotopic dating and ¹⁴⁷Sm-¹⁴³Nd analyses of monazites from Mt. Narryer and Jack Hills metasedimentary rocks.

U-Pb isotopic data reveal the occurrence of detrital monazites with ages up to 3.6 Ga (Iizuka et al., 2010). All detrital monazites have negative initial εNd(t) values, indicating that their parental magmas formed by remelting of older crustal materials. The comparison between the initial εNd(t) values of the detrital monazites and granitoids in the Narryer Gneiss Complex indicates that the Mt. Narryer and Jack Hills sediments were partly derived from the most isotopically enriched surrounding granitoids with ages of ca. 3.6 and 3.3 Ga (Fig. 1).

The U-Pb and Sm-Nd isotope systematics of the Mt. Narryer and Jack Hills monazites are consistent with either of two hypotheses for the source of Hadean detrital zircons: (i) the zircons were originally derived from granitic rocks containing igneous monazite, but experienced prolonged sedimentary recycling leading to complete dissolution of the monazite, or (ii) the parental magmas of the zircons were not granitic and generated by remelting of 4.5–4.4 Ga mafic crust that had also contributed to the genesis of some Archean Narryer granitoids. The latter hypothesis can be further tested by investigating ¹⁴⁶Sm-¹⁴²Nd systematics of the monazites.

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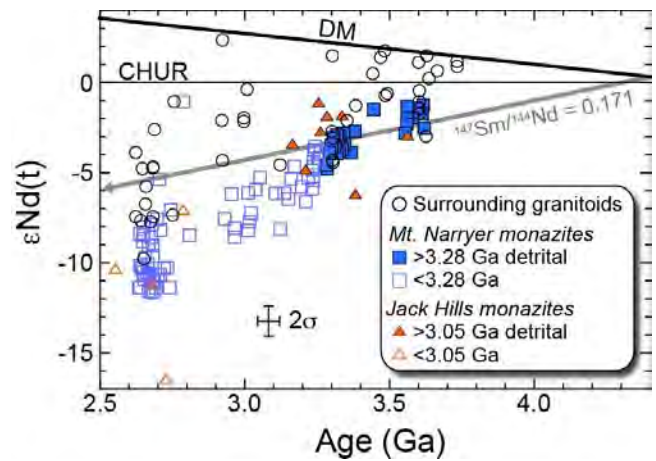


Figure 1. Comparison of the Nd isotopic composition of the Mt. Narryer and Jack Hills monazites with previously published whole-rock Nd isotopic data for the granitoids in the Narryer Gneiss Complex (Nutman et al., 1993). A Nd isotopic evolution curve of 4.4 Ga mafic crust with ¹⁴⁷Sm/¹⁴⁴Nd of 0.171 is also shown for reference.

Enrichment of Rh, Ru, Ir and Os in Cr spinels from oxidized magmas: evidence from the Ambae lava, Vanuatu arc

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Cr-spinel has been considered to be an important host for Rh and IPGEs (Iridium-group elements: Os, Ir and Ru). The correlation between whole rock Cr and Rh and IPGEs contents observed from various magmatic suites and the enrichment of Rh and IPGEs in chromitites from the layered intrusions, ophiolites and alpine-type peridotites suggest that there is a genetic link between Rh and IPGEs contents in a rock and Cr-spinels. It is, however, controversial whether the trends are mainly controlled by the Cr-spinels which accommodate Rh and IPGE in solid solution or platinum group minerals (PGM) and PGE-bearing sulphides which are entrapped in Cr-spinels during their growth.

Experimental studies on partitioning of PGEs (Platinum Group elements) between spinels and silicate melts showed that Rh and IPGE can be held in solid solution, showing high compatibility of Ir ($D_{Ir}=5-22000$), Ru ($D_{Ru}=20-4000$) and Rh ($D_{Rh}=41-530$) to Cr-spinel in oxidized condition ($> QFM+2$). However, Cr-spinels often occur in association with PGE-bearing microinclusions in natural samples from layered intrusions, ophiolites and komatiitic basalts, and the main host for Rh and IPGE in the chromite-rich rocks is thought to be PGE-rich inclusions trapped in Cr-spinels indicating that the physical process appears to be dominant in more reduced environment ($\sim QFM$). This discrepancy suggests that the partition coefficients for PGEs between silicate melt and Cr spinel from the experimental studies were overestimated or they are dependent on oxygen fugacity.

Platinum group element (PGE), Au and Re abundances in Cr spinels from the relatively oxidized magma (Ambae lava, Vanuatu Arc) and relatively reduced magma (the Jimberlana layered intrusion, Western Australia and the Bushveld complex, South Africa) have been measured using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS).

Preliminary results show that the Ambae Cr-spinels contain tens of ppb Rh, Ru, Ir and Os (Fig. 1). The uniform count rates during the laser ablation and the correlations of Rh and IPGEs with Cr-spinel compositional parameters indicate that these elements are held in solid solution. In contrast, although their magmas are thought to be more enriched in PGE than the Ambae magma, most of the Jimberlana and Bushveld Cr spinels contain no detectable PGE except for some grains containing <15 ppb of Ru, Ir and Os (Fig. 1). Pt-Fe alloys with variable Ir, Os and Rh were entrapped in some of the Ambae Cr-spinels. The low Mg# Cr-spinels ($0.6 < Mg\#$) are depleted in Rh and Os compared to the high Mg# Cr-spinels ($0.6 > Mg\#$), indicating that these elements may have migrated from Cr-spinel to Pt-Fe alloy inclusions during subsolidus reequilibration (Fig. 1). Rhodium, Os and Ru contents in the high Mg# Ambae Cr-spinels are positively correlated with spinel $Fe^{3+}/(Fe^{3+}+Cr^{3+}+Al^{3+})$. The empirical partition coefficients for Rh, Ru and Ir in Cr spinel ($D_{Rh} \sim 600$, $D_{Ru} \sim 2400$ and $D_{Ir} \sim 500$) are comparable experimentally determined values at a similar oxygen fugacity. Our results confirms the high compatibility of Rh and IPGEs in Cr-spinel in oxidized condition and suggest that the partition coefficients for Rh and IPGEs between silicate melt and Cr-spinel are strongly controlled by oxygen fugacity.

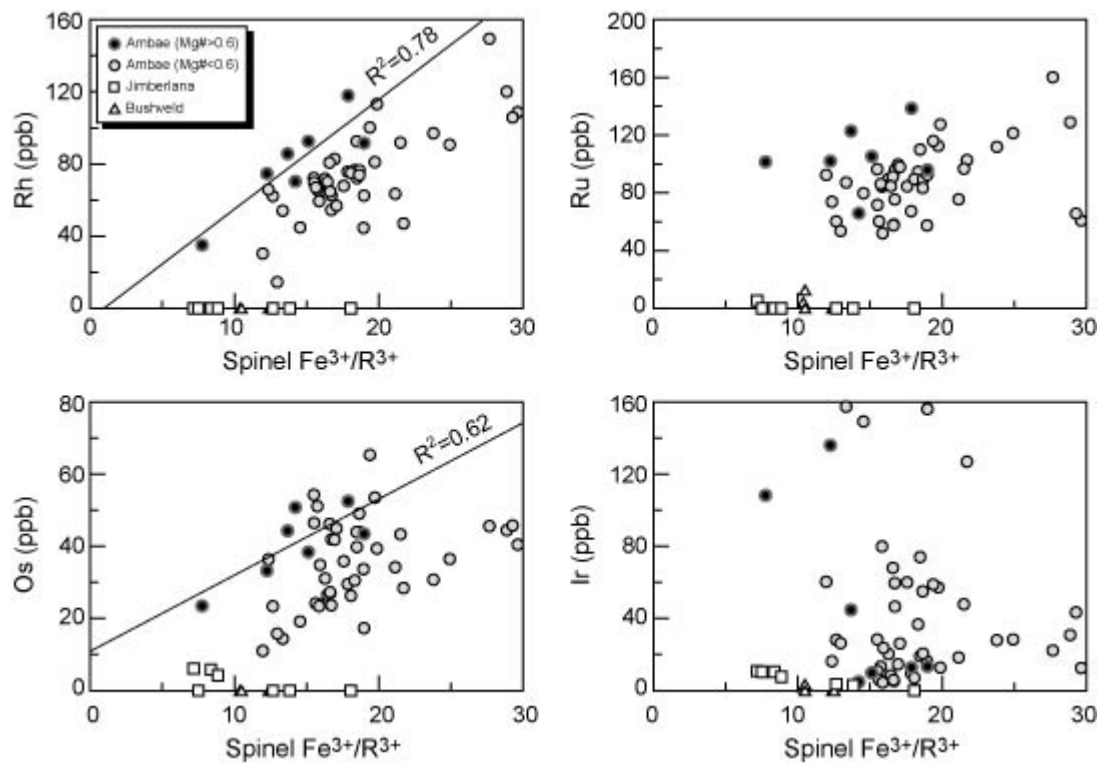


Figure 1. Variation of Rh, Ru, Os and Ir in Cr-spinels from the Ambae lava, Jimberlana layered intrusion and Bushveld complex as a function of $\text{Fe}^{3+}/\text{R}^{3+}$.

Biogeochemical Evolution in Neoproterozoic Oceans

The search for a 'turbid ocean'

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The fossil record indicates that the first morphologically-complex animal phyla appear in the Ediacaran (630-542 Ma) and rapidly diversify during the 'Cambrian Explosion' after 542 Ma (Xiao and Laflamme, 2009). Chemical, geological and isotopic evidence demonstrate that the oceans in the late Neoproterozoic (800 – 542 Ma) were subject to significant environmental and chemical change. Relationships between ocean chemistry and the evolution of organisms in the Neoproterozoic remain largely unclear. The aim of our study is to resolve some of the relationships between ocean chemistry and evolutionary events by testing the hypothesis of organically-loaded 'Turbid Oceans'.

Logan *et al.* (1995) noticed a distinctive shift of biomarker assemblages as well as preservation of organic material across the Precambrian-Cambrian boundary. Bacterial biomarkers isolated from Proterozoic sediments appear unusually highly biodegraded indicating reworking in a stagnant organically-loaded water column. These conditions are thought to have dominated the carbon cycle for a quarter of Earth history between 1,800 – 580 Myr ago (Fike *et al.*, 2006; Logan *et al.*, 1995; Rothman *et al.*, 2003). In Phanerozoic sediments, preservation of algal lipids greatly improves due to rapidly sinking organic material due to larger organism size and the evolution of organisms which produce fecal pellets. This process is termed the 'biological pump' and was also thought to have facilitated oxygenation of the deeper ocean (Fike *et al.*, 2006).

A turbid ocean would firstly be populated by high levels of picoplankton-sized (0.2 -2 μm in size) bacteria thought to dominate the Neoproterozoic oceans due to the absence of predators before the late Ediacaran (Butterfield, 2009). Secondly, organic material in the turbid ocean would be highly biodegraded due to constant microbial reworking of material sinking slowly through the water column. Finally, the ocean state would be anoxic, or possibly euxinic (anoxic and sulfidic) or ferruginous, due to the lack of oxygen dissolved in the ocean at depth. At present, there is no direct geological evidence to suggest that such an ocean with suspended organic material existed. In this study we are using the above characteristics to test for the presence of a 'Turbid Ocean' using samples from the Centralian Superbasin, Australia and searching for evidence for a transition to a clear water, ventilated ocean state expected to coincide with the 'Shuram excursion' ~560 – 570 Ma (Fike *et al.*, 2006).

We have recently acquired iron and sulfur speciation data and complementary biomarker assemblages from Neoproterozoic sections of the Centralian Superbasin. Our data indicate that the Neoproterozoic oceans in Australia were anoxic and ferruginous. In contrast to previous biomarker studies, our recent work has shown that Neoproterozoic molecular fossils are not as abundant as initially thought. The majority of biomarkers found in this study were contaminants from drilling fluids and diesel oil. In this study we found that samples older than 635 Ma did not have detectable amounts of indigenous steranes in the interior fraction, however they were abundant on the exterior surfaces of the drill core. Furthermore, indigenous steranes from samples dated between 635 Ma and the Precambrian-Cambrian boundary (~542 Ma) contained sterane ratios fundamentally different to those in the Phanerozoic (542 Ma - present).

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He, Ne and Ar in peridotitic and eclogitic paragenesis diamonds from the Jwaneng kimberlite, Botswana

Implications for mantle evolution and diamond formation ages

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Diamonds have several unique characteristics that make them invaluable as robust capsules of mantle noble gases: (1) diamond is highly retentive of mantle-derived noble gases, which are sometimes present in relatively high concentrations, (2) most diamonds appear to be derived from the sub-continental mantle lithosphere at depths of 150 km to 200 km, (3) diamonds crystallized over a wide time range, with most measured ages between 0.6 and 3.5 billion years, (4) diamonds exhibit very low diffusivities for noble gases even under mantle conditions, and (5) diamonds are chemically inert with little interaction with the crust or atmosphere.

We have undertaken helium, neon and argon step-heating, isotopic analyses of eleven polycrystalline diamonds of known peridotite/eclogite paragenesis from the Jwaneng kimberlite pipe, Botswana. 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 contain similar noble gas isotopic compositions (particularly Ne; see Figure x) to those representing a mantle source for MORBs. This implies that the Jwaneng polycrystalline diamonds may have formed in recent times, possibly close to the time of kimberlite emplacement at ~235Ma. In contrast, Jwaneng framesites could be as old as gem-diamonds (oldest mineral inclusion ages of ~2.9 Ga). If correct, this suggests at least three diamond forming events in the mantle region beneath the Jwaneng kimberlite: ~2.9 Ga, ~1.54 Ga and ~0.24 Ga.

Furthermore, the contrast in Ne isotopic compositions between the Jwaneng polycrystalline and framesite diamonds, in conjunction with the inferred age differences, may imply that primordial noble gases in the sub-continental mantle lithosphere, in which the Jwaneng diamonds formed, was outgassed (or overprinted) at an early stage of Earth's history (~2.9 Ga), with crustal noble gases introduced into the region by subduction-related processes. Subsequently primordial noble gases were supplied continuously from the underlying mantle, resulting in the present-day MORB-like Ne compositions in the sub-continental lithospheric mantle.

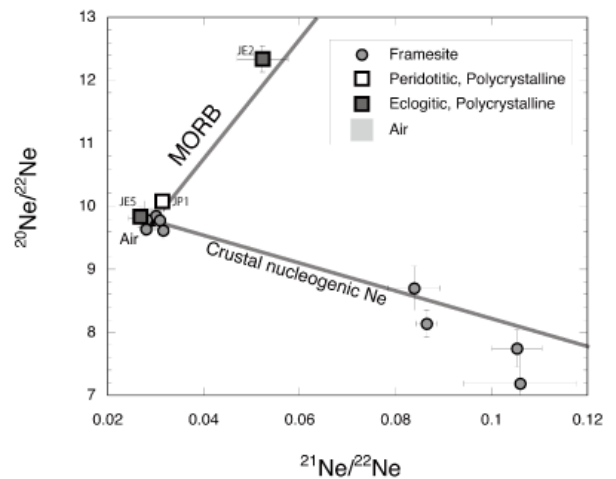


Figure 1. Neon isotope diagram, showing results from Jwaneng polycrystalline diamonds and framesites. The MORB correlation line and a mixing line between atmospheric and crustal nucleogenic neon are also plotted. Note the contrast in Ne isotopic compositions between the polycrystalline diamonds (MORB-like) and the framesites (crust-like).

Assessing microbial diversity during the deposition of a Neoproterozoic (c.800 Ma) saline giant: evaporites as an archive for Precambrian halophiles

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We conducted the first molecular investigation of the biotic composition and biogeochemistry of an evaporitic, hypersaline environment from the mid-Neoproterozoic (c.800 Ma). Through detailed analyses of both sedimentary textures and their lipid biomarkers, we provide evidence for potentially the oldest saline sensitive molecular fossils. In addition, we provide confirmation for the syngeneity of these molecules and demonstrate the ease with which hydrocarbon contamination can alter the indigenous biotic signal. Such research is timely, since the discovery of evaporite deposits on Mars highlights the need to understand their capacities as biological archives.

Samples for this study were derived from evaporitic sediments of the Neoproterozoic Bitter Springs Formation, Amadeus Basin, central Australia. Due to the broad shallow nature of the 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 [1]. All samples for this study were derived from drill cores held at Geoscience Australia (Canberra) and at the Northern Territory Geological Survey at Alice Springs.

We extracted biomarkers from evaporitic sediments composed of dolomite, anhydrite and/or halite. The dolomite layers commonly assume the shape of microbial mat-like formations that exhibit roll-up structures and tearing. Pyrite was commonly associated with the dolomite. Full scan gas chromatography-mass spectrometry (GCMS) of the saturate fraction revealed high ratios of mono- and dimethylalkanes relative to *n*-alkanes. Such a pattern is typical of Precambrian and Cambrian samples and observed in a number of facies settings. However, both hopanes and sterane signals are absent in these samples. This observation is in direct contrast to previous studies of Neoproterozoic sedimentary rocks from the Amadeus Basin [2], where these molecules are purported to be present.

An outstanding characteristic of these evaporites are the presence of several pseudohomologous series of both regular (to C₂₅) and irregular (to C₄₀) acyclic isoprenoids. It is important to note that the relative concentrations of these molecules vary and depend on the mineralogy of the host rock. Indeed, concentrations of these molecules were observed to vary within millimetre scales, depending on the textural characteristics of the sedimentary rock. However, through these observations, we were able to identify saline-sensitive biomarkers and potentially the oldest occurrence of haloarchaea in the geological record.

Based on these results, we present an ancient and extreme, saline environment dominated by prokaryotes. We also demonstrate that only a spatially and texturally integrated study can yield a maximum amount of information pertaining to biomarker distribution in a sedimentary host rock. Currently, such studies are rarely conducted. Furthermore, we show that the presence of exceptionally well preserved biomarkers in anhydrite (CaSO₄), despite the fact that sulphate and biomarkers are thermodynamically not stable together, raises the prospect of finding biomarkers in sulphate deposits on Mars.

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Figure 1. Example of a Neoproterozoic evaporite, featuring dolomitic laminae (dark layers) and anhydrite (light layers). Such rocks are an ideal target in the search for evidence of ancient hypersaline organisms.

New constraints on the global halogen cycle

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Figure 1. Halogen data for serpentinites and serpentinite breakdown fluids; porphyry copper arc magmas and the sedimentary marine pore fluid trend (organic Br/I ~ 1).

There is a great deal of interest in the global halogen cycle. Limited Br/Cl data have been available for Mid-Ocean Ridge Basalts (MORB) since the 1970's. However, Br and I are difficult to measure by conventional techniques and most recent studies have focused on Cl abundances or isotope analyses only. Unfortunately the Cl isotopes exhibit very limited variation which has restricted advances in our understanding of the Cl cycle.

We have adopted an entirely different approach by combining analysis of halogens (Cl, Br plus I) with noble gas isotopes. This technique is an extension of the Ar-Ar method, it provides very high sensitivity and recently developed monitors enable Br/Cl and I/Cl reproducibility at the 2% level.

Serpentinites formed on the seafloor and by sedimentary pore fluids are estimated as the dominant mantle input for Cl in subduction zones. Br/Cl and I/Cl are strongly fractionated when serpentine breaks down to olivine, orthopyroxene and water at sub-arc depths (e.g. 60-200 km; Fig 1). The serpentinite data are combined with published data for sedimentary marine pore fluids and mineralizing fluids derived from porphyry copper arc magmas (Fig 1). These data show Cl is recycled more efficiently than Br or I.

Further analyses are now required to test the extent to which seawater controls MORB Br/Cl (or visa versa) and the halogen composition of ocean Island Basalt.

Dating Himalayan microstructures using $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology

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$^{40}\text{Ar}/^{39}\text{Ar}$ geochronology is used to investigate the timing of tectonic events in NW India. The step-heating method can record multiple apparent ages, rather than a singular age from a thermally disturbed rock.

Most Himalayan $^{40}\text{Ar}/^{39}\text{Ar}$ studies investigate the timing of cooling to determine rates of cooling, exhumation and erosion, the timing of peak metamorphism, or the age of emplacement of for example, an igneous body. However the processes of deformation and recrystallisation can also change or “reset” the argon isotopic system, meaning that the timing of deformation can potentially be preserved in a rock. This is particularly the case with incompletely reset rock systems which may have escaped younger and/or more intense deformation and metamorphism, and is applicable to Himalayan terrane. Multiple apparent ages potentially correspond to various tectonic and thermal events affecting the history of the rock, and can be obtained from structures and even microstructures an argon partial retention zone.

The South Tibetan Detachment System (STDS), a series of major interlinking extensional fault systems in the Himalaya, has been given “across-the-board” deformation ages of 22-17 Ma from various geochronological methods, using $^{40}\text{Ar}/^{39}\text{Ar}$. The Rohtang Mylonite, which is within this STDS zone, was studied to investigate the effect of different microstructures on argon apparent ages. White micas from S-surface and C-surface foliations, were separately analysed. Preliminary results show that the S-surfaces crystallized at about 60 Ma, and the C-surfaces crystallized at about 22 Ma during a mylonitisation event. The preservation of distinctly older deformation ages from older microstructures in a “young” rock shows the differentiation of argon system into two immediately adjacent domains. This demonstrates the necessity of microstructurally focused argon geochronology when dating complexly deformed metamorphic rocks.

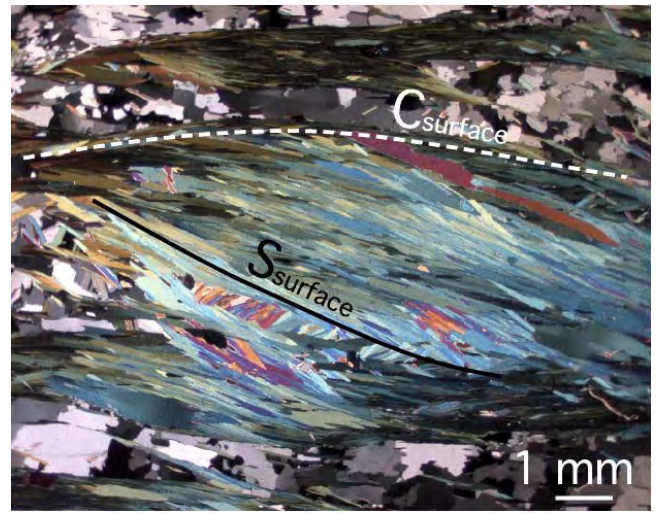


Figure 1. S- and C-surface foliations from the Rohtang Mylonite.

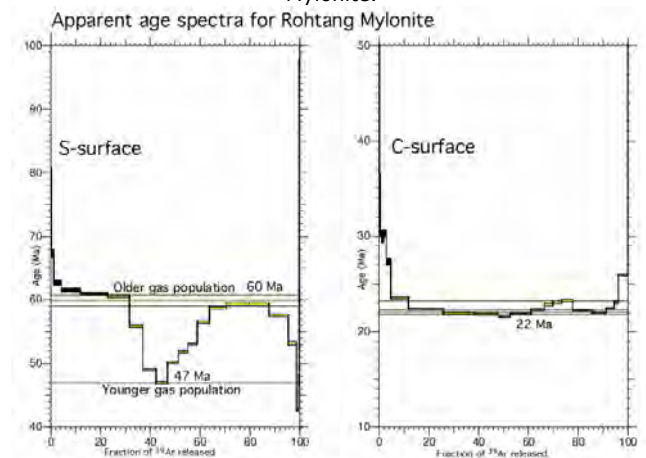


Figure 2. Older S-surfaces yield older apparent ages of between 60-47 Ma, while younger C-surfaces yield apparent ages of about 23-22 Ma.

Exhumation of rocks from great depth: squeezed out in a channel, or a roller-coaster ride as they are torn out by deep crustal faults?

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The processes behind the bringing of high-pressure rocks from depths greater than 50km to the surface of the Earth are phenomena that are still heatedly disputed. One model sees rocks buried and brought back up within a subduction channel, and this is the most accepted model today. However such models have significant flaws. These are being illustrated by research in the southern region of Evia, west Aegean Sea, Greece. Here we find a well-preserved record of the processes that operated.



Figure 1. High-pressure rocks are juxtaposed against rocks from higher in the Earth crust, different rocks preserving different histories. Periods of both extension and compression occur throughout the zone. Significant folding sequences are preserved, as seen here in marble sequences, between extensional shear zones.

These high-pressure rocks occur on the western side of a high-pressure belt that outcrops across the Aegean. Preliminary research is proving this site important in providing new data on the timing and character of processes involved. Two crustal-scale faults, or movement zones, have been found that are associated with the exhumation of these deep rocks. Microstructurally focused ⁴⁰Ar/³⁹Ar geochronology has been undertaken to time the different periods of shear zone activity, and thus verify the distinct stages of movement. The structurally deepest fault has been found to have operated at a time >~30 Ma, while the more complex movement zone immediately adjacent operated at least 14 million years earlier. The structurally higher major movement zone has largely been ignored in the literature - yet it is this contact that has brought these rocks up from the deepest zones. Movement has taken place across a broad heterogeneous zone and may have operated over an extended period spanning at least 10 million years. The effects of alternating compression and extension may explain the shuffling of tectonic slices along the zone.

The character of these two distinct movements zones differ greatly, the younger zone being a narrow intense zone overprinted by a brittle fault which may eventually be proven to be a major low-angle extensional detachment fault. The older zone is uncommonly broad and characteristic of what has previously been referred to as an ophiolitic mélange. We consider this to be a 'tectonic shuffle zone' due to the actual character of shuffling that has occurred during the exhumation of these rocks.

Details of research and resources available in the Structure and Tectonics Team.

<http://rses.anu.edu.au/tectonics/>

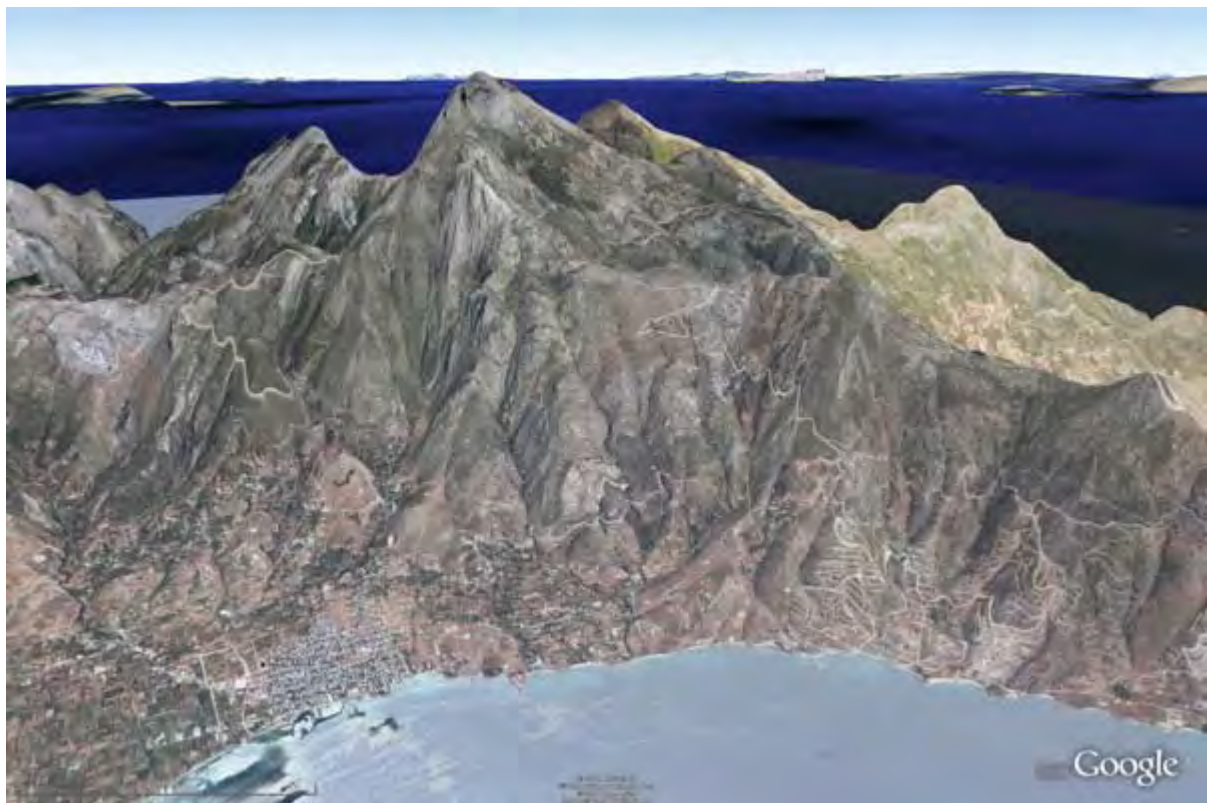


Figure 2. The high mountains of southern Evia, Greece preserve the high-pressure rocks that have been exhumed from greater than 50 km depth. The Evia detachment lies below these high peaks. On the highest point of Mt Ochi are the rocks exhumed from the greatest depth within this sequence and are surrounded by extensional shear zones. Google Earth Image.

Solar-wind exposure effects on lunar soil:

Light nobles gases implanted in 10084 olivines

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Characterisation of oxygen isotope signature implanted on lunar soil still remains unsolved. Various analyses on solar wind implantation in lunar grains show very different results, from ^{16}O -enriched [1, 2] to ^{16}O -depleted [2, 3] compositions. Comparison with results unveiled by analyses from the Genesis mission [4] lead to even more questions than answers. One of the most important ones: Why haven't we found the solar oxygen isotope ratios recorded in the Genesis targets in the lunar soil?

Analysing the surface of lunar soil grains was originally an attempt to identify the isotopic oxygen signature of the solar wind and the Sun. The main goal is to understand solar wind exposure effect on lunar soils and the implications for oxygen isotopic fractionation.

In order to gain further insights on the different oxygen signatures found in lunar soil we have attempted to correlate the measurements of oxygen isotopes with light noble gas isotopes, particularly helium and neon.

In a pilot study on lunar olivine grains solar isotope signatures of helium and neon were successfully measured. Noble gases from 24 single lunar olivine grains were individually extracted by total fusion experiments using a diode laser (800nm wavelength). The released gases were analysed with the VG5400 noble gas mass spectrometer.

The obtained measurements show good agreement with previous studies [5, 6] on light solar noble gases in lunar grains (Figure 1) and modelled data of a mixture of fractionated solar Ne as a function of implanted depth and a cosmogenic end-member (Figure 2).

These experiments have effectively demonstrated that solar helium and neon were preserved in all of these grains. We will now look to extend our noble gas analytical set-up to lunar ilmenites and metal grains, and ultimately to combine noble gas and oxygen isotope analyses on the same samples.

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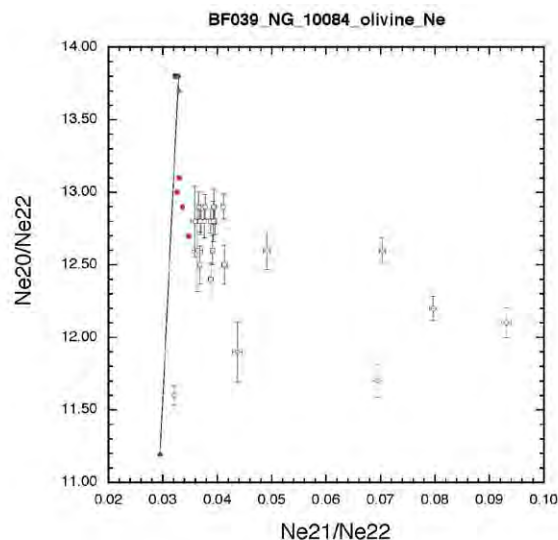


Figure 1. The results of this study demonstrate the successful extraction of solar noble gas ratios from 24 individual lunar olivine grains (circles with error bars). These compare well with other solar noble gas studies on lunar (red circles: [5, 7]). The solar Ne fractionation line is included in the figure with the solar wind and SEP components (green triangles: [8, 9]) as anchor points, as well as the Genesis data set (blue cube: [10])

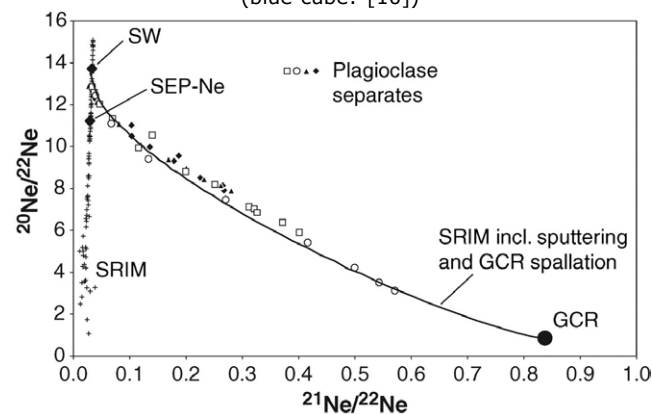


Figure 2. This figure shows the result of SRIM (Stopping and Range of Ions in Matter) modelling isotopic fractionation effects upon implantation mixed with cosmogenic Ne (GCR).

The comparison with Ne ratios measured in lunar plagioclases reflects a good agreement with the simulation. This data based on Genesis mission results suggests that a second heavy solar component (SEP) is not needed to explained solar wind ratios recorded in the lunar soil [11].

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Trace element mapping of olivine from pallasite meteorites using LA-ICP-MS

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Pallasite meteorites are mixtures of olivine (Mg_2SiO_4) and Fe-Ni metal alloy that may represent mixtures of core and mantle material from now destroyed asteroids or minor planets. We have mapped trace-element distributions in olivine from these meteorites using laser-ablation inductively-coupled-plasma mass spectrometry (LA-ICP-MS). Olivine interiors have heterogeneous distributions for most trace-elements; these features often bear no relation to current crystal morphologies. Rather, cross-cutting relationships suggest they predate olivine-metal mixing and may have formed in the pallasite precursor's mantle. The elemental distributions appear to be controlled by Al, which acts as a point defect in the olivine crystal lattice and has very specific charge balancing requirements.

In contrast, the divalent elements Ni and Co are homogeneously distributed and have smoothly decreasing concentrations near crystal margins. These elements enter olivine with no special charge-balancing requirements (substituting for Mg and Fe) and their distributions are consistent with freezing-in of diffusion-out profiles formed during re-equilibration with metal during cooling. This probably occurred after fragmentation of olivine and mixing with metal during the pallasite-forming event.

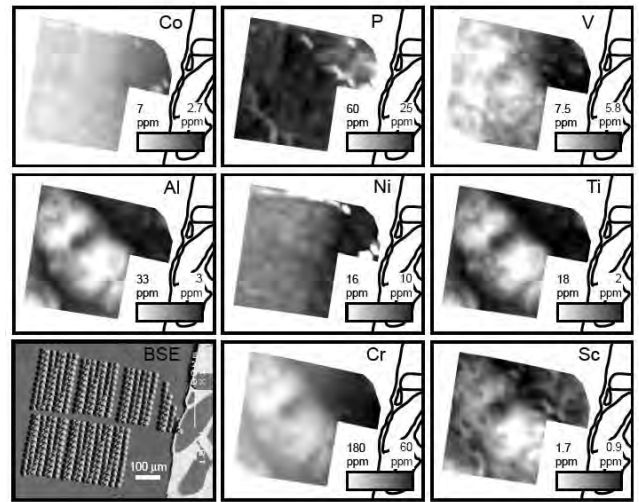


Figure 1. Back-scatter electron and trace elemental maps for an olivine grain in the Brehm pallasite meteorite. Divalent element distributions (Ni and Co) are controlled by olivine morphology. Other elements have distributions that date to before the olivine-metal mixing event.

Age Determination and Growth Rates in Deep-Water Bamboo Corals (Isididae)

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Gorgonians are a major element of the fauna of deep-water coral reefs and very long-lived recorders of deep-water paleo-oceanography. Both ecological studies and paleoclimate reconstructions require accurate age determination and dating of colony formation. However these corals reside in water depths between 1000-4000m which makes direct validation of aging methods logistically difficult. Analyses were carried out on specimens of deep-water Bamboo (Isididae) corals. Specimens were collected by dredge from seamounts south and east of Tasmania, Australia.

We use radiocarbon (¹⁴C dating) analysis of both the node organic tissue and internode calcite (Figure 1) to provide robust age and growth rates. Growth rates ranged from 40 to ~140 microns per year in samples collected from 600 to 3500m water depth. These corals had lifespans of 100-350 years. These age models will then be used to reconstruct climatic information.



Figure 1. Figure 1. Left panel shows a decalcified and peeled node from the bamboo coral, right panel shows the typical alternating organic node (black) and calcite node (white). Radiocarbon analyses were performed on both the organic and calcite portions of the coral.

Calibration of GA1550 biotite standard for K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dating

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The mineral GA1550 biotite, separated from a shallow monzonite intrusion near Central Tilba Tilba, Mount Dromedary, southwest of Narooma in eastern NSW, has become an international standard for K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dating studies, although it was prepared as an intralaboratory standard at ANU to monitor tracer depletion from a gas pipette. It is one of a small number of samples that has been calibrated against ^{38}Ar tracers, some of which had been mixed with known amounts of atmospheric argon, so that a so-called primary calibration has been performed. By measuring GA1550 biotite against additional tracers from the same batch we have determined the radiogenic argon content of this sample as $1.342 (\pm 0.007) \times 10^{-9}$ mol/g, and together with the measured K content of 7.645 (± 0.050) weight percent, we derive a best estimate for the K/Ar age as 98.5 ± 0.5 Ma, where the error is derived from averaging the ages determined relative to the ^{38}Ar tracer.

This work has been accepted for publication in Chemical Geology. Peter Wellman is a former PhD scholar.

Biomarkers show that complex life is 1 billion years younger than previously thought

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Hydrocarbon biomarkers are the molecular fossils of natural products such as lipids and pigments. They can yield a wealth of information about early microbial ecosystems and are particularly valuable when preserved in > 1 billion-year-old (Ga) sedimentary rocks where conventional fossils are often lacking.

Therefore, in 1999, the detection of traces of biomarkers in 2.7 Ga shales from Western Australia was celebrated as a breakthrough. The fossil hydrocarbons were more than 1 billion years older than previous discoveries. The discovery, which was later confirmed by several independent studies, led to far-reaching conclusions about the early evolution of oxygenic photosynthesis and the earliest eukaryotes, that are the ancestors of all protists, plants and animals.

However, there always remained nagging doubt about the real origin of the molecules: the concentration of the carbon isotope ¹³C in the molecules was much too high for organic matter of that age and resembled more the pattern seen in much younger oil or, in fact, petroleum products. However, if the hydrocarbons were later additions, then they should have left a distinct spatial distribution in the ancient rocks. In the simplest case, recent contaminants should be entirely surficial, while syngenetic hydrocarbons should be homogeneously distributed throughout the rock.

To test these predictions, we determined the spatial distribution of biomarkers in drill core material by cutting the rock into millimeter-thin slices, grinding the slices to powder, and extracting molecules from the powder with organic solvents. We then plotted the concentration of individual molecule types against the distance from the surface of the rock. We received a clear answer. The abundance of heavy molecules decreased from the surfaces towards the centre of the rock, a pattern that indicates that the rock was tainted on the surfaces followed by migration of petroleum towards the interior. It demonstrated that the molecules must have entered the rock much later in Earth's history.

The elimination of the Archean biomarker data has immense implications for our understanding of Earth's early biosphere. Specific biomarkers of cyanobacteria had suggested that oxygen was already released into the biosphere 2.7 Ga ago, about ~300 million years before the atmosphere became oxygenated during the Great Oxidation Event. Now, the oldest direct fossil evidence for cyanobacteria and biological oxygen production reverts back to 2.15 Ga. The most ancient robust sign of first oxygen in the atmosphere is the Great Oxidation Event itself at ~2.4 Ga. Moreover, the presence of steroid biomarkers used to indicate that eukaryotes, the ancestors of modern complex life and the inventors of sexual reproduction, existed 2.7 Ga ago. However, without the steranes, the oldest fossils for this group of life occur at about 1.8 Ga.

Our laboratory has now taken on the challenge to find real biomarkers that are more than 2 billion years old. We predict they will look weirdly different from anything observed before.



Figure 1. 2.7 billion years old shales from the Fortescue Group exposed in an open gold mine in the Pilbara in Western Australia. The dark colour of the shales reveals the presence of organic matter, the remains of mysterious organisms that thrived in Earth's early oceans.

Deglacial CO₂ rise and ventilation of the deep Southern Ocean

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There is a broad consensus that glacial-interglacial atmospheric CO₂ change depends primarily on marine processes operating in the Southern Ocean. The region is important because of the link seen between atmospheric CO₂ and Antarctic temperature change on both orbital and millennial time-scales. The Southern Ocean is the region of the global ocean where most deep-water makes its first contact with the sea surface, and where CO₂ that has accumulated in the deep-sea can be released to the atmosphere.

Records of atmospheric radiocarbon activity (Fig. 1) provide an important clue regarding the oceans role in atmospheric CO₂ variability. This record shows an apparent excess of atmospheric ¹⁴C during the last glacial period relative to the present and relative to concurrent ¹⁴C production rates. This excess was eliminated across the last deglaciation in two steps, each of which coincided with a sharp rise in atmospheric CO₂ (Fig. 1). The main explanation is that the lowered glacial CO₂ and the rapid deglacial CO₂ rise were made possible by the sequestration of an aged, carbon-rich deep-water mass that was mixed with the atmosphere in two pulses across the deglaciation.

Using radiocarbon (¹⁴C) records trapped in foraminifera from sediment cores we demonstrate the existence, during the last glaciation, of a poorly ventilated carbon pool deep in the Atlantic sector of the Southern Ocean that dissipated across the deglaciation. This old and presumably CO₂-enriched deep water played an important role in the pulsed rise of atmospheric CO₂ through its variable influence on the up-welling branch of the Antarctic overturning circulation.

Full paper in Science

http://www.sciencemag.org/cgi/content/abstract/328/5982/1147?ijkey=9485db9103c7ed60e74cd5e4551e689d5a49c2f5&keytype2=tf_ipsecsha

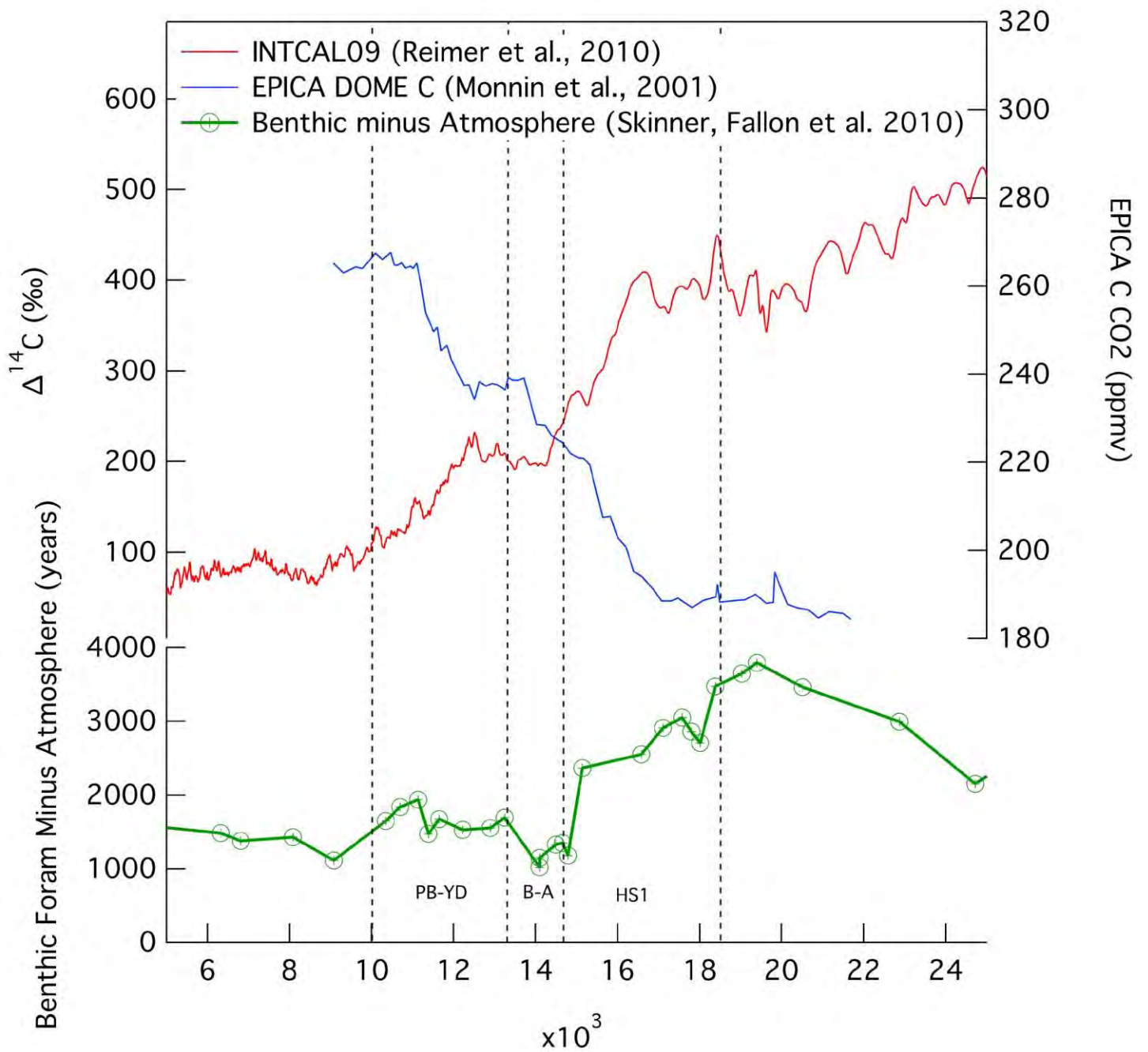


Figure 1. The top panel of this figure shows the EPICA dome CO₂ concentration (in blue), and the atmospheric radiocarbon content (in red) from 5ky to 25ky ago. The bottom panel shows the benthic foraminifera age minus the atmospheric CO₂ age (in green). During HS1 the atmospheric CO₂ increases, the age of the CO₂ drops rapidly and the age of the deep water from the benthic forams decreases.

The Potato Radius

a Lower Minimum Size for Dwarf Planets

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Gravitational and electronic forces produce a correlation between the mass and shape of objects in the universe. For example, at an average radius of ~ 200 km – 300 km, the icy moons and rocky asteroids of our Solar System transition from a rounded potato shape to a sphere. We derive this potato-to-sphere transition radius -- or “potato radius” -- from first principles. Using the empirical potato radii of asteroids and icy moons, we derive a constraint on the yield strength of these bodies during their formative years when their shapes were determined. Our proposed ~ 200 km potato radius for icy moons would substantially increase the number of trans-Neptunian objects classified as “dwarf planets”.

Lineweaver publications on personal homepage

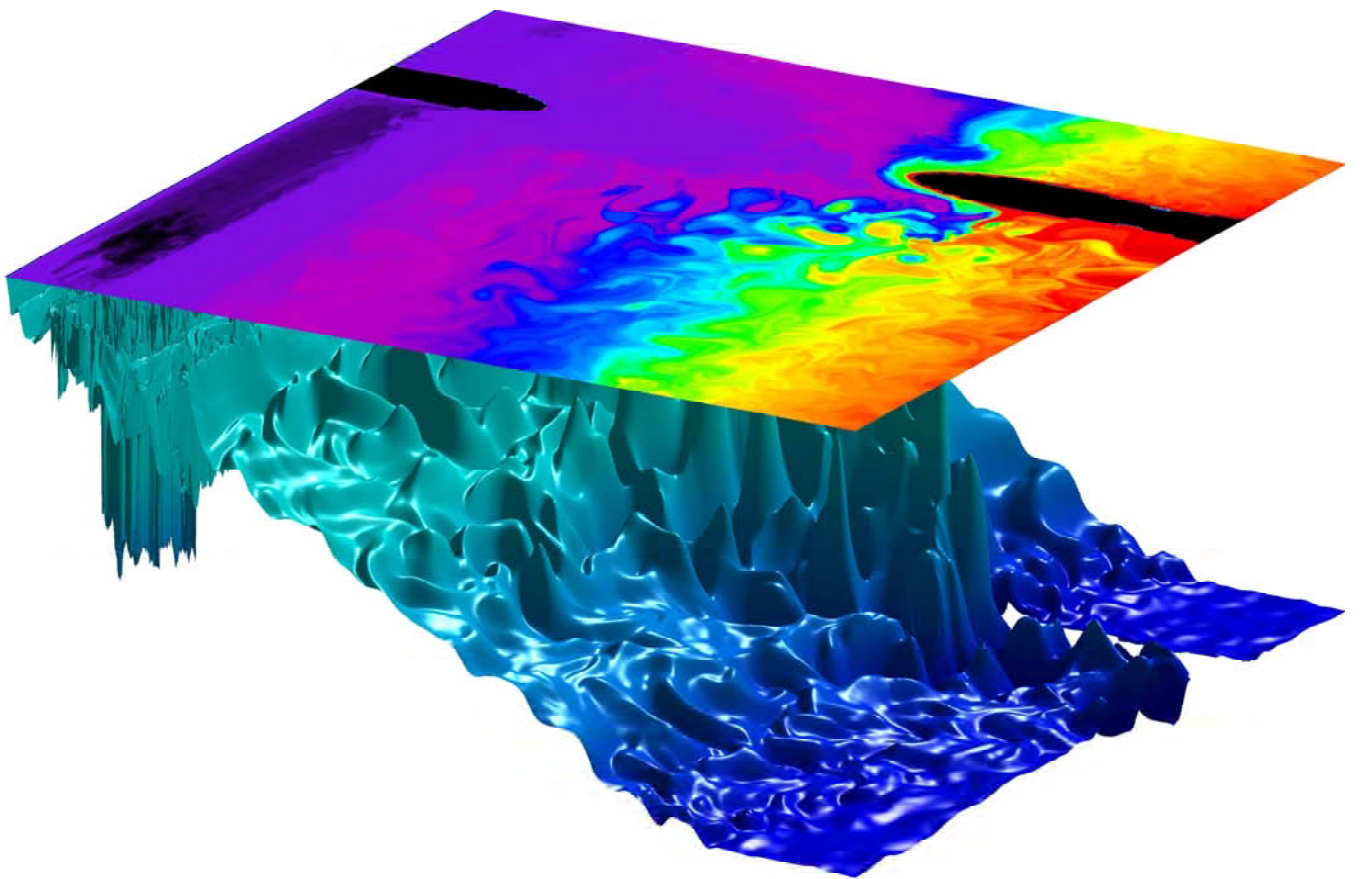
<http://www.mso.anu.edu.au/~charley/publications.html>

ADS Link

<http://adsabs.harvard.edu/abs/2010arXiv1004.1091L>

Research School Of Earth Sciences (Earth Environment)

Research Activities 2010



Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.

Introduction

2010 has mostly been a year of stability for the Earth Environment Area, although two people left us: Dr K. Fitzsimmons accepted a position in Germany and Dr A. Dutton accepted a position at Florida University in USA.

2010 stood out also for our Area as we had a 70% success rate with our ARC Discovery Grant applications, although funds awarded to most of us were well below those requested, with the consequence that not all proposed targets will be achieved.

Dr T. Barrows continues his association with our group, having been successful in obtaining an ARC Discovery Grant with Prof B. Pillans, and together they conducted fieldwork in Papua New Guinea. Some equipment went to the University of Western Australia with Prof M. McCulloch (who left RSES late last year), but our collaboration with his group and access to the Triton instrument for our jointly supervised students is assured. The OSL facility and the cosmogenic preparation laboratories have been decommissioned during the year.

A new Finnigan MAT253 stable isotope mass spectrometer has been delivered in Dr M. Gagan's area and refurbishments completed for the new facility. This will help diversify our research output and enable us to analyse much smaller samples. Dr Marc Norman has now joined the Earth Environment Area, together with Dr Bear McPhail, with groundwater investigations, especially with respect to geochemical analyses and innovative uses of isotopes in hydrogeology, forming part of the Earth Environment Area's research interests.

Several new PhD students enrolled this year (L. Brentegani, K. James, N. Scroxton, R. Norman), while others have submitted their theses, and some have graduated (R. Berdin, J. Boyau).

A number of our postgraduates gained experience at sea in 2010 and several successfully presented at both national and international conferences. Noteworthy were the presentations made at the Australian Earth Science Convention, held in Canberra in July. It was extremely pleasing to see the great variety of topics presented by the students, and these were well received. In addition, Prof P. De Deckker gave the AESC plenary talk as a result of having been awarded the Douglas Mawson Medal by the Australian Academy of Science, for outstanding contributions to earth science in Australia.

Many members of the academic staff excelled at teaching this year and took on additional commitments over the previous year. PhD candidate Miss C. Thompson organised our bi-weekly seminar series, which was overall well attended.

We acknowledge the administrative services of Mrs S. Hutchinson, who transferred to the College Research Management Office in February, and to PRISE Administrator Mrs B. Armstrong who assisted with administration and distributed the our administrative workload among the School's four Area Administrators. In June, we welcomed Ms R. Petch, who moved from the Earth Chemistry Area to be the on-going Earth Environment Area Administrator.

In late November, we also welcomed four Summer Research Scholars, who will gain experience in our laboratories and in the field during the summer break.

The surprise has been that little has changed since the Geochemistry and Petrology review held in 2009. Several of the review committee's recommendations have not yet been implemented, but some of those may happen in 2011 with the advertisement of new, exciting positions at RSES.

In 2011, we look forward to the appointment of two new Super Science Fellows to work on novel dating techniques for Quaternary marine sequences, and to the arrival of Dr D. Heslop who will join Prof A. Roberts, Prof P. De Deckker and Dr M. Norman to work on magnetic properties and geochemical signals of aeolian sediments in deep-sea cores and terrestrial sequences.

Indonesian stalagmite record of abrupt Heinrich stadial changes in the Australian monsoon

Sophie C. Lewis¹, Michael K. Gagan¹, Linda K. Ayliffe¹, Jian-xin Zhao², Wahyoe S. Hantoro³, Pauline C. Treble⁴, John C. Hellstrom⁵, Allegra N. LeGrande⁶, Maxwell Kelley⁶, Gavin A. Schmidt⁶ and Bambang W. Suwargadi³

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³ Research and Development Center for Geotechnology, Indonesian Institute of Sciences, Bandung 40135, Indonesia

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Speleothems are calcium carbonate cave deposits, such as stalagmites, which can yield high-resolution

records of past climate change. In the tropics, changes in the oxygen isotopic composition ($\delta^{18}\text{O}$) in stalagmites are related to the composition of local rainfall and are often interpreted in terms of the amount of rainfall. The last glacial period (between 100 and 20,000 years ago) was punctuated by abrupt cool periods (the Heinrich stadials) that result from iceberg discharges into the North Atlantic. Throughout the tropics, isotopic shifts in speleothems during Heinrich stadials are interpreted as a widespread drying in the Northern Hemisphere and an increase in precipitation in the south.

In this study, we reconstruct changes in rainfall associated with the Australian monsoon system during Heinrich stadial 3 (HS3, around 30,000 years ago), using a fast growing stalagmite (LR07-E1, Fig. 2) from Flores in southern Indonesia. During HS3 cooling in the North Atlantic, wetter conditions are proposed further south in Brazil and drier conditions in the northern tropics in China. In Flores, higher stalagmite $\delta^{18}\text{O}$ values and a hiatus in growth around HS3 (Fig. 1) indicate a decrease in precipitation at this site, showing spatial complexity in tropical responses. We suggest that Flores is highly sensitive to changes in the position of the intertropical convergence zone (ITCZ) and HS3 was characterised by a strong southward ITCZ migration. Collectively, stalagmite records from Flores also show a complexity through time in climate responses in the region during North Atlantic-driven excursions, depending on the magnitude of the event and its ability to propagate into the Southern Hemisphere tropics.

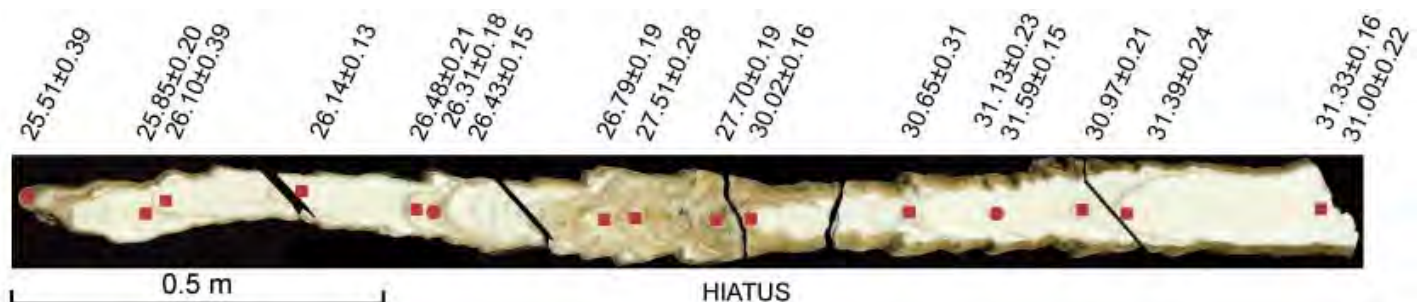


Figure 2. Photograph of stalagmite LR07-E1. Symbols show sampling locations for the uranium-series ages and the location of the ~2,300-year hiatus is also shown.

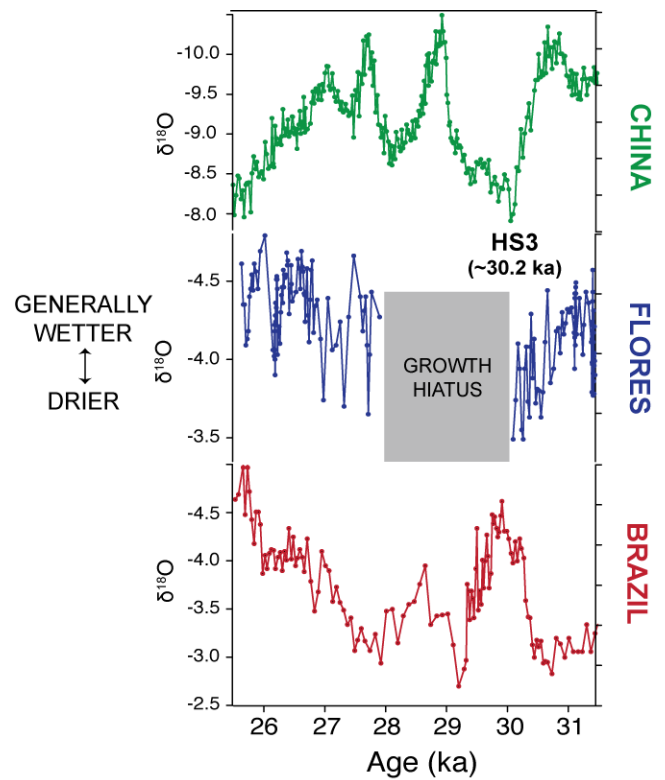


Figure 1. Comparison of Flores stalagmite $\delta^{18}\text{O}$ record (blue, middle) with records from China (top, green) and Brazil (bottom, red). The timing of Heinrich stadial 3 (HS3) is shown, coinciding with higher $\delta^{18}\text{O}$ values and a hiatus in Flores that indicate drier Heinrich conditions.

The Caribbean coral bleaching crisis

Jennie Mallela¹ and Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, Alvarez-Filip L, Baca B, Bartels E, Bastidas C, Bouchon C, Brandt M, Bruckner AW, Bunkley-Williams L, Cameron A, Causey BD, Chiappone M, Christensen TRL, Crabbe MJC, Day O, de la Guardia E, D'Áz-Pulido G,²

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² 2 Coral Reef Watch, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, United States of America, 2 NOAA Coral Reef Watch, IM Systems Group, Silver Spring, Maryland, United States of America, 3 NOAA Coral Reef Watch, ReefSense Pty. Ltd., Townsville, Queensland, Australia, 4 School of Engineering and Physical Sciences, James Cook University, Townsville, Queensland, Australia, 5 Center for Marine and Environmental Studies, University of the Virgin Islands, St. Thomas, United States Virgi

As the temperature of the world's oceans rise coral reefs are being threatened globally. Coral bleaching occurs when corals become stressed due to extreme environmental conditions (e.g. during periods of elevated ocean temperatures). So, what is coral bleaching? Corals host a microscopic algal symbiont (zooxanthellae) in the coral tissue. The corals require the presence of zooxanthellae in order to survive, indeed, up to 90% of a corals energy requirement comes from Zooxanthellae. Unfortunately, when stressed the corals expel their endosymbiotic algae and bleaching conditions persist this can result in partial or total coral mortality (death).

The Caribbean bleaching event of 2005 occurred between June and October. These region-wide anomalies were detected by Satellite-based sea surface temperature observations (SST) from the US National Oceanic and Atmospheric Administration (NOAA). NOAA was able to warn coral researchers about the anomalous temperatures as they developed across the region. As a result, scientists from 22 countries documented the most comprehensive basin-scale bleaching event to date. Findings for this period showed that average ocean temperatures exceeded temperatures seen at any time in the last 150 years. Surveyors continued to monitor corals beyond the bleaching event and noted that extensively bleached corals were more susceptible to disease. Findings showed that a combination of bleaching and disease outbreaks killed heat stressed colonies with continued mortality still occurring two years later in October 2007. Repeated coral bleaching events in the Caribbean since the 1980's have been strongly linked to human induced climate change. Based on current climate change predictions coral bleaching is likely to be an even greater threat to coral reefs in the future.

Related publications:

Eakin et al 2010 Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005 - PLoS ONE. DOI: 10.1371/journal.pone.0013969
<http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0013969>

Status of Caribbean coral reefs after bleaching and hurricanes in 2005 - A book
http://cmsdata.iucn.org/downloads/status_carib_corals.pdf

Climate change, storms and coral reefs: Mallela J, Crabbe MJC (2009) Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago. Marine Environmental Research 68:158–162
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Figure 1. A bleached *Acropora* coral colony being monitored in the Turks and Caicos Islands (photo: Jennie Mallela October 2005).

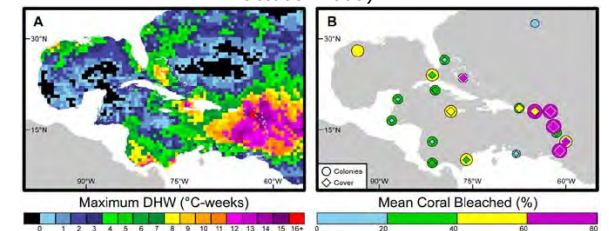


Figure 2. Thermal stress and bleaching during the 2005 Caribbean bleaching event. (A) Maximum NOAA Coral Reef Watch Degree Heating Week (DHW) values showing the highest thermal stress recorded at each 0.5-degree pixel during 2005. Values ³ 4 C-weeks typically resulted in significant bleaching; ³ 8 C-weeks typically resulted in widespread bleaching and significant mortality. (B) Jurisdictional means of coral bleached; marker color and size denote the severity measured as either percent live coral colonies (circles) or cover (diamonds). Figure from: Eakin et al 2010 Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005. PLoS ONE. doi:10.1371/journal.pone.0013969.g001

Millennial-scale changes in the Australasian monsoon during the last deglaciation

Ayliffe, L.K.¹, Gagan, M.K.¹, Drysdale, R.N.², Zhao, J.-x.³, Hantoro, W.S.⁴, Hellstrom, J.C.⁵ and Suwargadi, B.W.⁴

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Establishing the record of Australasian monsoon dynamics, and teleconnections to higher latitudes, is crucial for understanding the role of the tropics in global climate change. In terms of global climate, the vast Australasian monsoon system is thought to be particularly relevant because it transports moisture and heat from the Indo-Pacific Warm Pool, the warmest open-ocean water on Earth, across the equator and to higher latitudes.

In tropical settings summer monsoon rainfall is greatly depleted in ^{18}O with respect to winter dry-season rainfall, and so the oxygen-isotope ratios ($\delta^{18}\text{O}$) recorded in speleothem calcite can be used as a measure of the relative amount of summer monsoon rainfall, or “summer monsoon intensity”. $\delta^{18}\text{O}$ signatures of speleothems from China have been found to record the dynamics of East Asian Monsoon precipitation, and the intertropical convergence zone (ITCZ) variability, since ~400 thousand years before the present (kyr BP, defined as 1950 AD) (Wang et al. 2001; Yuan et al. 2004; Cheng et al. 2006; Wang et al. 2008; Wu et al. 2009; Cheng et al. 2009). However, complementary high-quality speleothem records from the “southern half” of the Australasian monsoon system are limited to the last 12.6 kyr BP and portions of 26 to ~31 kyr BP (Griffiths et al., 2009, Lewis et al., *in press*). We report here on an absolute-dated speleothem $\delta^{18}\text{O}$ record from the island of Flores, southern Indonesia, that records millennial-scale shifts in the Australian-Indonesian monsoon (AIM) rainfall over the full course of the last deglaciation (~24 to 10 kyr BP).

Speleothem $\delta^{18}\text{O}$ records of monsoon intensity from Flores, Indonesia are found to be correlated to local insolation variations and the millennial-scale climate changes commonly observed in oceanic and terrestrial palaeoclimate archives during the last deglaciation

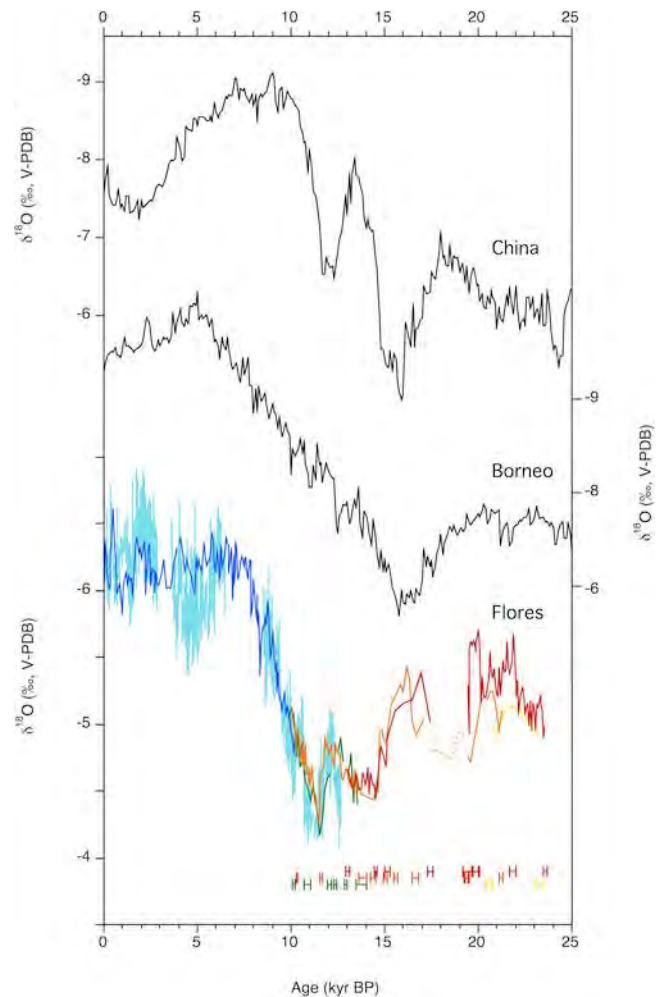


Figure 1. Oxygen-isotopes of speleothems from China (composite record from Wang et al. (2001); Yuan et al. (2004) and Wang et al. (2008), Borneo (composite record from Partin et al. (2007)) and Flores (stalagmites: LR06-C2 (green); LR06-C3 (yellow), LR06-C5 (orange); LR06-C6 (red) this study and stalagmites LR06-B1 (light blue), LR06-B3 (dark blue) (Griffiths et al. (2009) and LR07-E1 (Lewis et al. (*in press*)). U-Th ages with 2s error bars are also shown for the stalagmites of this study. Portions of LR06-C5 (dashed) were found to be mixtures of magnesian calcite and aragonite and have been corrected to magnesian calcite-equivalent $\delta^{18}\text{O}$ values on the basis of X-ray diffraction analysis.

throughout the world, Fig.s 1 and 2. Past monsoon intensity is governed by the positioning of the ITCZ which is, in turn, determined by changes of interhemispheric thermal gradients. We speculate that 23 to 20 kyr BP, when local insolation was at a maximum and monsoon intensity peaked in our speleothem record, that heat and moisture was transported to higher latitudes via ocean/atmosphere teleconnections. This resulted in melting of Northern Hemisphere (NH) ice and partial re-establishment of the Atlantic thermohaline circulation producing the melt water pulse at ~19kyr BP. These events, together with the subsequent increases in NH insolation, ultimately culminated in the termination of the last ice age.

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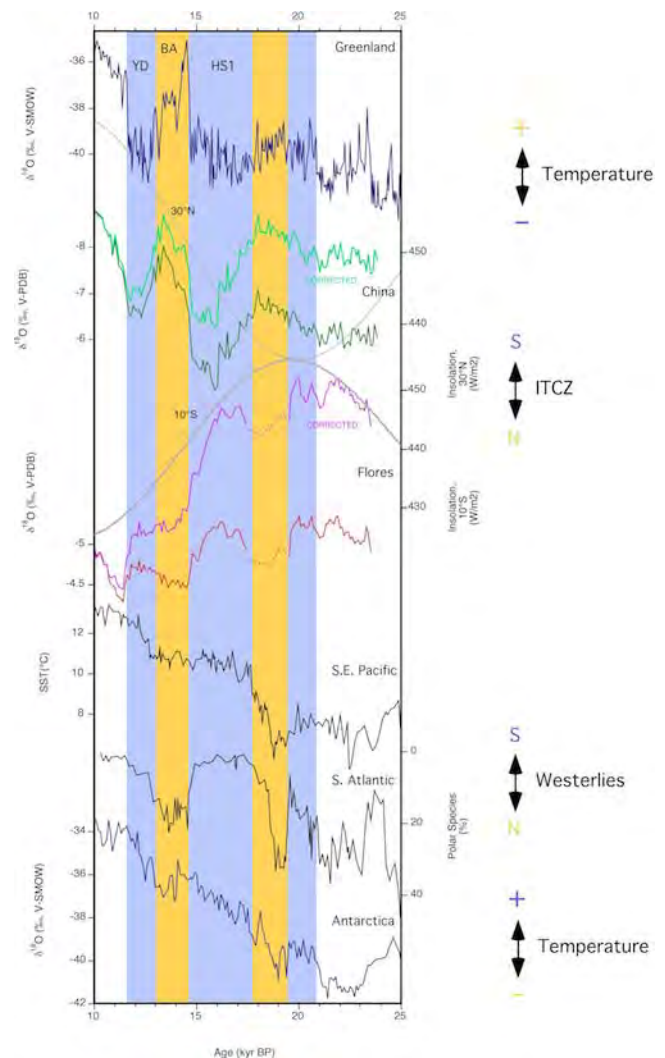


Figure 2. Oxygen-isotopes of the Greenland Ice Sheet Project 2 (GISP2) ice core (Stuiver and Grootes (2000)). Composite oxygen-isotope curves of speleothems from China (Wang et al. 2001; Yuan et al. 2004; Wang et al. 2008) and Flores (this study), shown as both raw $\delta^{18}\text{O}$ values plus those corrected for the effects of changes in ice volume and local sea surface temperatures. Summer Insolation (10°S and 30°N) (Berger et al. (1998)). Alkenone SST from the southeast Pacific (Lamy et al. 2007). Polar species abundances from the south Atlantic (Barker et al. 2009). Oxygen-isotopes from the Byrd ice core, Antarctica (Johnsen et al. 1972) on the GISP2 timescale (Blunier and Brook 2001).

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Australian landscapes

A new book on Australian geomorphology

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Australian Landscapes (Bishop & Pillans 2010) is the third major volume in a trilogy of edited books on Australian geomorphology that have been published in the last 50 years, the previous two volumes being *Landform Studies from Australia and New Guinea* (Jennings & Mabbutt 1967) and *Landform Evolution in Australasia* (Davies & Williams 1978). There is a strong thread running between these three volumes, not only through the enduring theme of the antiquity of Australian landscapes, but also through the people themselves. Joe Jennings, who was Professor of Geomorphology at ANU from 1953 to 1978 and considered by many to be the father of modern Australian geomorphology, was an editor of the first volume. The second volume marked the retirement of Joe Jennings, and one of Joe's former PhD students, Martin Williams, was an editor of that volume, while Paul Bishop, an editor of the third volume, was a PhD student of Martin Williams.

Australian Landscapes was born out of discussions at the 13th biennial conference of the Australian & New Zealand Geomorphology Group (ANZCGG), held in Queenstown in Tasmania in February 2008, and provides an up-to-date statement on the geomorphology of Australia. A wide range of environments and topics are covered, including karst, coasts, glaciation, tectonics, biogeomorphology and deserts, showcasing the latest geochronological techniques and remote sensing methods.

Further details about the book may be accessed online through the Lyell Collection of the Geological Society: <http://sp.lyellcollection.org/content/vol346/issue1/>

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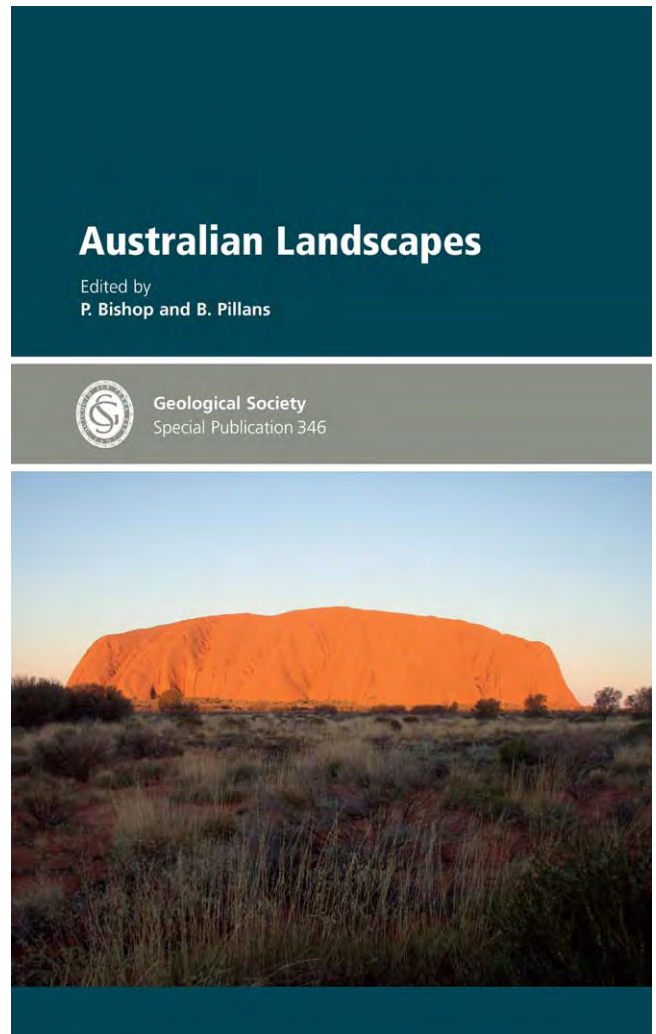


Figure 1. Cover of *Australian Landscapes*, featuring a spectacular Uluru sunset

The chronology of the WLH 50 human remains, Willandra Lakes World Heritage Area, Australia

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Ever since its discovery in 1980, the Willandra Lakes Human 50 (WLH 50) has played an enigmatic role in our understanding of recent human evolution. There is general agreement, that WLH 50 is a modern human. However, some see strong resemblances between WLH 50 and the Ngandong specimens, whilst others attribute its robusticity to a pathological source. Considering the importance of the WLH 50 individual, it is timely to report previously unpublished as well as the most recent dating results.

Dating was carried out at different times, partly due to the development and availability of dating methods. Initially, two samples were collected for radiocarbon dating. ANU-2921 consisted of freshwater shells collected at the surface of Unit 3; ANU-3124 was a carbonate sample, which encrusted the human bone. In 1997, gamma spectrometry was carried out on the WLH 50 cranium (Figure 1), and thermal ionisation mass spectrometric (TIMS) U-series analysis on a small postcranial bone fragment. Around the same time, two OSL samples were collected to bracket the age of WLH50. ANU_{OD}-1146 was collected from Unit 3, from which WLH 50 may have been eroded and ANU_{OD}-1145 from the underlying sediments. While the association of the former sample is perhaps ambiguous, the latter should give a firm maximum age for this human specimen. For the spatial and stratigraphic relationships of the sample, see Figure 2, below.

Radiocarbon analyses were carried out in 1981 and 1982. The following information was retrieved from the archive of the ANU radiocarbon laboratory. We cannot find any evidence that this information has been published elsewhere. The radiocarbon age estimates were hand-written on the data sheets (by H. Polach) without any further analytical detail. The carbonate encrusting human bone (ANU-3124) yielded a result of 9050 ± 310 BP (calibrated to 9.5 - 11.1 ka, 2- σ error) and a fresh water shell (ANU-2921) 14380 ± 240 BP (calibrated to 16.5 to 18.0 ka). The TIMS U-series results formed an isochron, indicating a single stage rapid U-uptake at 12.2 ± 1.8 ka. The gamma spectrometric measurements resulted in Th/U ages of 13.1 ± 2.7 ka and Pa/U of 13.5 ± 1.2 ka. The optical dates were calculated to 32.8 ± 4.6 ka (ANU_{OD}1145) and 25.8 ± 3.6 ka (ANU_{OD}1146).

As we cannot think of any naturally occurring process that would allow WLH50 to be older than the underlying unit, its OSL age of 32.8 ± 4.6 ka provides the older age limit for the WLH50 specimen. In the most likely scenario, where WLH 50 weathered out from Unit 3, the best age estimate for WLH 50 is that of ANU_{OD}1146: 25.8 ± 3.6 ka with the younger age bracket of 16.5 - 18.0 ka cal BP provided by the shell ANU-2921. If WLH 50 was deposited from younger units, it could be as young as 12.2 ± 1.8 ka, the younger age bracket established by the U-series isochron age on the WLH50 bone fragment.

For more detailed information about the exact stratigraphy, interpretation of the age results and their significance, check the website of the Journal of Human Evolution for our forthcoming paper. We thank the custodians of the Willandra Lakes Area, the 3 Traditional Tribal Groups, for their active support of this study and the permission to submit this publication.

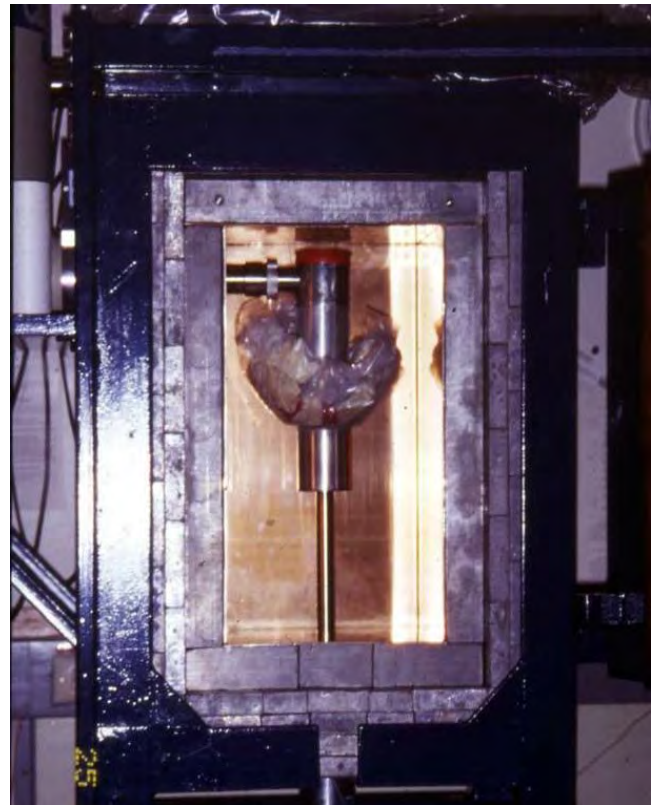


Figure 1. The WLH 50 skull in the RSES gamma spectrometer

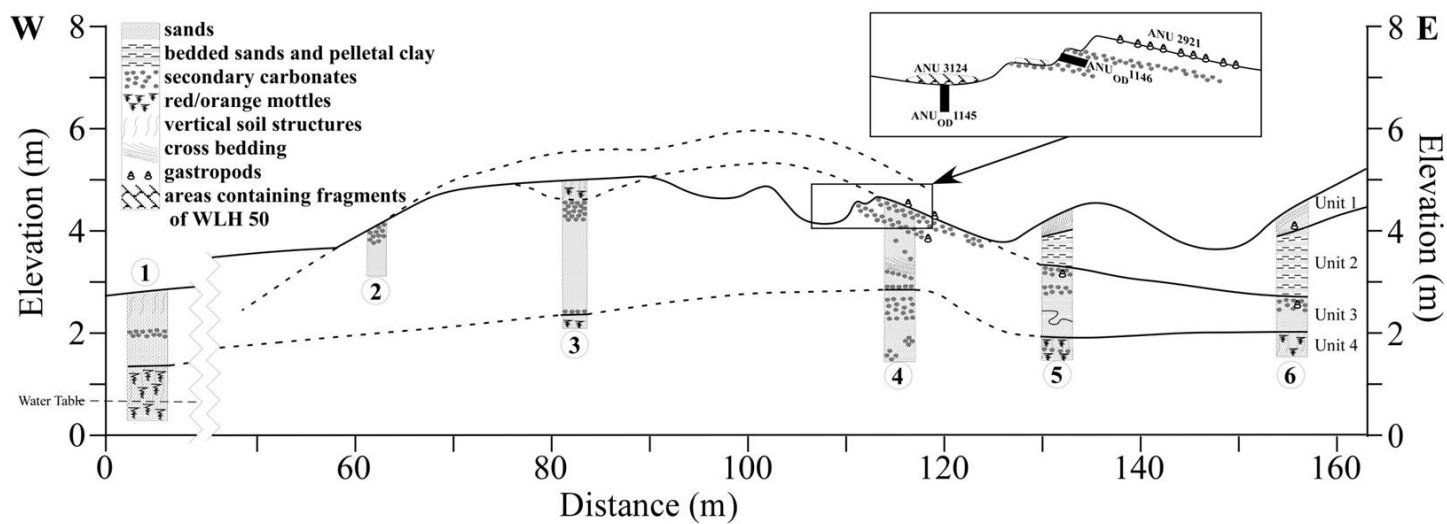


Figure 2. Stratigraphy of the WLH50 burial site.

Coral records of calcification and reef water chemistry from the southern Great Barrier Reef

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The accumulation of anthropogenic carbon dioxide (CO₂) in the atmosphere and ocean over the last ~100 years is causing global warming and ocean acidification, with potential effects on the secretion of calcium carbonate by marine biota. To-date concern has mainly focused on the fate of tropical corals and reefs with less attention being given to calcification in subtropical environment, where corals develop under more limiting conditions of reduced solar radiation and lower ocean pH. Thus, it is of critical importance to investigate how subtropical corals are responding to environmental changes. To constrain the matter, we have measured geochemical proxies ($\delta^{11}\text{B}$, $\delta^{13}\text{C}$, $\delta^{18}\text{O}$, Sr/Ca, Mg/Ca, and calcification rates) in ~100 year old *Porites* at annual resolution and bimonthly for the recent 5 years (2000-2005).

From coral boron isotopic systematics shows the obvious impact of enhanced uptake of anthropogenic CO₂ on the ocean chemistry, resulting in a trend of decreasing seawater pH and decreasing $\delta^{13}\text{C}$ compositions due to fossil fuel burning (Suess effect). Ocean warming is also observed in the coral skeleton Sr/Ca record, whereas calcification rate is almost constant from 1907 to 2005. This lack of response of calcification is consistent with modeled calcification rate using calculated aragonite saturation state and in-situ temperature records, suggesting an increase in coral calcification by increasing sea surface temperature may buffer a decline of calcification by reduced carbonate ion concentration in this region. Investigating the influence of the natural variability in these records also carried out by removing the long-term linear trends from each of coral proxies. The detrended coral records are strongly correlated with the Interdecadal Pacific Oscillation (IPO), which is best explained by the redistribution of Pacific water masses and entering alkaline, warmer, and saltier tropical surface water to this study area during negative IPO. Moreover, the physiological process of coral calcification effects both $\delta^{13}\text{C}$ compositions and reef water pH, showing that $\delta^{13}\text{C}$ of coral skeleton decreases with increasing the calcification rate. Therefore, this study suggests that the modulation of the reef water chemistry in this region is best explained by three main mechanisms; (1) the anthropogenic driven increasing levels of CO₂ in the atmosphere, causing ocean warming and ocean acidification, (2) the natural variability of ocean and atmospheric anomalies in the Pacific, and (3) decrease in local reef water pH by build-up CO₂ as a result of coral calcification.

Figure 1. Fig. 1: Geochemical proxies and calcification trend from the Middle Pompey coral core for the last ~100 years.

Linear regressions of $\delta^{11}\text{B}$ -derived pH and Sr/Ca (Sr/Ca-derived temperature) are represented by solid lines over the all study period, whereas linear regression of $\delta^{13}\text{C}$ is shown since 1960 with solid line. A solid line superimposed on calcification rate indicates 5-year running average. Note that Sr/Ca axis is inverted.

High-pressure experiments on anhydrous carbonated eclogite at 9-20 GPa

Implications for the recycling of carbonate into the mantle

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It is generally agreed that large amounts of carbonates together with oceanic basalts can be subducted deep into the mantle. However, little experimental work has been done on the fate of carbonated eclogites deeper than about 300 km (>10 GPa). In this study we present the phase relations and solidus temperatures of carbonated eclogite at pressures ranging from 9-20 GPa.

Multianvil experiments were conducted using the 3000-ton press at Tohoku University, Sendai. The experiments were conducted under the range of pressures and temperatures of: 9, 13, 17, and 20 GPa at 1200-1800°C. The experimental compositions were two synthetic mixtures, which are GA1 and Volga [1] with an addition of 10% of calcite (10%cc). All the experiments were conducted in the Au25-Pd75 capsules with 12-72 hours run durations.

The mineral assemblage in the runs differed depending on the pressure, however garnet is the most abundant phase in all the experimental runs. At 9 and 13 GPa, the major phases were garnet, clinopyroxene, carbonate (both calcitic and magnesitic), high-pressure modified form of rutile (only at 9 GPa) and minor stishovite. No K-rich phase was detected and presumably K partitions mainly in clinopyroxene. At 17 GPa clinopyroxene was no longer stable; the mineral assemblage consisted of Na-rich majoritic garnet, carbonate (both calcitic and magnesitic) and K-hollandite, which contained most of the K. Stishovite was observed in most of the runs at 17-20 GPa. With the increase of pressure up to 20 GPa, CAS (in GA1+10%cc) and Ca-perovskite (in Volga+10%cc) appeared in addition to garnet and calcitic carbonate, but not in all experiments. K-hollandite was also detected at low temperatures.

The melts produced in our experiments are highly carbonatitic with the increasing of the amount of alkali elements (Na and K) with pressure.

In most GA1+10%cc and few of Volga+10%cc runs crystallization of diamonds were observed (Fig 1). The possible explanation to that is a pressure-induced increase of the Fe³⁺ content in garnet. Accordingly, this oxidation process can cause partial reduction of carbonates to diamond. However, we did not measure Fe³⁺ in garnet and this question requires further investigation.

A striking feature of the new data is the relatively flat solidus located between 1200 and 1300°C for all the analyzed pressures. This may be the result of the relative incompatibility of Na₂O and K₂O with increasing pressure. In the lower pressure runs, Na behaves compatibly due to the relative stability of the jadeite component in clinopyroxene. With increasing pressure progressive dissolution of clinopyroxene into majoritic garnet may lead to Na becoming incompatible and it may flux melting at a sodic carbonate solidus. Although being located at lower temperatures relative to other (K-free) carbonated eclogite studies [2] it remains at higher temperatures than the hottest estimated subduction geotherm (e.g. [3]), in a good agreement with previous, lower pressure studies [4,5,6]. Thus, subducting carbonates in eclogite may reach the deep convecting mantle, where they may partially melt to produce carbonate-rich liquids which could have a role in fertilizing the surrounding peridotite mantle and producing enriched magmas.

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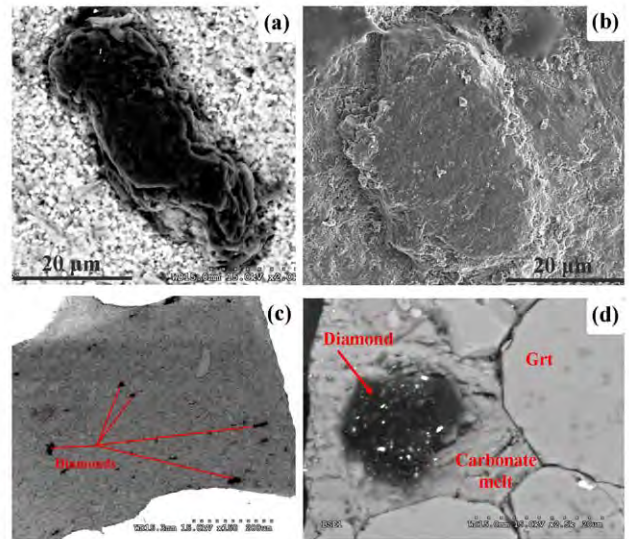


Figure 1. Diamonds from the experimental runs. (a) GA1+10%cc at 1400°C and 20GPa, BSE, (b) GA1+10%cc at 1200°C and 17GPa, SE, (c) GA1+10%cc at 1300°C and 20GPa, BSE, (d) GA1+10%cc at 1400°C and 13 GPa, BSE

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IODP Expedition 325 to the Great Barrier Reef

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In February-April 2010, Integrated Ocean Drilling Program (IODP) Expedition 325 drilled 33 boreholes into submerged reef structures preserved along the outer margin of the Great Barrier Reef. The objectives of Expedition 325 are to establish the course of sea level change, define sea-surface temperature variations, and analyze the impact of these environmental changes on reef growth over the course of the last deglaciation (Expedition 325 Scientists, 2010).

Co-Chief Scientists Jody Webster and Yusuke Yokoyama, and Expedition 325 scientists Mike Gagan and Tezer Esat, examined the 225 m of drill-core during the Onshore Science Party at the IODP Bremen Core Repository (Germany) in July 2010 (Fig. 1). Remarkably, the cores intersected >200 individual massive fossil coral colonies that will provide unique archives of climate change in the Great Barrier Reef, as revealed by isotope and trace element signatures preserved in their aragonitic skeletons. 60 U-series and radiocarbon dates confirm that the corals range in age from >30 to 9 cal. y BP (Fig. 2), an outstanding outcome for the Expedition.

Given these exciting findings, the stage is now set for the Australian team members to play key roles in producing the exacting U-series (Esat, Dutton) and radiocarbon (Yokoyama, Fallon) chronologies required to establish the course of postglacial sea level rise (Webster) and climatic change (Gagan, McGregor) in the Great Barrier Reef. All going well, the records will allow us to see how the reef responds to a broad range of past climatic regimes, and thus improve our understanding of how the reef might change as the world warms.

Reference

Expedition 325 Scientists, 2010. Great Barrier Reef environmental changes: the last deglacial sea level rise in the South Pacific: offshore drilling northeast Australia. *IODP Preliminary Report, 325*. doi:10.2204/iodp.pr.325.2010.



Figure 1. Expedition 325 scientists examine drill-cores during the July 2010 Onshore Science Party at the IODP Bremen Core Repository (Germany).

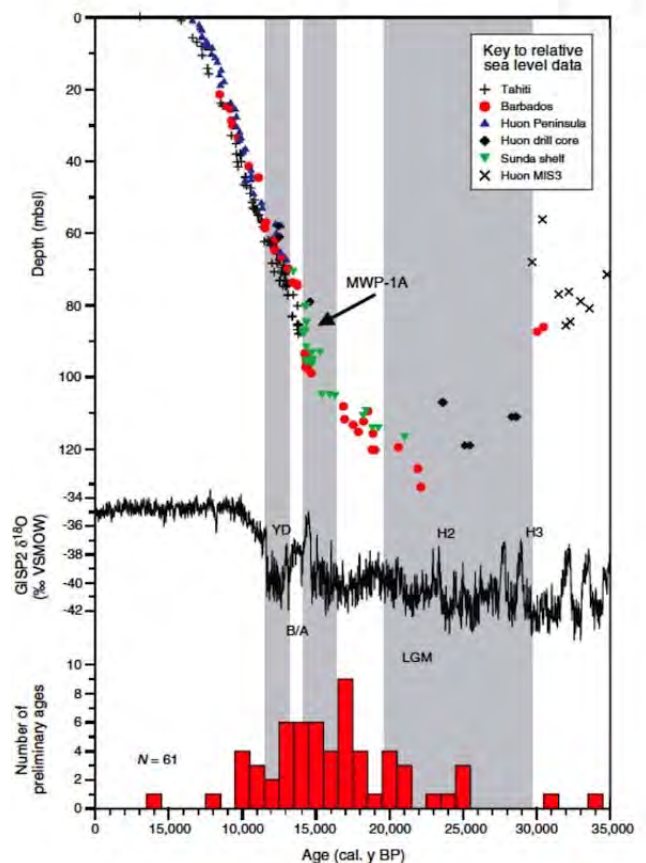


Figure 2. Comparison of the distribution of coral ages in Expedition 325 drill-cores (red bars), the GISP2 ice core record (black curve), and reconstructed relative sea level (coloured symbols) since 35,000 cal. y BP (Fig. F37 from Expedition 325 Scientists, 2010).

New archaeological finds below Liang Bua: a split-level home for the Hobbit?

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Figure 1. Wahyoe Hantoro of the Indonesian Institute of Sciences negotiates the 23 m descent into the cave-chamber below Liang Bua.

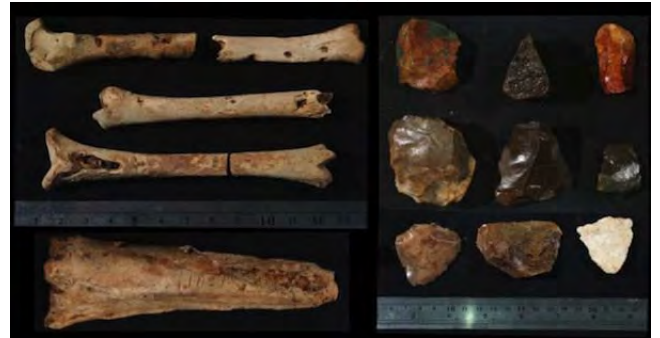


Figure 2. Examples of bones and stone artefacts from the surface sediment of the cave-chamber below Liang Bua.

We report new archaeological finds for a cave-chamber hidden below Liang Bua on the island of Flores in eastern Indonesia, where the dwarf hominin *Homo floresiensis* ("the Hobbit") was recovered from Late Pleistocene sediment. In search of speleothems, we abseiled into the lower chamber where, to our surprise, the surface-sediment contained abundant, well-preserved bone material and stone tools that allow us to describe the archaeological potential of this archive for the first time.

At the rear of Liang Bua, a narrow 23-m-long passage inclined at 60° leads to the impressive lower chamber measuring 23 m x 24 m x 5.4 m high (Fig. 1). The floor area is ~430 m² (about half the size of Liang Bua) and covered with firm, sticky, reddish-brown mud. Bones and stone tools were clearly evident in the surface sediment at the base of the passage and around the perimeter of a ~5 m-high mud-mound filling the northwest sector of the chamber.

Preliminary analysis of the faunal remains yielded specimens belonging to *Stegodon* (tibia fragment, metapodia), giant endemic rats, endemic pigs, primates, small murid rodents, and introduced species. The bones are exquisitely preserved in the anoxic mud and clear butchering marks (sharp cuts and percussion dents) are common (Fig. 2). Stone tools made from chert and volcanics include bifacial flakes, points, perforators, scrapers, and hammer-stones.

Exploratory uranium-series dates for flowstone layers and stalagmites capping the ~5 m-high mud-mound range in age from 12,000 to 3,000 years before the present, thus the sediment itself could be late Pleistocene in age. It is possible, therefore, that the lower chamber could house a unique archive of late Pleistocene faunal evolution and, potentially, remains of the Hobbit. The floor of the upper occupation chamber of Liang Bua was at least 10 m lower in the Late Pleistocene and in close proximity to the lower chamber, thus they may have been connected in the past. Whether the lower chamber acted as a convenient refuse tip for the Hobbit, or a split-level home, is yet to be determined.

The 8.2 ka event in southern Australasia: a different response between the ocean and atmosphere?

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Corals and speleothems have the potential to resolve outstanding questions about changes in the Australasian monsoon during the 8.2 ka “cold event”. We present an analysis of Sr/Ca and $\delta^{18}\text{O}$ in massive *Porites* corals from Alor (southern Indonesia) with U-series ages of 8.5 to 7.9 ka (thousand years ago). The Alor corals are well suited for reconstructing tropical ocean-atmosphere systems at seasonal to interannual timescales. In contrast, $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ in tropical speleothems from the nearby island of Flores provide information on Indonesian monsoon dynamics and surface air temperature at millennial to centennial timescales. Together, these records have allowed us to explore how the ocean and atmosphere of southern Indonesia responded to the 8.2 ka event.

We measured Sr/Ca and $\delta^{18}\text{O}$ in the corals at 5-year resolution across the 8.2 ka event to detect any changes in the mean climate state. Whereas the $\delta^{18}\text{O}$ record shows two sharp increases reaching maxima at 8.3 and 8.0 ka, ICP-AES measurements of coral Sr/Ca show a gradual cooling of sea-surface temperature (SST) starting at ~ 8.3 ka and finishing with an abrupt $\sim 1.5\text{--}2^\circ\text{C}$ cooling at ~ 8.0 ka. The coral $\delta^{18}\text{O}$ record is consistent with the $\delta^{18}\text{O}$ analyzed at 5-year resolution in the speleothem from Flores. The coral and speleothem records from southern Indonesia show that the atmosphere responded rapidly (over decades) to the 8.2 ka event, whereas the SSTs appear to have responded more slowly (over centuries).

The result is unanticipated, given that recent studies of the Younger Dryas in southern Indonesia and the 8.2 ka event in South America indicate an antiphased response to northern hemisphere cooling. In order to investigate the rainfall response in Alor/Flores during the 8.2 ka event, we analysed the annual cycle of $\delta^{18}\text{O}$ in the Alor corals, the amplitude of which primarily reflects the intensity of summer monsoon rainfall. The results indicate that Indonesian summer monsoon rainfall was generally weaker during the early Holocene, compared to today, and did not change significantly during the 8.2 ka event. We propose that the flooding of the Indonesian maritime continent and cooler SSTs around Alor/Flores during the 8.2 ka event reduced Australian monsoon rainfall to suppress the antiphased response (stronger SH monsoon) to high-latitude northern hemisphere cooling. To confirm this result, we are in the process of analyzing the annual cycle of Sr/Ca in the same Alor corals.



Figure 1. Giant fossil coral in Alor, Indonesia (1999)

Sea Level variation and the Zonation of Stromatolites in Hamelin Pool, Shark Bay

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The zonation of stromatolites of Hamelin Pool, Shark Bay, Western Australia (see Fig. 1), has, since their discovery in 1954, been related to tidal variations of sea-level. Initially these stromatolites were considered to be entirely intertidal ecosystems (Logan 1961), though they were later recognised also in shallow subtidal waters (Logan et al 1974). Data from various sources were drawn together into a notional cartoon by Playford (1980) that summarised his understanding of the tidal zonation of stromatolite types in Hamelin Pool. This cartoon has been frequently cited since to account for stromatolite zonation in Hamelin Pool. Detailed surveys of stromatolite types by John Bauld (pers. comm) confirm the conclusion of Burne and James (1986) that Hamelin Pool stromatolite principally grow in shallow subtidal environments where they are colonised by colloform microbial mats, with some being later exposed by falling sea levels. The intermittently exposed stromatolites are re-colonised by smooth or pustular microbial mats.

The application of modern methods of time-series analysis to a record of sea-level variation at Flint Cliff, Hamelin Pool between October 1983 and April 1985 has shown that tidal variation accounts for only a minor component of sea level variation in Hamelin Pool (Fig. 2). We have identified five key components of the variation of sea level in Hamelin Pool; a seasonal oceanic cycle; a short term irregular cycle; the complex tidal system in the Pool; isolated major events; and less marked variations, still able to defeat the tide in the short term, probably by wind stress. Clearly it is not valid to conceptualize the zonation of stromatolite types in terms of tidal variation alone. The dominance of a seasonal cycle is the fundamental determinant of the timing of immersion and exposure. We conclude that the zonation of microbial communities in Hamelin Pool (Fig. 1) is controlled by duration of periods of inundation and exposure in the littoral zone, but that tidal variation is not the major cause of this variation. The stromatolite forming colloform mat is virtually never exposed. The exposed stromatolites have been stranded by relative fall of sea level, and are colonised by intermittently submerged microbial communities capable of modifying but not creating the club-shaped stromatolites characteristic of this locality.

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Figure 1. Intermittently submerged benthic microbial mats colonising sediment surface and re-colonising and modifying stromatolites exposed by falling sea level. Hamelin Pool, Shark Bay

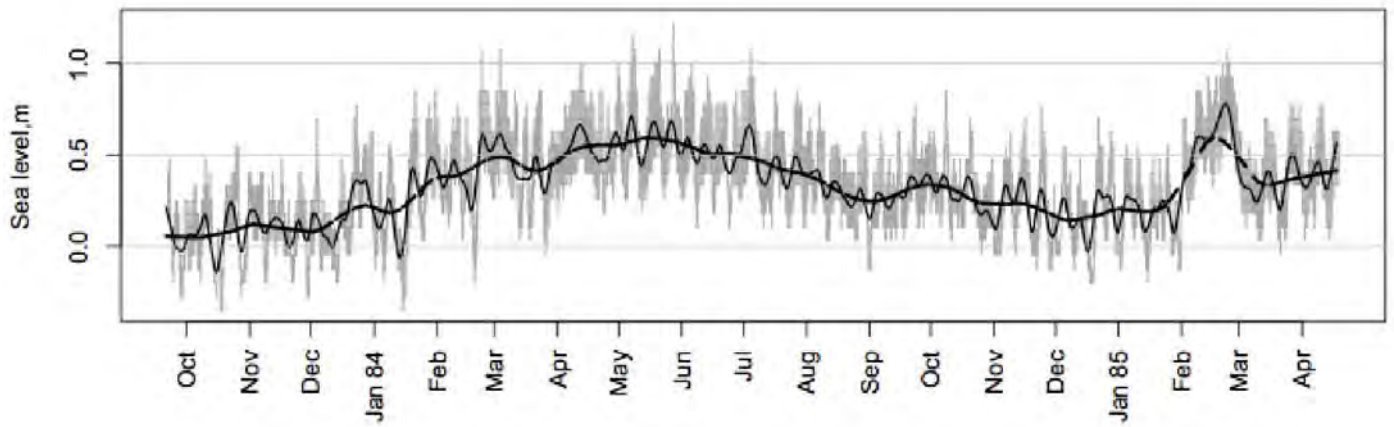


Figure 2. The first pass of the time series analysis identified the varying amplitude characteristic of tidal activity, the seasonal cycle of sea level, and an irregular 11 day cycle.

Studying the Earth by oceanic scientific drilling

Integrated Ocean Drilling Program (IODP)

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Figure 1. Great Barrier Reef expedition co-chief scientists with coral cores: Yusuke Yokohama, formerly of ANU, and Jody Webster of Sydney University

Integrated Ocean Drilling Program (IODP) cores through sediments and rocks beneath the world's oceans contain a remarkable story of how the Earth has worked in the past, and may work in the future.

IODP's main research fields are broad - *environmental change, processes and effects; solid earth cycles and geodynamics; and the deep biosphere and ocean floor*. ANU, through RSES, hosts the Australian IODP Office. The Australian and New Zealand IODP Consortium (ANZIC) has access to all IODP activities (www.iodp.org.au). A review of Australia's involvement in IODP and its predecessors was published in mid-2010: see link.

In 2010, eight Australians participated in IODP science parties, but only early scientific results are known. The University of Queensland's Kevin Welsh took part in palaeoclimate expedition 318 (January-March) to the Wilkes Land region off Antarctica. The cores collected document the onset of cooling at around 33.5 million years ago, leading to the first Antarctic glaciers. The growth and retreat of Antarctica's ice sheets impact upon global sea level, and oceanographic and biotic evolution, and keep the planet cool by reflecting heat from the sun. It is vital that we understand what drives these ice sheets so that we can make predictions about what will happen in the future.

Expedition 325 to the Great Barrier Reef (February-April) investigated the history of the 120 m sea level rise in the Great Barrier Reef since the last glacial maximum about 18,000 years ago, and the associated changes in the coral reefs and their water properties as they migrated landward. Australian participants were Jody Webster from Sydney University, Michael Gagan from ANU and Tezer Esat from ANU/ANSTO. Understanding what has happened to the reef as the ocean warmed and sea level rose can surely help us better understand what might happen to the reef in a future warming world.

Recent published review of IODP and Australian research within it:

<http://www.iodp.org.au/IODP%20AJMOA%20article%20only.pdf>

Rhodoliths: archives of environmental change.

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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 up to hundreds of years and form a high-Mg calcite skeleton that presents periodical growth bands.

Recent geochemical studies on coralline algae have focused on sea-surface temperature (SST) secular changes and have shown a strong relationship with the variations of the Mg/Ca ratio in the algal skeleton at a monthly or bi-weekly resolution. By analysing a *Sporolithon durum* rhodolith species from the tropical Pacific (New Caledonia) presenting a high growth rate ($\sim 0.7\text{--}0.8$ mm/yr), we are able to characterise that Mg/Ca_SST relationship on a couple-of-days to a daily basis.

Improvements on the method of the Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA ICPMS) technique enable us to reach a spatial resolution $< 5\mu\text{m}$ along the rhodoliths' axis of main growth. Chronology is established with the support of Single Stage Accelerator Mass Spectrometer (SSAMS) radiocarbon dates and geochemical data can, then, be correlated to daily local SST measurement over a period of over 45 years.

Although the Mg/Ca_SST relationship is strong at different timescales ($r > 0.75$), it appears that some of the Mg/Ca variations cannot be strictly explained by the local temperature variations. Therefore, other factors (environmental and/or biological) are to be investigated. For example, Electron Probe Micro Analysis (EPMA) intensity maps, associated with LA ICPMS data at the micrometre scale, suggest that *S. durum* displays well-defined, sub-monthly Mg/Ca cycles that seem to be primarily biologically-driven and correspond to lunar cycles.

Further research will be directed towards the understanding of the other factors potentially contributing to the variations of the Mg/Ca ratio in coralline algae and the quantification of their effect on the reliability of the proxy as a palaeo-temperature recorder.

Other aspects are focused on the use of trace elements and stable isotopes to reconstruct different environmental parameters such as salinity and river discharge.

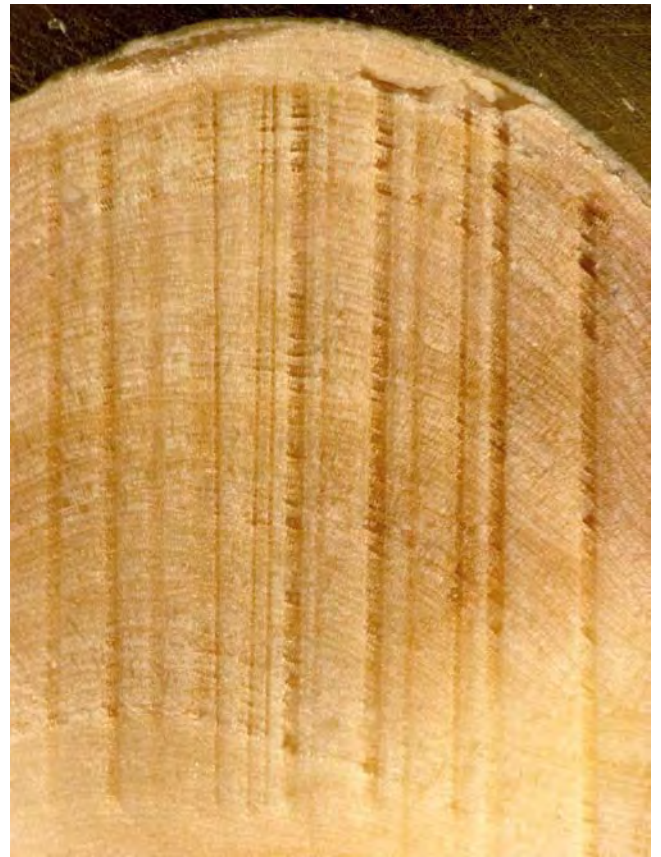


Figure 1. Part of a rhodolith branch showing different sizes of laser tracks used as a contribution to the improvement of the LA ICPMS measurement method. Individual track length is $\sim 2\text{mm}$.

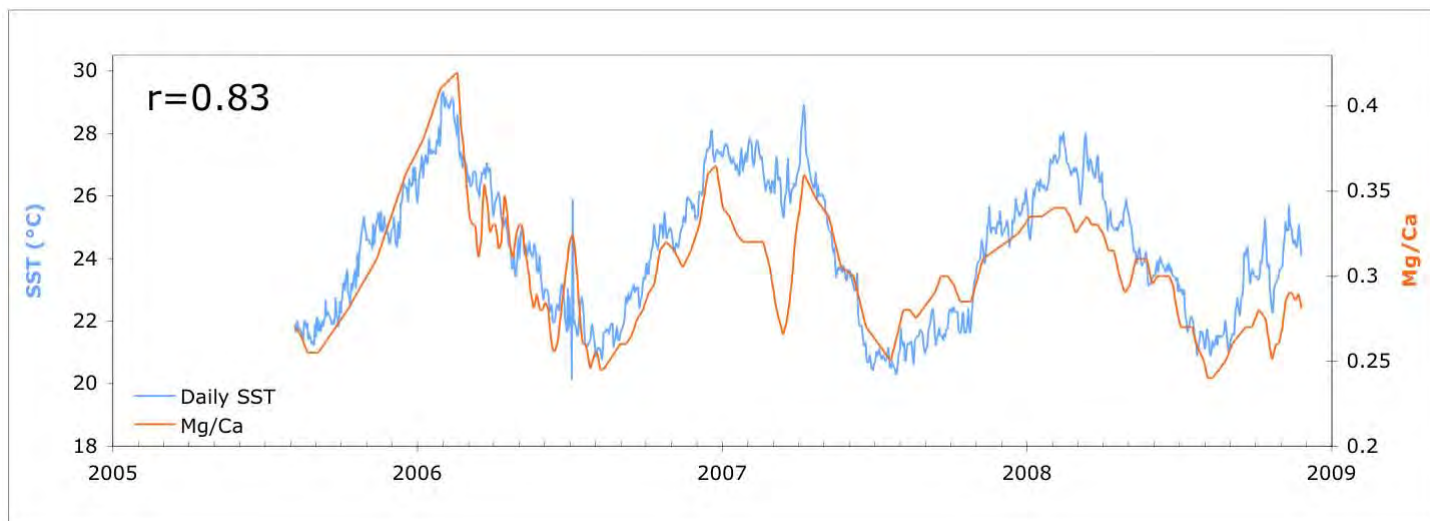


Figure 2. *Sporolithon durum* LA ICPMS high resolution Mg/Ca variations compared against local, daily Sea Surface Temperature (SST) data for Ricaudy Reef (New Caledonia) over the mid-2005 to end-2008 period.

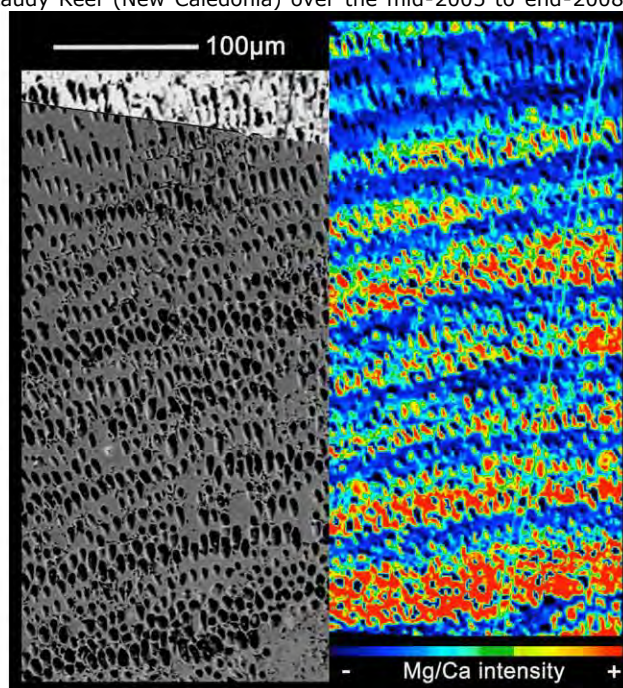


Figure 3. Left: Back Scattered Electron (BSE) image of a part of a rhodolith branch showing the high porosity of the sample. Right: EPMA intensity map showing variations of Mg/Ca at the micrometre scale in correspondance to the BSE image. High frequency variations can be determined (30-50µm) and are thought to be associated with lunar cycles. A portion of a lower frequency cycle (annual cycle) can also be observed that is to extend beyond the area covered by the map (>500µm period).

Air-breathing adaptation in a marine Devonian lungfish

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Our research shows that as far back as 380 million years ago, *Rhinodipterus*, a marine lungfish possessed skeletal specialisations required for air-breathing. Lungfishes were most likely driven to breathe air, not from venturing into lower oxygen, freshwater habitats (as was previously thought), but directly from pressures arising from lower global oxygen levels, which were down to 12% at this time (current levels are about 21%). This also drove other marine fishes in the same environment to simultaneously develop air-breathing adaptations.

Thus air-breathing arose twice in this early time in vertebrate evolution; once in lungfishes, and once in the line leading to tetrapods (or land animals), and ultimately to us.

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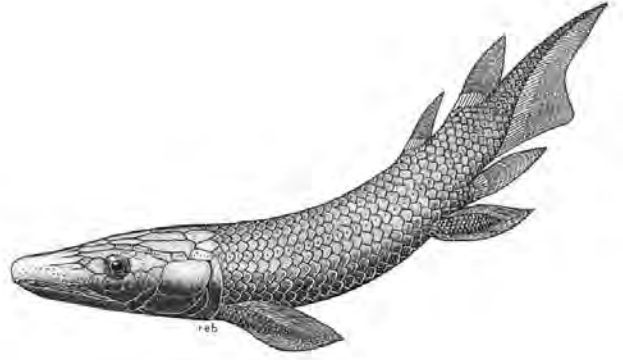


Figure 1. An artists impression of *Rhinodipterus* (Richard Barwick)



Figure 2. *Rhinodipterus* skull in dorsal view.

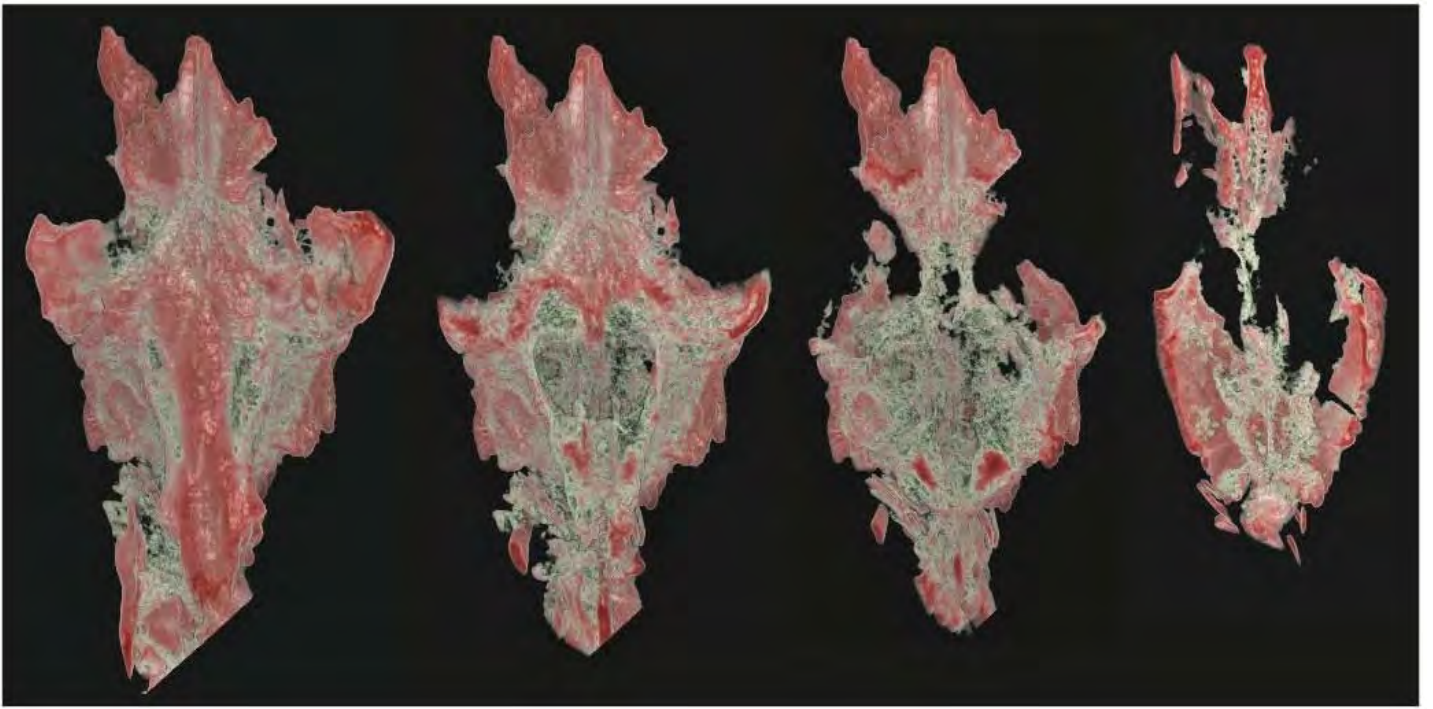


Figure 3. An x-ray CT scan of the *Rhinodipterus* skull, visualised in ANU software Drishti, courtesy of Dr. Tim Senden (ANU).

Groundtruthing coral chemo-geodesy

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Catastrophic earthquakes, such as the 2004 Sumatran earthquake and subsequent tsunami, are poorly understood due to the limited understanding of the recurrence interval of great submarine earthquakes. Characterization of past earthquakes is necessary to predict future earthquakes and mitigate disasters in the Indonesian region. Large corals inhabit fringing reefs in the tectonically-active islands offshore of the Sumatran mainland. During an earthquake, coral reefs experience co-seismic uplift (or submergence), and it has been shown that carbon isotope ratios ($\delta^{13}\text{C}$) in coral skeletons respond to changes in water column properties (i.e. light intensity, turbidity; Gagan et al. in prep) brought about by crustal deformation. Here we present geochemical evidence from massive *Porites* corals that ground-truths the use of $\delta^{13}\text{C}$ and elemental ratios in coral skeletons (coral chemo-geodesy) to reconstruct past earthquakes. To test the proxy we drilled corals from reefs surrounding the island of Nias, west Sumatra, that experienced a 8.7 magnitude earthquake in March 2005. Fortuitously, a GPS array in place during the earthquake recorded the magnitude of uplift and submergence associated with the event. Corals were collected from four study sites that experienced 2.5 m, 1.8 m, and 0.5 m of uplift, and 0.5 m of submergence. Our preliminary findings suggest that changes in $\delta^{13}\text{C}$ are sensitive to vertical motion during an earthquake, but only in simplistic environments such as fringing reefs. Supplementary data from Mn and rare earth elements record dramatic shifts in environmental conditions related to the earthquake. Together, the $\delta^{13}\text{C}$ and trace elements provide a unique geochemical signal for paleoseismic events. With further development, the coral chemo-geodesy technique potentially could provide an archive of pre-historical earthquakes and shed light on the recurrence interval and precursors of great earthquakes.



Figure 1. Emergence (+2.5 m) of massive *Porites* corals on the Island of Nias during the M 8.7 March 2005 Earthquake.

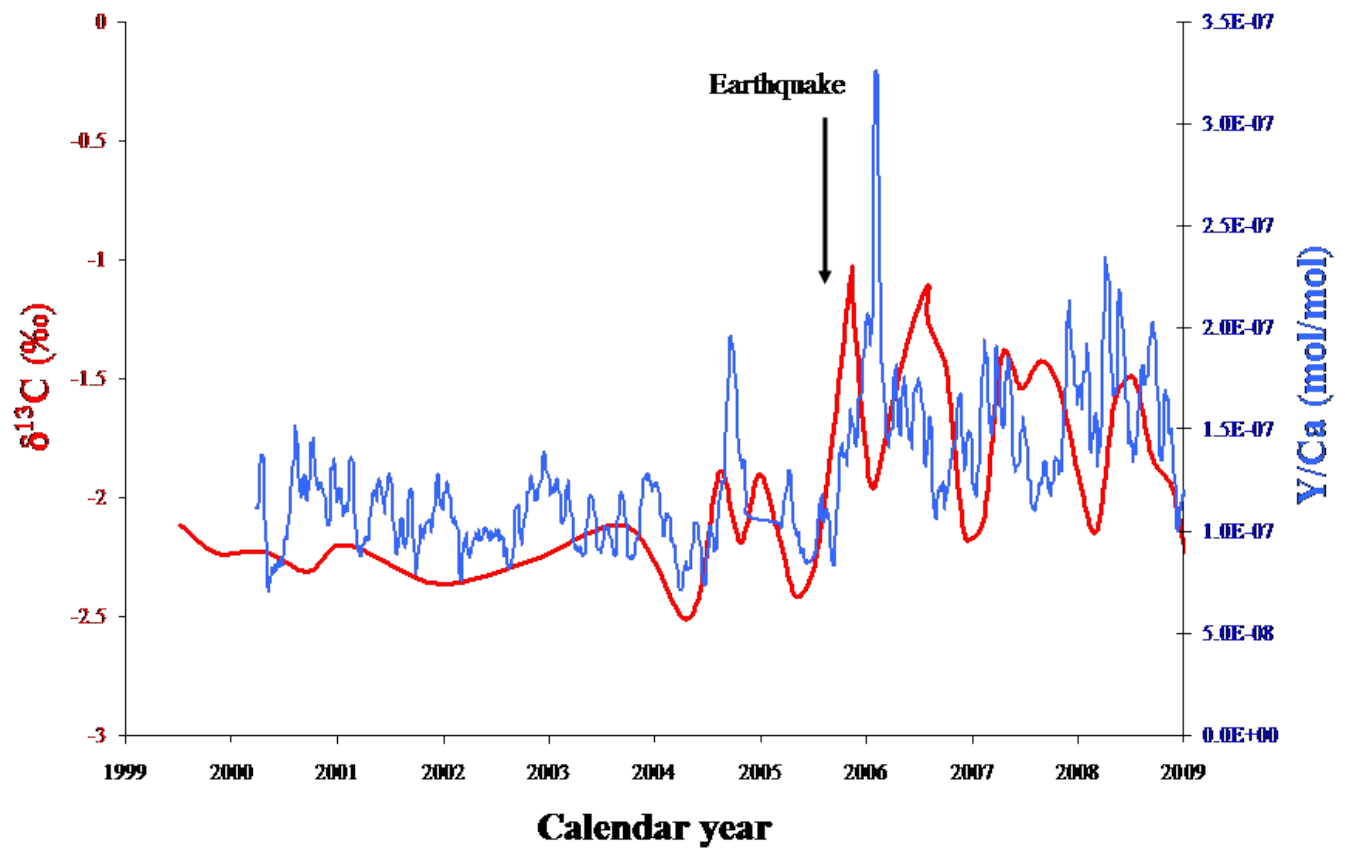


Figure 2. Carbon isotope and Y/Ca (yttrium-to-calcium ratios) data from a coral collected from a 1.8 meter uplift site off the island of Nias. Note the dramatic shift in both tracers associated with the 2005 earthquake.

Characterising the macro and micro-nutrient status of the North Tasman Sea

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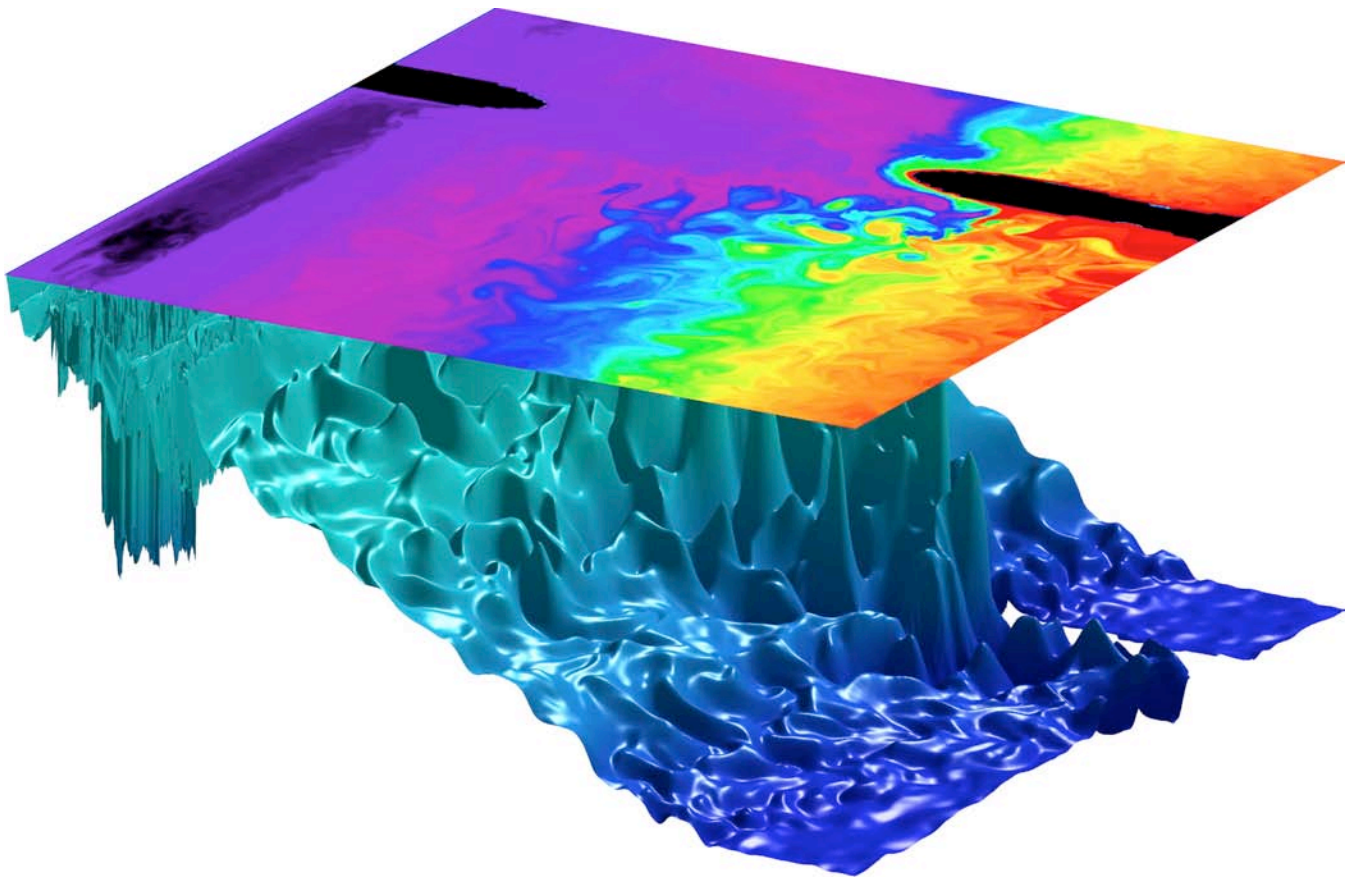
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The Tasman Sea is one of the most sensitive oceanic regions to climate change and iron supply. Current predictions are for this region to warm by 2 degrees by 2060 potentially resulting in a floristic shift in the plankton community toward nitrogen fixers, which have a high iron requirement. However, it remains uncertain to what extent an increase aerosol iron supply would aid this floristic shift and its associated impact on the marine food-web. Three research voyages were conducted in 2005, 2006 and 2010 to examine the degree of nitrogen limitation and the role of macro- and micro-nutrients in stimulating the phytoplankton community in the water north of the Tasman Front. Water column measurements confirmed that these waters are oligotrophic with surface nitrate and phosphate concentrations less than 10 nmol/L and 60 nmol/L, respectively, and dissolved iron concentrations varying between 0.05 and 0.7 nmol/L depending on dust inputs. Deck-board perturbation experiments involving the addition of macro- (NH_4 & PO_4) and micro- (Fe, Co, Cu & Zn) nutrients confirm nitrogen availability to be the primary control on phytoplankton production, with phosphate and iron availability playing minor secondary roles even though the concentration of these elements are close to bio-limiting. Within these experiments, the addition of nitrogen was found to stimulate eukaryote, prokaryote and bacterial production and inhibited nitrogen fixation. Current work from our 2010 voyage is centred on further elucidating the role of redox active trace elements play in regulating the nitrogen cycle in this region.

Research School Of Earth Sciences (Earth Materials & Processes)

Research Activities 2010



Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.

Introduction

The Earth Materials and Processes area comprises research groups in Rock Physics, Experimental Petrology, and Structure & Tectonics. Our research has traditionally centred 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 complimented 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.
- Speciation 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. Laboratory studies of the seismic properties of the cracked and fluid-saturated rocks of the upper crust.
- Building "The Map That Changes The Earth" 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. To provide critical data for the tectonic reconstructions "listening posts" are being established that provide samples that can be analysed and dated using $^{40}\text{Ar}/^{39}\text{Ar}$ and U-Pb geochronology.

Fluid pathway evolution within intrusion-related hydrothermal systems.

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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 permeability. 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 moderately 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. Textural and compositional banding in stage 2 veins indicates multiple episodes of vein growth and sealing. Each cycle of vein growth is marked by deposition of a zone rich in roscoelite (vanadian mica) and pyrite, together with Al-rich quartz. The initial Au-rich phase of each cycle is overgrown typically by a quartz-rich zone with low Au grades and marked oscillatory zoning in Al content of quartz. Individual veins may contain several of these gold-rich to gold-poor cycles of vein growth. The coarse-scale crack-seal textures, mineralogical zonation and trace element zoning in quartz in Stage 2 veins suggest growth in an episodic flow regime. Each cycle of vein growth is interpreted to be triggered by breaching of the magmatic-hydrothermal fluid reservoir due to progressive build-up of fluid pressures. Flow cycles are terminated by partial draining of the fluid reservoir and consequent loss of driving pressure, or by hydrothermal sealing of fluid pathways.

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/

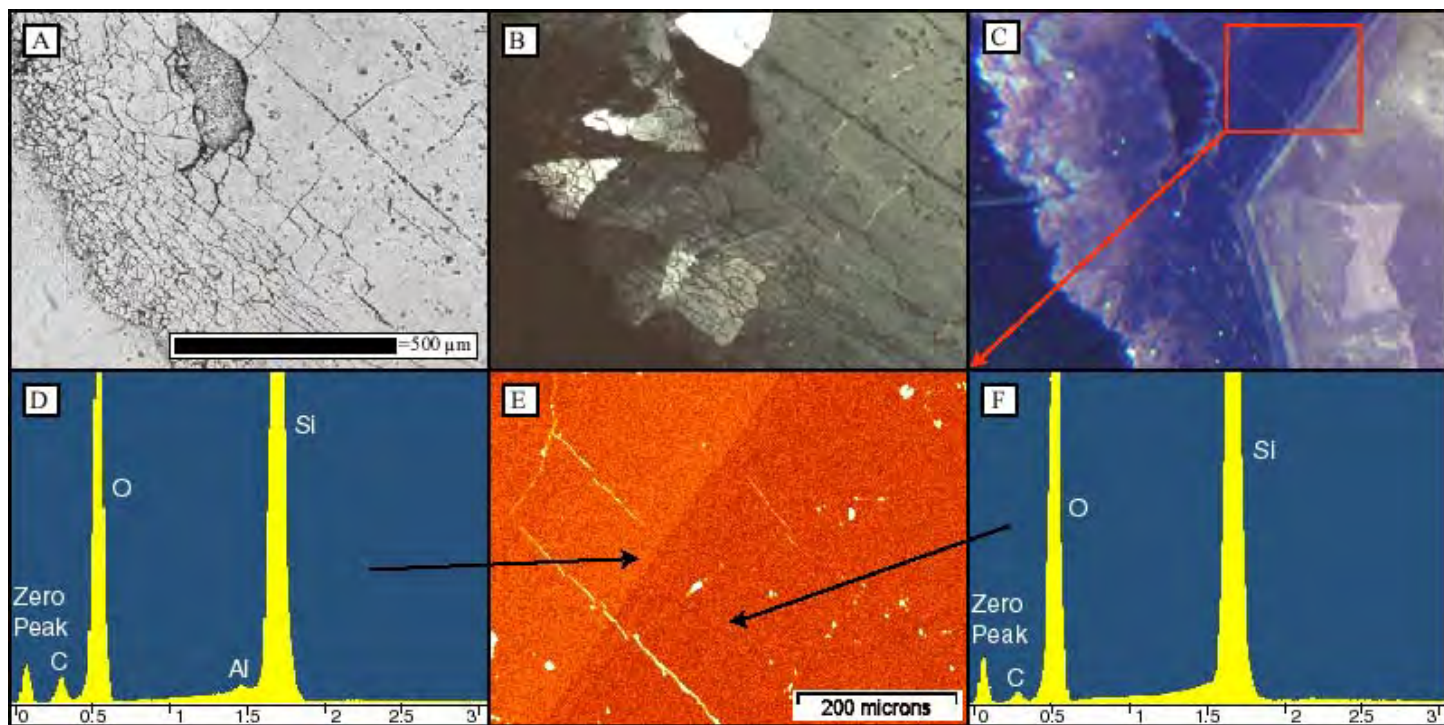


Figure 1. Figure 1. (a) Plane-polarised light photomicrograph of quartz rich PNG44. Roughly the same area is shown in figures 1a, b, and c. (b) Cross-polarised light photomicrograph of quartz rich PNG44. (c) Optical colour cathodoluminescence photomicrograph exhibiting colour variations within the quartz crystals and between quartz layers. The red box marks the location of the energy dispersive X-ray map shown in figure 1e. (d) Energy dispersive X-ray spot analysis collected from the location pointed to in figure 1e (scale bar in keV). The spectra highlights the incorporation of Al into the quartz crystal. (e) Energy dispersive X-ray map highlighting relative variations in Al content. Light orange indicates the highest amount of Al in the quartz crystal and dark orange indicates no Al in the quartz lattice. (f) Energy dispersive X-ray spot analysis collected from the location pointed to in figure 1e (scale bar in keV). The spectra highlights that the crystal is pure quartz with no incorporation of Al.

The seismic properties of cracked and fluid-saturated crustal rocks

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The seismic properties of cracked and fluid-saturated rocks, typical of the Earth's upper crust, are expected to be strongly frequency dependent, on account of stress-induced fluid flow between different parts of the pore space. This expectation places a special premium upon laboratory measurements at seismic frequencies – many orders of magnitude lower than those of conventional laboratory wave propagation experiments. We have therefore modified novel equipment to allow both torsional and flexural oscillation measurements under conditions of independently controlled confining and pore-fluid pressures – providing seismic-frequency constraints on both the shear and compressional wave properties.

The new low-frequency methods have been applied in an exploratory study of thermally cracked specimens of polycrystalline alumina and quartzite, tested dry or saturated with either argon or water. The marked increase of the shear modulus for Cape Sorrell quartzite (Fig. 1, lower) with increasing effective pressure (confining pressure minus pore-fluid pressure) is attributed to the progressive closure of low-aspect ratio cracks (Fig. 1, upper). Similar results for the same specimen tested dry and with argon pore fluid suggest conditions in which spatially variable pore pressures are equilibrated by fluid flow on the time scale of the ~ 0.1 Hz oscillations.

Systematic application of these methods, in conjunction with ultrasonic measurements, promises new insight into the seismic properties of crustal rocks in scenarios ranging from earthquake fault zones to geothermal power extraction.

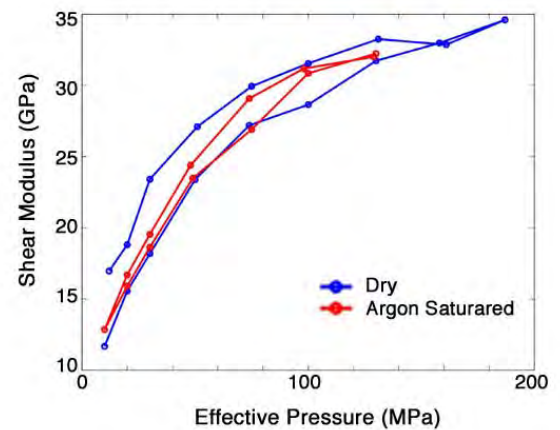
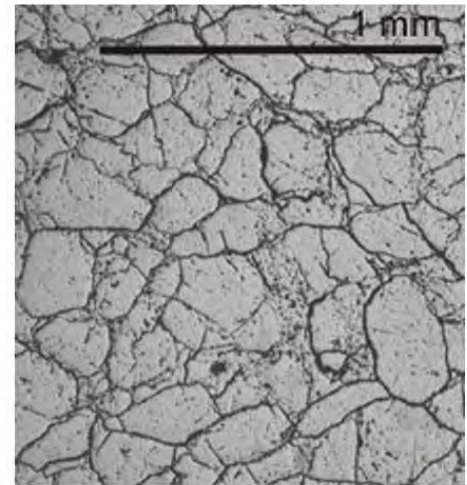


Figure 1. Reflected-light micrograph of a quartzite rock, cracked by rapid thermal cycling, and subsequently used to generate the plotted trend of increasing shear modulus (rigidity) with increasing pressure, attributed to crack closure.

Dynamic permeability and the evolution of fluid pathways in fault networks

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This project combines geochemistry and structural studies of an exceptionally well exposed, calcite-rich vein system in a limestone-hosted normal fault network from the Jabal Akhdar dome, Oman. Structural and microstructural observations are used in conjunction with high spatial resolution C/O stable isotope, Sr isotope and trace element analysis to study 4D variations in vein mineral chemistry. The vein chemistry is being used to map the distribution and evolution of geochemical fronts within the vein system. The geometry and distribution of geochemical fronts will be used to constrain flow directions. Reactive transport modeling of geochemical profiles along fluid pathways will be used to map 4D variations in fluid flux.

The majority of the fieldwork in Oman has focused on a single 25km long normal fault zone called the Northern Boundary Fault (NBF) and an adjacent subsidiary fault network. Mapping along this fault system has defined a close temporal and spatial relationship between extension veins and fault veins (Fig. 1a), indicating that the system formed under near-lithostatic fluid pressures and low differential stress. Complex mutually crosscutting vein networks within the proximal damage zone of the NBF indicate that fluid flow in this system was episodic (Fig. 1b).

$\delta^{18}\text{O}$ of vein calcite shows a depletion trend from host rock values ($> 26\text{‰}$) down to 13‰ (Fig. 2). The ^{18}O depleted vein calcite is clearly out of equilibrium with the host rock, indicating the influence of an external reservoir. An up-section shift in median $\delta^{18}\text{O}$ towards host rock values suggests that this external reservoir entered the system through episodic breaching of a seal near the base of the carbonate sequence.

Assuming that the most depleted vein $\delta^{18}\text{O}$ represents an essentially fluid-buffered composition then the ^{18}O of calcite can be converted to an equivalent ^{18}O of water for a given temperature (O'Neil et al. 1969). This gives a range of $4.2\text{--}8.1\text{‰}$ ($T = 200\text{--}300^\circ\text{C}$), which is consistent with a number of potential sources. However, given an upward flow direction and considering the geological setting the preferred interpretation is for a connate water source.

The along-strike distribution of fluid flux on the NBF is highly variable. Structural complexity is the first order control on this variation, with features such as jogs, splays and termination zones hosting strongly depleted ^{18}O vein chemistry and thus high fluid flux. In contrast, the geochemical front in planar segments is more than 2500m lower in the system than for some structural complexities, indicating much lower fluid

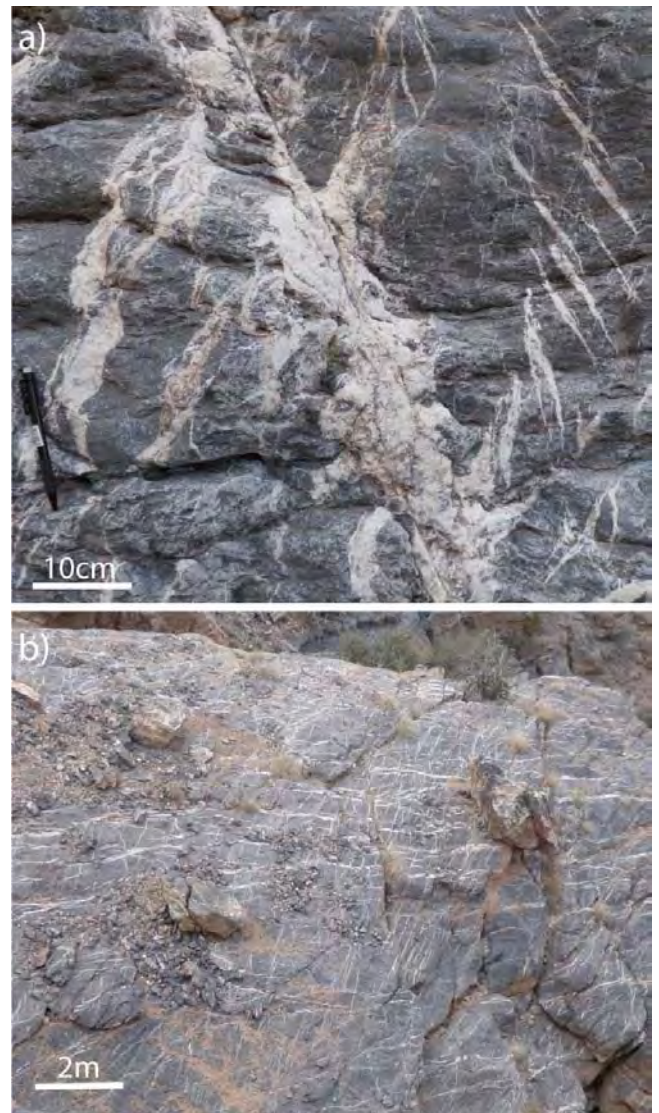


Figure 1. (a) Extension veins connected to a larger throughgoing fault vein on a strand of the NBF. This close association between extension veins and fault veins indicates near-lithostatic fluid pressures and low differential stress. (b) Complex vein network adjacent to the NBF. Since these veins cannot have all been open to fluid flow simultaneously, formation of this network must have involved episodic fracturing and sealing.

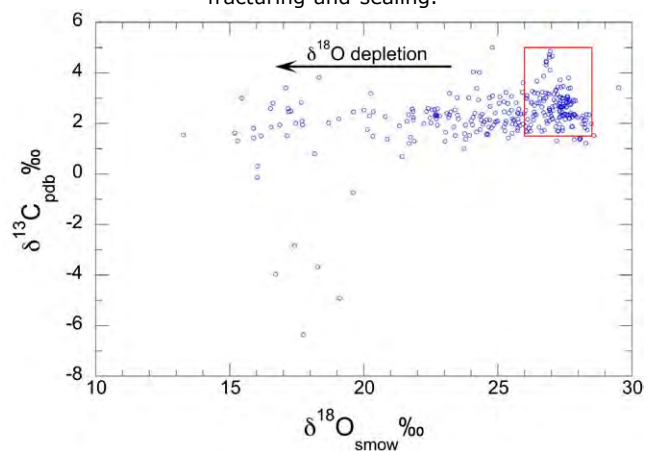


Figure 2. All calcite vein analyses. There is a strong cluster of samples in the distal host rock field (red box, $>26\text{‰}$) and a tail of decreasing $\delta^{18}\text{O}$ (minimum = 13‰). This tail of decreasing $\delta^{18}\text{O}$ indicates the influence of an ^{18}O depleted external reservoir.

flux. Displacement may also act as a second order control on fluid flux distribution, with most high flux zones located in low-displacement segment of the fault. This relationship needs further investigation.

The NBF is bounded by a network of low to moderate displacement faults. Mapping in this network by Arndt et al (2010) indicates displacements between 1 and 60m. Reconnaissance sampling has identified veins with depleted ^{18}O similar to the most depleted analyses from the NBF. This indicates that networks of low to moderate displacement faults are capable of hosting fluid fluxes similar to those on large, high displacement faults. Depleted ^{18}O veins within the low to moderate displacement fault network are localised in zones of structural complexity similar to the NBF.

Work during 2011 will focus on:

- Further along-strike sampling comparing structural complexities vs. planar fault segments and low-displacement vs. high-displacement fault segments.
- Across strike sampling to understand the distribution of fluid flow within the NBFs' proximal damage zone and also between the NBF and the adjacent low to moderate displacement fault network.
- Establishing relative timing relationships to explore how the position of the isotopic front changes with time.
- Understanding the P-T conditions of the system.
- Reactive transport modeling to quantify time-integrated fluid flux.

References:

Arndt, M., Z. Sobisch and S. Virgo (2010). High-resolution structural mapping of an area on the southern flank of Jabal Shams, Oman Mountains. Endogene Dynamik, RWTH Aachen University.

Diplomkartierung: 193.

O'Neil, J. R., R. N. Clayton and T. K. Mayeda (1969). "Oxygen Isotope Fractionation in Divalent Metal Carbonates." Journal of Chemical Physics **51**(12): 5547-&.

Dislocation damping & upper-mantle seismic wave attenuation

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The possibility that crystal imperfections, known as dislocations and introduced during tectonic deformation at large scales, might be responsible for reduced seismic wave speeds and appreciable wave attenuation in the Earth's upper mantle has been explored in a laboratory study.

Tiny crystals of the dominant ferro-magnesian silicate mineral olivine were synthesised, pressed together into dense and solid specimens, some of which were deformed in the laboratory (Fig.1, upper). Undeformed and deformed examples were then compared in experiments to measure the response to seismic-shear waves at timescales (periods) similar to those for seismic waves travelling in the mantle: both modulus (which controls the shear wave speed) and energy dissipation (related to wave attenuation) were measured. Lower, and more strongly period-dependent shear moduli and stronger energy dissipation (Fig. 1, lower) were observed in the deformed specimens - more so for those deformed so that dislocations readily reactivate during the seismic-property measurements.

The new results suggest that dislocations might significantly influence the seismic properties of the Earth's upper mantle, and also that such effects might be most pronounced for particular directions, of wave propagation and polarisation, in seismic waves travelling in the shear-stress fields associated with mantle flow deep within the Earth.

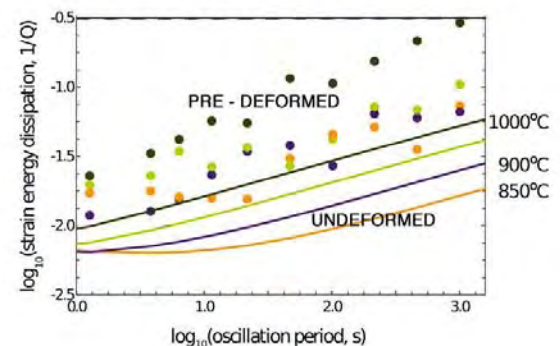


Figure 1. Photo of a steel-jacketed specimen following torsional deformation at the University of Minnesota. Subsequent testing in the ANU laboratory yielded the plotted seismic properties, showing greater strain-energy dissipation for the pre-deformed specimen (plotting symbols) than for an undeformed specimen (curves).

The relationship between rock fabric and acoustic anisotropy in reservoir sandstones

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Some oil reservoir sandstones have seismic velocities that vary by 15-20% azimuthally in the bedding plane. We have been investigating the causes of this anisotropy using X-ray tomograms obtained from small cores of rock samples and also computer-generated control samples. After tomography, the cores are sectioned, and scanning electron micrographs taken. The plane of a micrograph is then accurately located within the original 3D dataset ("registered") using in-house software, and the faithfulness of the tomogram checked by comparing the two views. Further processing of the tomogram allows us to generate a model rock (Fig. 1) which is segmented into pore space and individual grains (Fig. 2). Grain sizes, shapes and orientations can then be approximated by triaxial ellipsoids of best fit, allowing us to calculate grain size, shape and orientation distribution data for the rock as a whole. Grain contact surfaces can similarly have their areas and mean normal directions fitted (Fig. 3), and the distribution of contact area orientation obtained. Thus, a range of aspects of the rock fabric can be captured from the segmented tomogram. The "virtual rock" can also be used to calculate elastic constants for the bulk rock by finite-element methods, and hence low-frequency acoustic velocities for arbitrary polarisation states and propagation directions. Simulated control samples with known fabric parameters allow us to check and refine the quality of the image segmentation procedures, and also to disentangle the effects on calculated velocities of different parameters such as grain preferred orientation, grain contact preferred orientation, and degree of cementation. Samples examined include:

(i) An almost isotropic sphere packing, annealed by dilation so as to reduce the porosity and obtain nonzero grain contact area. calculated V_p varied by less than 1% as a function of propagation direction, as expected. The elastic properties used were those of quartz, which makes up 96% of the mode in our real rocks, and the velocities obtained of ca. 5 km/s are in line with what we would expect for a packing of quartz spheres with 25% porosity.

(ii) A real rock showing "normal" uniaxial variation of 7% in experimental V_p between the slow direction (in bedding plane) and fast direction (normal to beds).

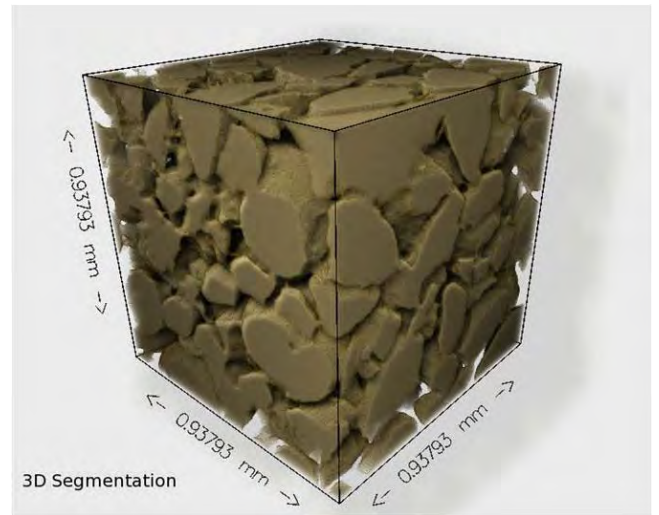


Figure 1. Perspective view of a cubic portion of the tomogram, segmented into grain space and pore space.

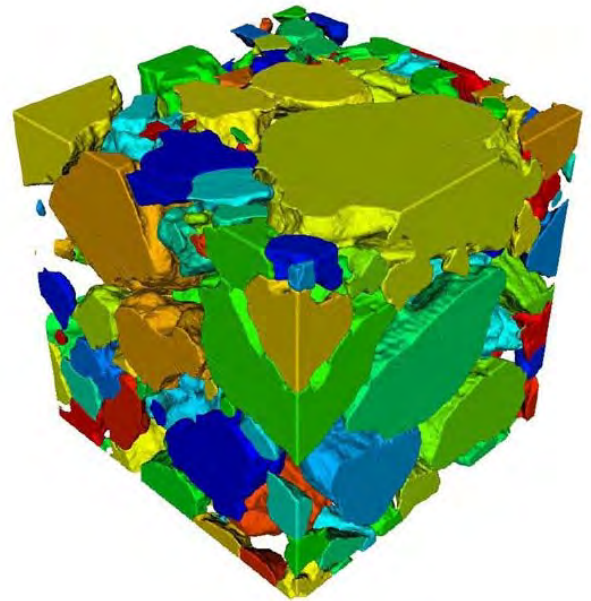


Figure 2. Segmented dataset after application of Euclidean Distance Map and Watershed Transform, which locate grain boundaries and distinguish individual grains (colours are arbitrary).

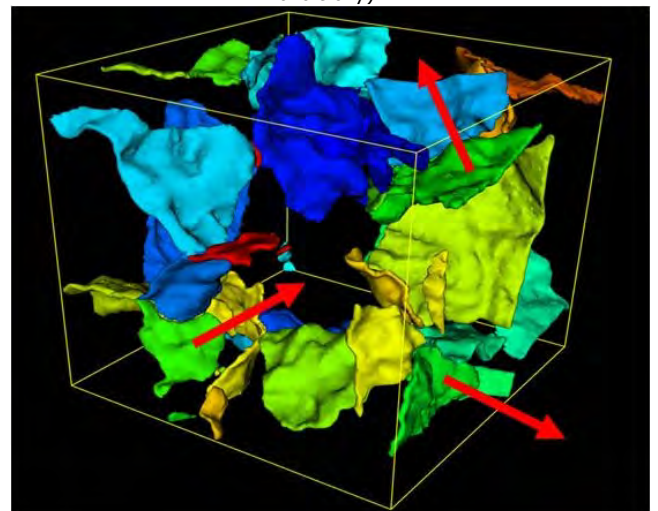


Figure 3. Grain boundary surfaces located by Watershed Transform, with mean normals indicated for three cases (red arrows).

Our processing revealed substantial preferred orientation of grains (Fig. 4), but this did not align with the acoustic anisotropy. However, grain contact surface normals correlated strongly with the fast direction for V_p (Fig. 5).

(iii) A rock showing triaxial variation of 15% in experimental V_p , with fast directions of similar velocity in the bedding plane and normal to it, and a slow direction in the bedding plane. There was no preferred orientation of grains in this rock. Again, however, fast and slow V_p correlated with the directions of respectively high and low concentration of contact surface area normals.

(iv) A simulated packing of identical $70 \times 60 \times 50$ voxel triaxial ellipsoids, with perfect preferred orientation of grains and no preferred orientation of contact surfaces. This demonstrated that about 10% directional variation in V_p can be produced by strong alignment of aspherical grains, and that this can be studied in isolation from the effect of grain contact directionality, which is clearly the dominant driver of acoustic anisotropy in the sandstones studied.

Related publication:

Arad, A., Mahdadi, M., Christy, A.G., Sheppard, A.P., Averdunk, H., Knackstedt, M.A.

Understanding elastic properties and acoustic anisotropy at the pore/grain scale. Society of Petrophysicists and Well Log Analysts 51st annual meeting, Perth, Australia, June 19-23, 2010. *Petrophysics* (in press).

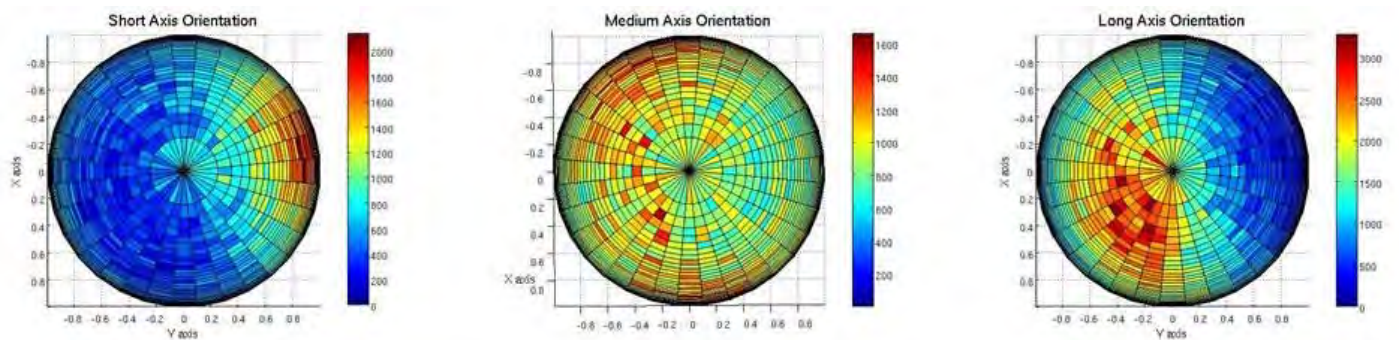


Figure 4. Orientation distribution of grain short, medium and long axes for rock showing uniaxial anisotropy in V_p . Hemispheres of directions, are subdivided into bins subtending equal solid angles and viewed in orthographic projection down the bedding plane normal. Note very strong preferred orientation of long and short axes.

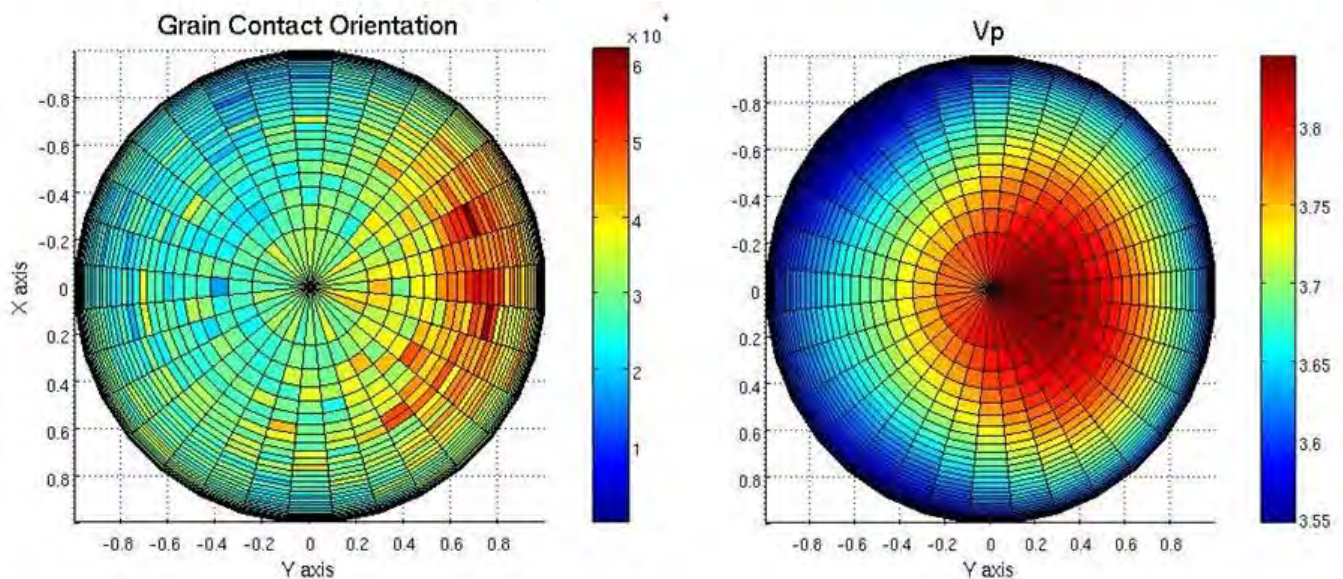


Figure 5. (Left) Orientation distribution of grain contact normals, weighted by contact area per solid angle, for same sample as above. (Right) Angular variation of V_p . Fast direction correlates well with predominant contact normal, but not with long or short axes of grains.

Experimental study of the diffusion of platinum group elements in rock forming minerals

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The experimental study of Rh, Ru and Ir diffusion in olivine and spinel is aimed at obtaining important information such as the rate of diffusion, mechanisms of element substitution and solubility of PGEs in rock forming minerals.

The series of experiments were performed on synthetic forsterite, San Carlos olivine and natural spinel at different temperatures, oxygen fugacities and silica activities. Experiments were carried out at the atmosphere pressure in a vertical tube furnace modified to control fO_2 by CO-CO₂ gas mixing and in a box furnace running in air. Temperatures: 1300 C and 1400 C, $\log fO_2$: -7.2, -5.7 and -0.7. Duration of experiments: 1, 2, 9, 31 and 35 days.

The following diffusion coefficients (m^2/s) were obtained:

	Synthetic forsterite	Spinel	S.C. olivine
T = 1300 C, $\log fO_2 = -5.7$			
Rh	$(0.1 - 2) \cdot 10^{-17}$	$(1.8 - 2.9) \cdot 10^{-17}$	$(0.8 - 4.6) \cdot 10^{-18}$
Ru	$(0.4 - 1.3) \cdot 10^{-17}$	$(0.9 - 1.6) \cdot 10^{-17}$	n/a
Ir	$(2.4 - 6.1) \cdot 10^{-18}$	$(1.2 - 1.6) \cdot 10^{-17}$	n/a
T = 1300 C, $fO_2 = -7.2$			
Rh	$(0.6 - 2.2) \cdot 10^{-18}$		$(0.6 - 2.2) \cdot 10^{-18}$
Ru	$(0.4 - 2.7) \cdot 10^{-18}$		$(0.4 - 3.9) \cdot 10^{-18}$
T = 1300 C, $fO_2 = -0.7$			
Rh (low SiO₂ activity)	$(0.4 - 1.4) \cdot 10^{-18}$		
Rh (high SiO₂ activity)	$(5 - 20) \cdot 10^{-18}$		
T = 1400 C, $fO_2 = -6.8$			
Rh (low SiO₂ activity)	$(7.6 - 20) \cdot 10^{-18}$		
Rh (high SiO₂ activity)	$(3.5 - 6.3) \cdot 10^{-17}$		

Diffusion coefficients of Rh in forsterite in the high silica activity experiments were higher than in the low silica activity experiments at high fO_2 ($fO_2 > -5.7$), whereas there is no difference when the same experiments were carried out at low oxygen fugacity experiments (See Fig. 1).

Diffusion coefficients in the low silica activity experiments remains constant at different oxygen fugacities whereas in case of high silica activity there are variations, which suggests that there are different diffusion mechanisms at low and high silica activities. Assuming that Rh substitutes in octahedral sites [1] and taken the likely oxidation states of Rh under conditions of our experiments to be Rh+2 and/or Rh+3 [1] we can suggest the following mechanisms of Rh substitution into forsterite:

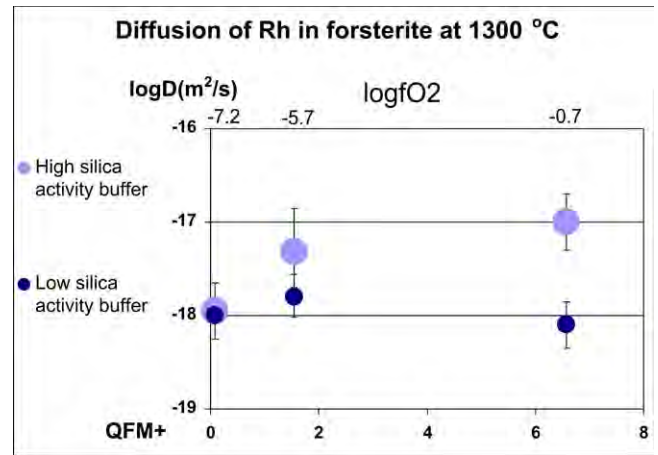
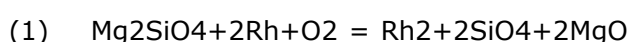
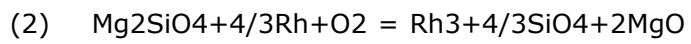


Figure 1. Diffusion of Rh in forsterite at 1300 C as a function of oxygen fugacity



References:

[1] J.M.Brenan, W.F. McDonough, C.Dalpe (2003) Experimental constraints on the partitioning of rhenium and some platinum-group elements between olivine and silicate melt. Earth and Planetary Science Letters 212: 135-150.

Experimental study of alumina diffusion in forsterite at different oxygen fugacities and different silica activities

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The Al diffusion rate in olivine is expected to be slow [1] and its concentration in olivine temperature dependent [2]. As a consequence, Al has potential to preserve zoning from early, high temperature stages of rock evolution. However the mechanism by which Al substitutes into olivine is still unclear and there are large differences in the values obtained for Al diffusion in olivine by different laboratories. The study of Al diffusion coefficient and Al solubility in olivine can give us a method of reconstructing the magmatic history of one of the most important mantle minerals.

Experiments on Al diffusion in synthetic forsterite was performed in an atmosphere pressure box furnace in air at 1300°C. Silica activity was controlled by composition of a buffer (Al_2O_3 – MgO – SiO_2 powder), painted onto a crystal. The duration of experiments was 5 and 25 days. Results were analysed by LA-ICP-MS, orientation of the crystals was analysed by EBSD.

Our study demonstrates that silica activity controls the rate of Al diffusion and solubility in forsterite. Two mechanisms of Al diffusion have been observed: 1) fast diffusion ($\log D = -14.1 \pm 0.03$ – -13.6 ± 0.04) which characterized by low concentrations of Al in forsterite (230 ± 30 ppm) and occurs at high silica activity; 2) low rate diffusion ($\log D < -18.5 \pm 0.05$) which results in comparatively high concentrations of Al in forsterite.

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- [2] Wan Z, Coogan LA, Canil D (2008) Experimental calibration of aluminum partitioning between olivine and spinel as a geothermometer. *Am Mineral* 93:1142–1147.

Mineralogical reservoirs for high-field strength elements in subducted crust in the mantle transition zone

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For the past 3 or 4 decades, isotope geochemists and mantle petrologists have viewed ocean island basalt (OIB) volcanism, and intraplate magmatism in general, through the prism of the "mantle plume" paradigm (Morgan, 1971). In this model, the age progression observed in linear chains of oceanic islands, or "hot spot" tracks, is produced as drifting plates of oceanic lithosphere migrate over fixed plumes rising from the deep mantle. Based upon the isotope systematics of OIB lavas, mantle plumes were seen to be tapping into a number of geochemically distinct reservoirs, several of which possess a geochemical signature characteristic of crustal rocks; this was taken as evidence that crustal material had been recycled into the plume source region somewhere in the mantle transition zone (MTZ), the lower mantle, or at the core-mantle boundary, where it could reside for billions of years. Since the 1960's, mantle geochemists have identified at least 4 reservoirs contributing to OIB volcanism: a so-called "HIMU" reservoir, linked to deep subduction of oceanic crust (MORB), and two "EM" or "enriched mantle" reservoirs, linked to the presence of small amounts of subducted "terrigenous" (EM1), and "pelagic" (EM2) sediments (see reviews by White, 2010; Willbold and Stracke, 2010). These components mix with one or more "common" mantle reservoirs (e.g., "PREM", "FOZO", and "DMM") in various proportions to produce an OIB isotopic "mixing array".

The legitimacy of the widely accepted mantle plume hypothesis for the origin of OIB volcanism has recently been questioned as part of "The Great Plume Debate" (Foulger, 2002; Anderson, 2003; Foulger and Natland, 2003; Niu, 2005, 2009). Foulger (2002; 2005) argues that the plume model has become untenable for a number of reasons, and that there are viable alternatives that do not require recycled crustal lithologies in the MTZ or lower mantle to explain the distinctiveness of ocean-island basalt geochemistry. For example, Niu (2005) argued that continental-derived sediments were "unsuitable as source material for OIB", because "fluid-mobile (or water-soluble) elements" (e.g., Ba, Rb, Cs, Th, U, K, Sr, Pb, La and Ce) in crustal rocks should be depleted by dehydration during subduction, thereby modifying their distinctive geochemical fingerprint during passage through the sub-arc regime. However, detailed geochemical studies of high-pressure mafic rocks demonstrated that dehydration accompanying prograde subduction zone metamorphism is marked by only limited mobilization of large-ion lithophile elements (LILEs), and recent high-pressure phase-equilibria experiments on continental sediments have shown LILEs can be carried into the MTZ in K-hollandite (Rapp et al., 2008), a polymorph of K-feldspar (KAlSi_3O_8). Niu (2009) subsequently argued that because the crystal structure of K-hollandite excluded high-field strength elements (HFSEs: e.g., Ti, Nb, Ta, Zr, Hf), deeply subducted sediments remained "unsuitable" as source material for OIBs (because it LILEs would be fractionated from HFSEs).

We have recently identified a Ti-rich, Mg-Al perovskite phase that is stable in both MORB and sediment compositions at pressures appropriate to the MTZ. This phase is the primary host for HFSEs in crustal rocks in the MTZ, containing up to 9 wt% TiO_2 , >150 ppm Nb, >25 ppm Ta, >1600 ppm Zr, and >45 ppm Hf, effectively counterbalancing the role of K-hollandite as a host for LILEs. The equilibrium phase assemblage in continental sediments in the MTZ will contain both LILE-rich K-hollandite, and HFSE-rich

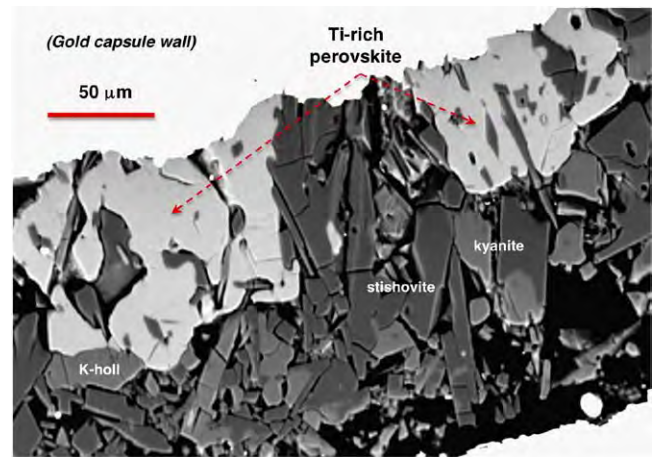


Figure 1. Back-scattered electron photomicrograph of high-pressure phase assemblage in continental sediment bulk composition at 23 GPa (~700 km depth) and 1400°C; mineral phases include Ti-rich Mg-Al perovskite, K-hollandite, stishovite and kyanite coexisting with a H_2O -rich supercritical fluid.

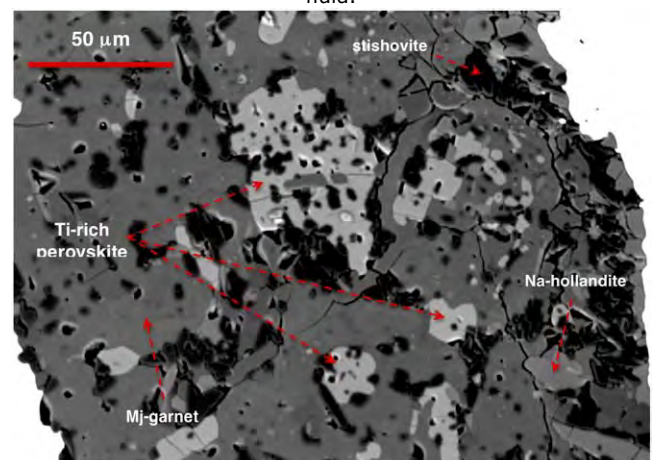


Figure 2. Back-scattered electron photomicrograph of high-pressure phase assemblage in MORB bulk composition at 23 GPa (~700 km depth) and 1300°C; mineral phases include Ti-rich Mg-Al perovskite, Na-hollandite, stishovite and majoritic garnet (dominant "matrix" phase) coexisting with a small volume H_2O -rich supercritical fluid.

Ti-perovskite, and consequently deeply subducted crust remains a viable source for the distinctive isotopic and geochemical “fingerprint” of OIB lavas.

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Mineral compositional controls on REE patterns in cratonic garnet lherzolite xenoliths and implications for mantle metasomatism

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The chemistry of Cr-pyrope garnets in kimberlite-bourne peridotite xenoliths or included in diamonds from the cratonic lithosphere has frequently been interpreted as recording significant events in cratonic evolution. Such events include early, pre-cratonic partial melting and later metasomatic enrichment by melts or fluids, which may or may not be associated with diamond crystallisation or resorption.

Early partial melting is evident in the high-Cr/Al nature of many garnets, consistent with partial melting of peridotite mainly in the spinel stability field. This resulted in a residue with higher Cr/Al, and was followed by compression during subduction into the garnet stability field with consequent recrystallisation as Cr-rich garnet harzburgite or refractory garnet lherzolite.

Cratonic Cr-pyrope garnets also exhibit a variety of normalised Rare Earth Element (REE) patterns, including so-called normal or sinusoidal patterns (Figure 1). Sinusoidal REE patterns are very common amongst the low Ca, high Cr garnets of the harzburgitic paragenesis in both xenoliths and diamond inclusions, whereas lherzolitic garnets exhibit both normal and sinusoidal patterns.

Explanations invoked to explain the normal and sinusoidal patterns have usually appealed to metasomatism by LREE enriched fluids or melts. For example, Stachel et al. (1998; 2004) and Creighton et al. (2008; 2010) considered that evolution of peridotitic garnet REE patterns from sinusoidal to normal results from a continuous transition from metasomatism dominated by fluids with highly fractionated LREE/HREE to metasomatism dominated by melts with less fractionated LREE/HREE.

Such models ignore the coexistence of garnet with clinopyroxene (at least in the lherzolite paragenesis). We have examined the garnet *and* clinopyroxene REE chemistries of a very well equilibrated suite of garnet lherzolites from the A154 kimberlite pipe at the Diavik Diamond Mine in the Canadian Slave Craton. We show that the distribution coefficients of the REE between garnet and clinopyroxene ($D_{\text{ga/cpx}}^{\text{REE}}$) vary as functions of equilibration temperature (T) and mineral compositional parameters.

We used the Diavik data to statistically parameterise the relationship between $D_{\text{ga/cpx}}^{\text{REE}}$ and T, garnet Ca contents and clinopyroxene Na contents. We then applied our parameterisation to new garnet lherzolites from the Udachnaya East kimberlite in the Siberian Craton and demonstrated that different degrees of metasomatism or types of metasomatic agents are unnecessary to explain the observed garnet REE chemistry. The observed variation from sinusoidal to normal garnet REE patterns is a consequence of variations in equilibration temperature and mineral compositional parameters. Hence, garnet REE contents in lherzolite do not necessarily faithfully record compositional information relating to metasomatic agents, which may have interacted with the garnet.

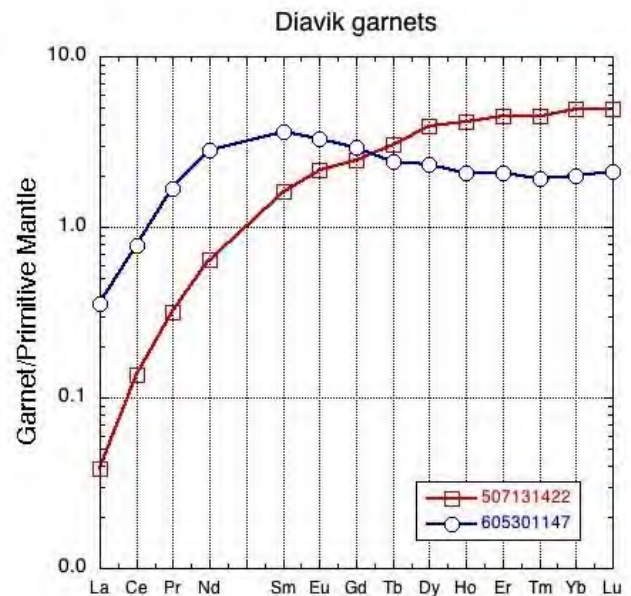


Figure 1. Primitive Mantle normalized REE plots for garnets from Diavik lherzolite xenoliths 507131422 (exhibiting a "normal" pattern) and 605301147 (exhibiting a "sinusoidal" pattern).

Determining the origin of high sulfidation gold deposits:

Insights from *in situ* oxygen isotopes in quartz using SHRIMP II.

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High sulfidation gold deposits are found in volcanic settings and are associated with intense acidic alteration. The dominant paradigm suggests that these deposits form in low temperature environments near the Earth's surface. However, recent textural studies of ore minerals have shown that these deposits are more likely to form from high-temperature volcanic gases deep beneath the volcano.

To test this new model, we have pioneered the use of *in situ* oxygen isotope analyses in quartz using SHRIMP II at the Australian National University. Oxygen isotopes tell us valuable information about the processes that occur during the formation of a quartz crystal. This includes the temperature at the time of crystallisation as well as fractionation effects from water to vapour.

Quartz crystals from high sulfidation gold deposits contain intricate zoning. We identify these zones by mapping the distribution of trace elements such as aluminium (Al) and potassium (K) using the Electron Microprobe (See Figure 1). The benefit of using *in situ* isotope analysis is that we can target specific zones in the quartz using a 20 μm ion beam.

Preliminary results show distinct zones of exceptionally heavy oxygen, confirming that high sulfidation ore deposits precipitate from magmatic vapour in a high-temperature setting.

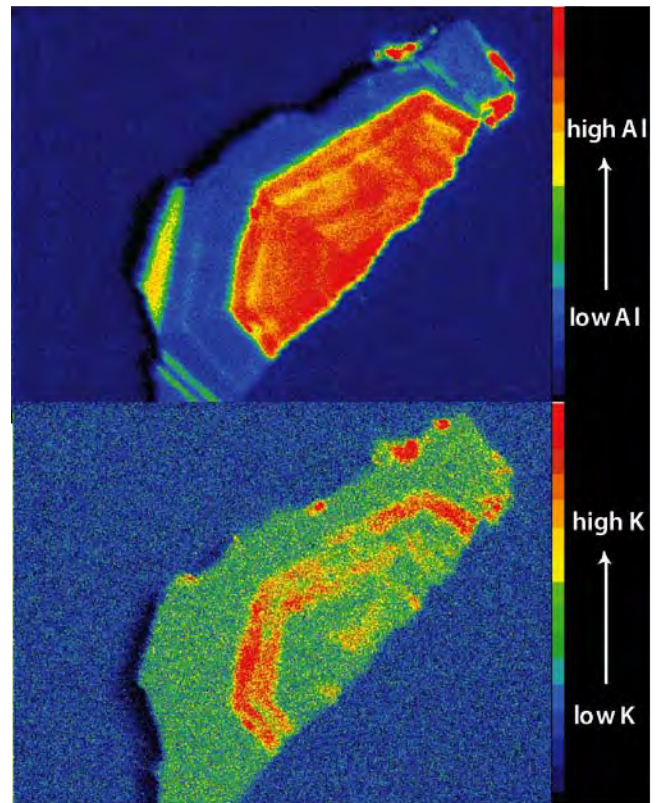


Figure 1. Figure One: Microprobe maps of a 20 μm quartz crystal from the El Indio copper-gold deposit in Chile. The maps show zonation of aluminium (Al) and potassium (K).

Rejuvenating Rb-Sr dating: a retarded Rb decay constant and the magic of *multiple collector inductively coupled plasma mass spectrometry*

OR: The evaluation of the ^{87}Rb decay constant by age comparison against the U-Pb system

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The absolute age of rocks and the events they formed in can be determined by the radiogenic ingrowth of daughter isotopes from radioactive decay of parental nuclides. One of the most popular dating tools is the Rb-Sr technique, where Rb-87 decays to Sr-87 with a half life of ~50 billion years.

Rb-Sr dating can be used to date events ranging back to the start of the solar system to the most recent events in Earth's history. It is one of the most widely used geochronometers for obtaining ages and cooling rates of terrestrial magmatic, metamorphic, and hydrothermal events, including ore deposition. It has further been extensively applied to date extraterrestrial, early solar system events. The accuracy of Rb-Sr ages, however, strongly depends on the accuracy of the ^{87}Rb decay constant ($\lambda^{87}\text{Rb}$). By using MC-ICP-MS for Rb isotope analyses [1], we determined $\lambda^{87}\text{Rb}$ relative to the decay constants of ^{235}U and ^{238}U by comparing Rb-Sr ages of minerals with U-Pb ages obtained from the same intrusion.

Comparison of U-Pb emplacement ages with high-precision Rb-Sr mineral ages from three rapidly cooled igneous rocks covering an age range of ca. 2.5 Ga yields an unweighted mean $\lambda^{87}\text{Rb}$ of $1.393 \pm 0.004 \times 10^{-11} \text{yr}^{-1}$ (i.e., $\pm 0.3\%$), corresponding to an exact half-life of 49.76×10^9 years [2]. This decay constant is 2% lower than the presently recommended value. As such, many previously published ages are also 2% too young and the resulting geologic interpretations may need revision.

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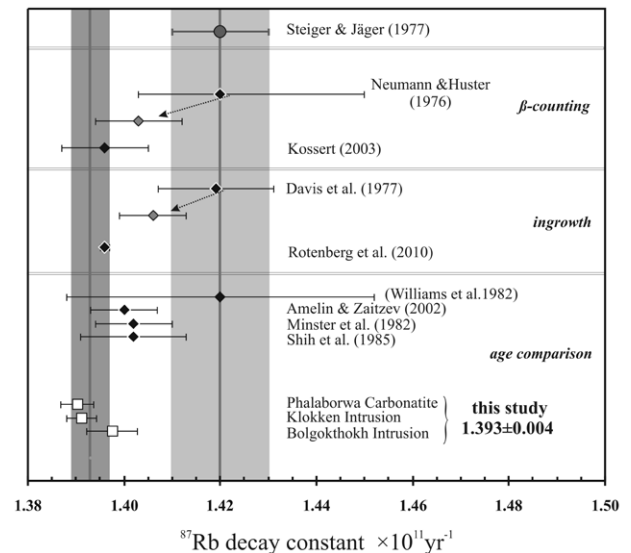


Figure 1. Compilation of different Rb decay constant determinations since publication of the recommended values (i.e., $\lambda^{87}\text{Rb} = 1.42 \times 10^{-11} \text{yr}^{-1}$) by the Subcommission for Geochronology in 1977 (light grey shaded area). The black dotted arrows show two recalculated values for $\lambda^{87}\text{Rb}$ from Begemann et al. (2001). The average $\lambda^{87}\text{Rb}$ suggested in this study is indicated by the dark grey shaded area and represents the weighted mean of the Klokken, Bolgokthokh, and Phalarborwa results.

Synthesis and crystal structure of the new compound CuZrTiO_5

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While using CuO as a flux for experimental work on the $\text{ZrO}_2\text{-TiO}_2$ system, an unexpected strongly pleochroic green reaction by-product was obtained in experiments run over the narrow temperature interval of 995-1010°C. Analysis showed this to be a new chemical compound, CuZrTiO_5 , the first known ternary oxide in the Cu-Zr-Ti-O system. Pure samples were synthesised in a muffle furnace at 1000°C from stoichiometric mixes of the component oxides, and eventually crystals were obtained of sufficient size (50 - 100 μm) and quality for structure determination by single-crystal X-ray diffraction (Fig. 1).

The crystal structure refined to $R(F^2 > 2\sigma(F^2)) = 0.032$ and was found to be orthorhombic, $a = 3.5871(3)$ Å, $b = 6.6968(4)$ Å, $c = 14.6679(9)$ Å, $V = 352.35(4)$ Å³, $Z = 4$, in the unusual acentric space group $P2_12_12_1$. A search of the Inorganic Crystal Structure Database revealed no known isostructural phases. However, the structure is closely related to that of In_2TiO_5 and In_2VO_5 . These compounds are also orthorhombic with similar cell dimensions, but have the centrosymmetric space group $Pmnb$ (in the axial setting corresponding to ours for CuZrTiO_5). The main difference between structures is that all atoms lie on the mirror plane in the In compounds, while they are displaced off the corresponding plane in the Cu-Zr compound. This leads to changes in the coordination polyhedra of the cations: while all cations are octahedrally coordinated in the In compounds, the Zr position in CuZrTiO_5 has two oxygens approach more closely to give it 7+1 coordination, and the Cu position has two oxygens withdrawn to give it the nearly square-planar, elongated-octahedral coordination polyhedron typical of Jahn-Teller distorted Cu^{2+} (Fig. 2).

The structure can be described as zigzag chains of edge-sharing TiO_6 octahedra running || **a**, alternating with parallel zigzag chains of ZrO_{7+1} to define (001) structural layers, which are parallel to the good cleavage of the crystal. Between these layers and cross-linking them, zigzag chains of CuO_{4+2} distorted octahedra run || **b** (Fig. 3).

Consideration of a hypothetical centrosymmetric CuZrTiO_5 with atoms moved back onto mirror planes reveals that the displacements away from the mirror are necessary in order to give the Cu ion its preferred environment of four short equatorial Cu-O (1.915 - 2.029 Å) and two long axial Cu-O bonds (2.565 - 2.591 Å), since the mirror plane would

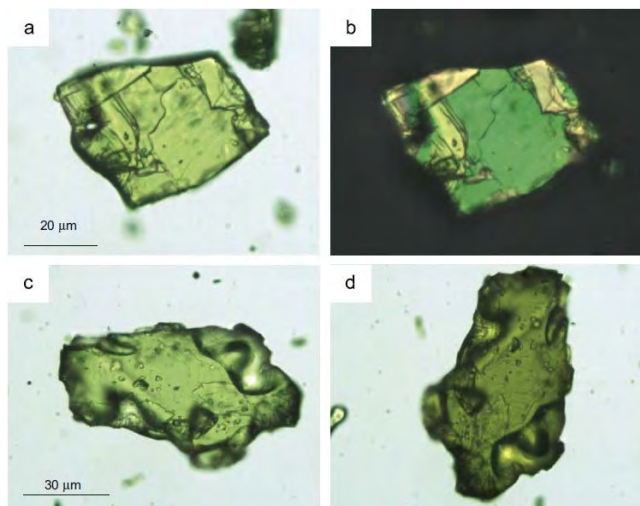


Figure 1. Optical micrographs of CuZrTiO_5 . (a) showing good cleavage, (b) same grain in crossed polars, showing birefringence, (c) and (d) a different grain demonstrating pleochroism.

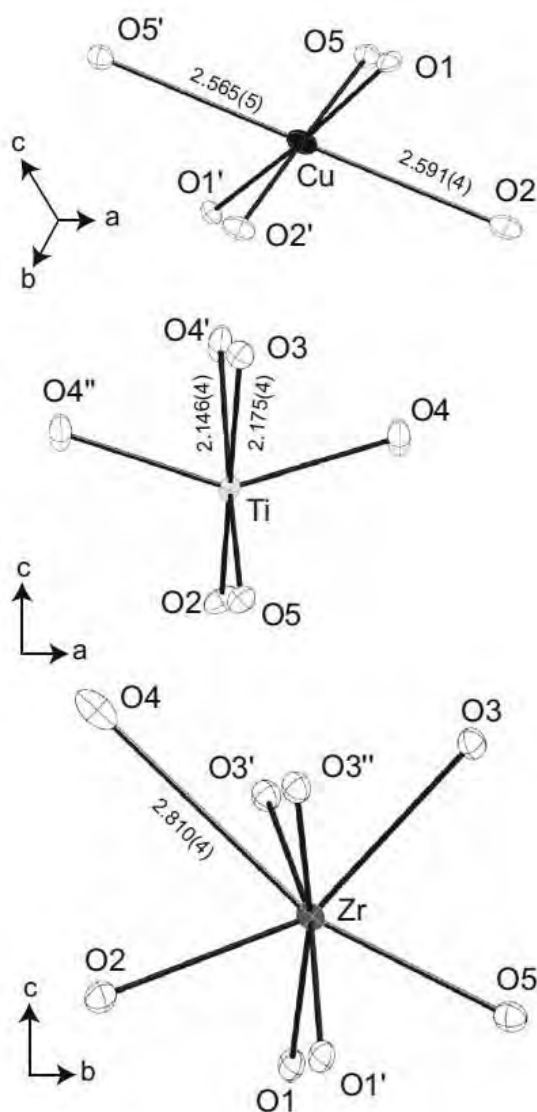


Figure 2. Coordination polyhedra of cations in CuZrTiO_5 , drawn to scale. The longer bond distances are indicated for the 4+2 and 7+1 polyhedra of Cu and Zr respectively.

otherwise require equality between a long and a short bond. Since the Jahn-Teller effect is a breaking of degeneracy of e_g atomic orbitals, it does not intrinsically break local inversion symmetry. Hence, its ability to force the loss of centrosymmetry in the structure as a whole is novel.

Reference:

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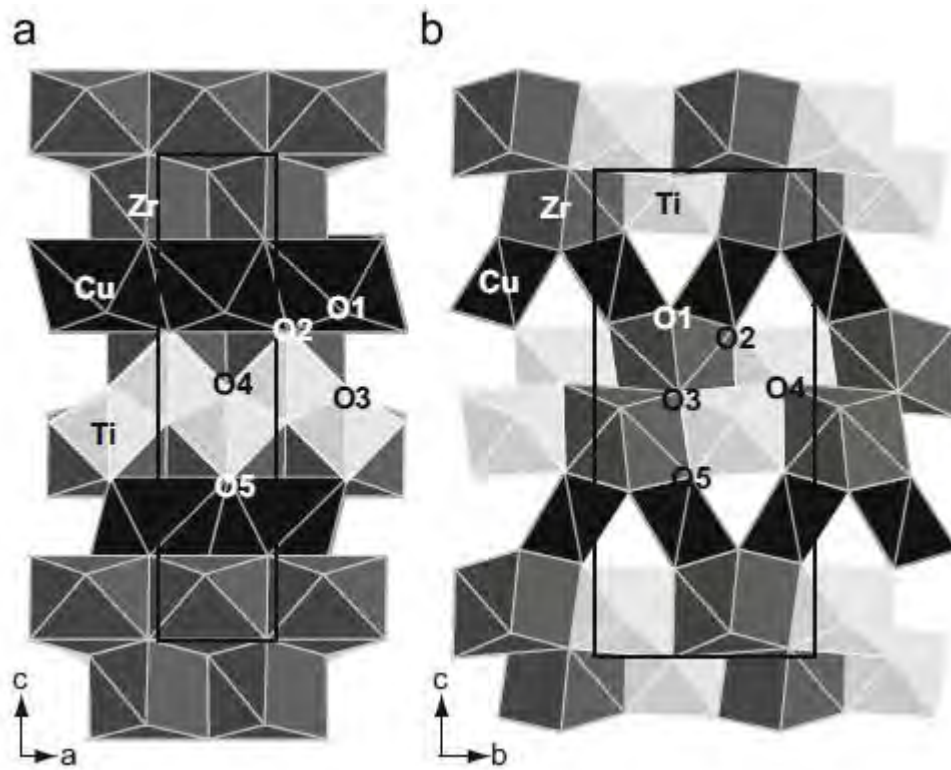


Figure 3. Polyhedral diagrams of the CuZrTiO_5 structure, viewed down a and b directions. Dense (001) layers made up of chains of edge-sharing TiO_6 polyhedra alternate with chains of ZrO_8 running parallel to a . These layers in turn are cross-linked by chains of CuO_4 polyhedra running parallel to b .

Zr-in-rutile thermometry of high-pressure and ultrahigh-pressure eclogites from western China

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The zirconium content of rutile is strongly dependent on temperature, but also on the associated phases in the Zr-Ti-Si-O subsystem (Fig. 1). If the Zr content is buffered by other phases, most likely zircon and quartz, then it is a valuable geothermometer. This is especially so given that while Zr is incorporated into rutile during growth via the simple isovalent substitution of Zr^{4+} for Ti^{4+} , subsequent loss of Zr is impeded if the rutile is enclosed by a phase such as garnet in which Zr is only accommodated by complex, coupled multisite substitutions, leading to a very high blocking temperature.

The larger size of Zr^{4+} relative to Ti^{4+} leads to a significantly larger calculated molar volume for the $\text{ZrO}_{2,\text{Rtl}}$ end member ($22.52 \text{ cm}^3/\text{mol}$ as opposed to $18.80 \text{ cm}^3/\text{mol}$ for $\text{TiO}_{2,\text{Rtl}}$) and a strongly positive ΔV of $+5.94 \text{ cm}^3/\text{mol}$ for the reaction $\text{ZrSiO}_{4,\text{Zrc}} \rightarrow \text{ZrO}_{2,\text{Rtl}} + \text{SiO}_{2,\text{Qtz}}$. From this, we would predict a decrease in activity of $\text{ZrO}_{2,\text{Rtl}}$ by a factor of about 2 for every 1 GPa increase in pressure at 600°C . The experimental study over 1 bar - 3 GPa by Tomkins et al. (2007) verified this pressure dependence, and calibrated it along with the temperature dependence (Fig. 2). Thus, failing to incorporate the pressure effect into the thermometer leads to a temperature error of about 40°C per GPa, and the earlier thermometers of Zack et al. (2004), Watson et al. (2006) and Ferry and Watson (2007), which assume a pressure of about 1 GPa, will systematically underestimate temperature for UHP rocks that equilibrated at pressures near the quartz-coesite transition.

We have studied a range of eclogites from the western Tianshan, north Qiadam and north Qilian regions of western China (Fig. 3), representing both continental (Tianshan) and oceanic (others) subduction zone settings and a range of peak temperatures and pressures. The P - T conditions for these rocks were all well characterised by other methods, and the garnets contained rutile inclusions large enough for Zr analysis by laser ablation ICP-MS. Application of the Tomkins et al. thermometer gave temperatures that were within $30^\circ\text{C} + 1\sigma$ of those obtained using thermometers not based on Zr (Fig. 4), while the other Zr-in-rutile thermometers showed the expected discrepancies.

We further note that:

- (i) In the north Dulan sample, rutiles included in garnet that were large enough for more than one laser spot analysis per grain showed some zonation, with Zr decreasing towards the rim. This indicates that the rutile was not completely homogenised at peak, and some information prograde is retained.
- (ii) Rutiles from near garnet cores had higher Zr than those from nearer the garnet rim. This observation and (i) are consistent with garnet growth along a trajectory with a P - T slope steeper than the Zr isopleths. Both zonation patterns are shown in Fig. 5.
- (iii) In several samples, rutiles that were not included in garnet, in conjunction with T estimates from their local assemblages, gave lower pressures consistent with the retrogression path.

Hence, the Zr-in-rutile thermometer, properly corrected for pressure, can provide information about the

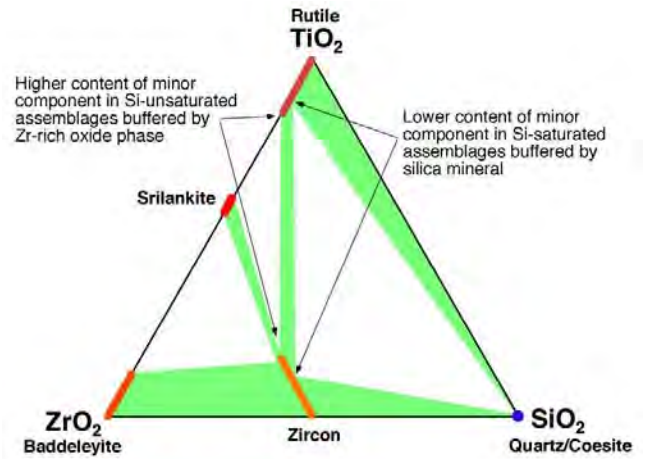


Figure 1. Schematic phase diagram of the ZrO_2 - TiO_2 - SiO_2 triangle.

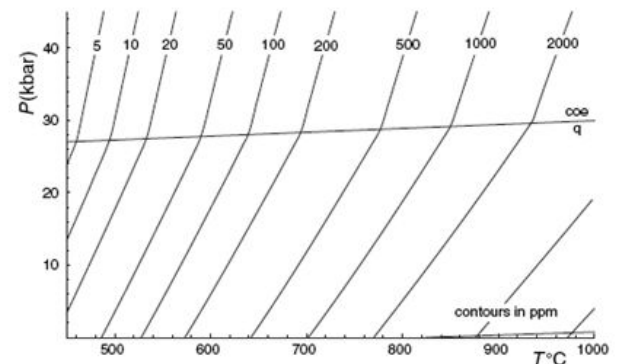


Figure 2. Isopleths of Zr in rutile coexisting with zircon and quartz or coesite, after Tomkins et al. (2007).

full prograde-peak-retrograde path for UHP rocks if some rutiles are included in a Zr-blocking phase such as garnet.

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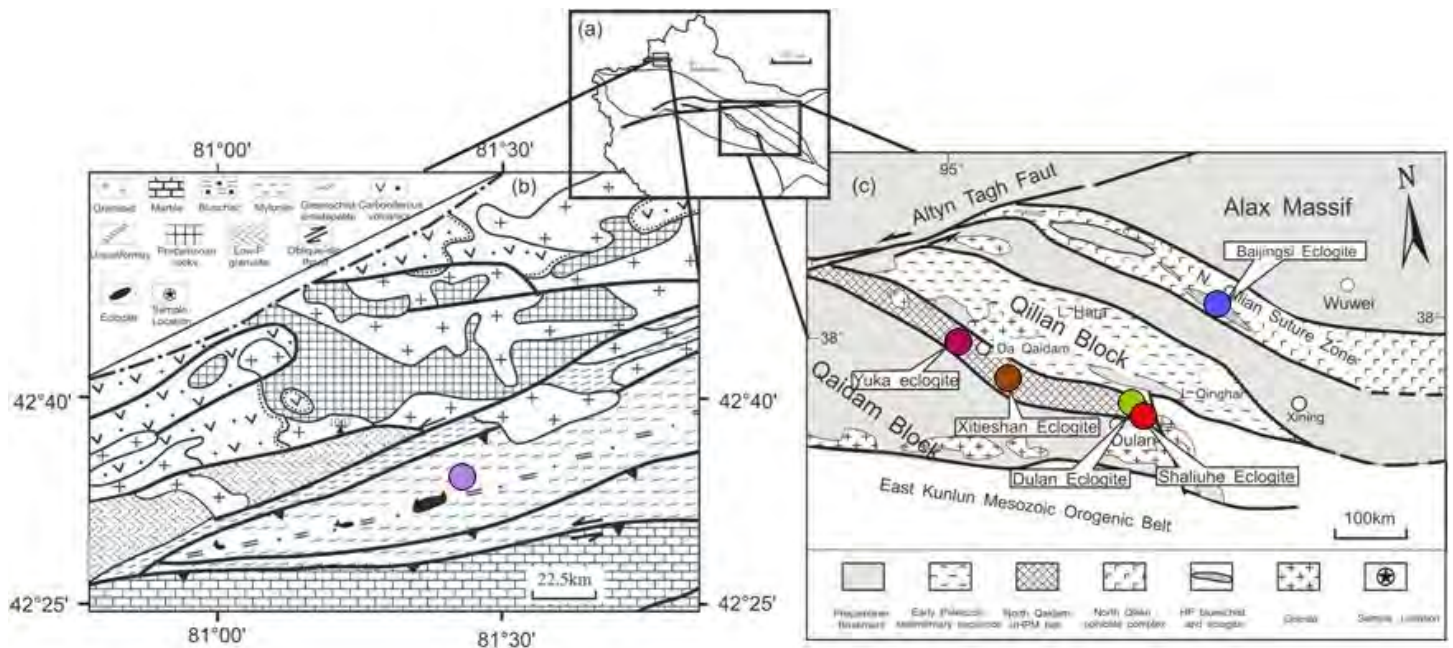


Figure 3. Sample locations for this study.

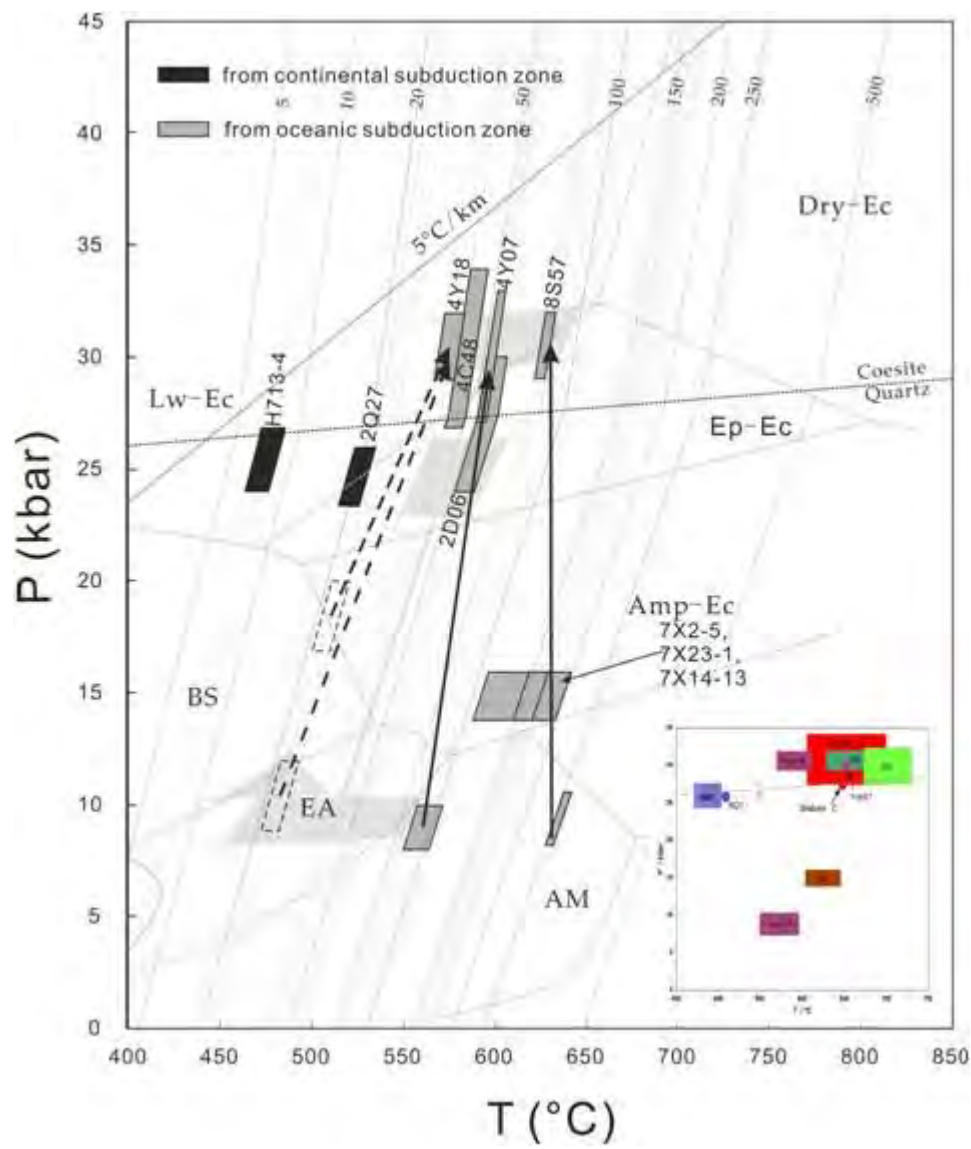


Figure 4. P - T estimates for the rutiles of this study. Inset key shows literature estimates, using the same colour coding as the locality map above.

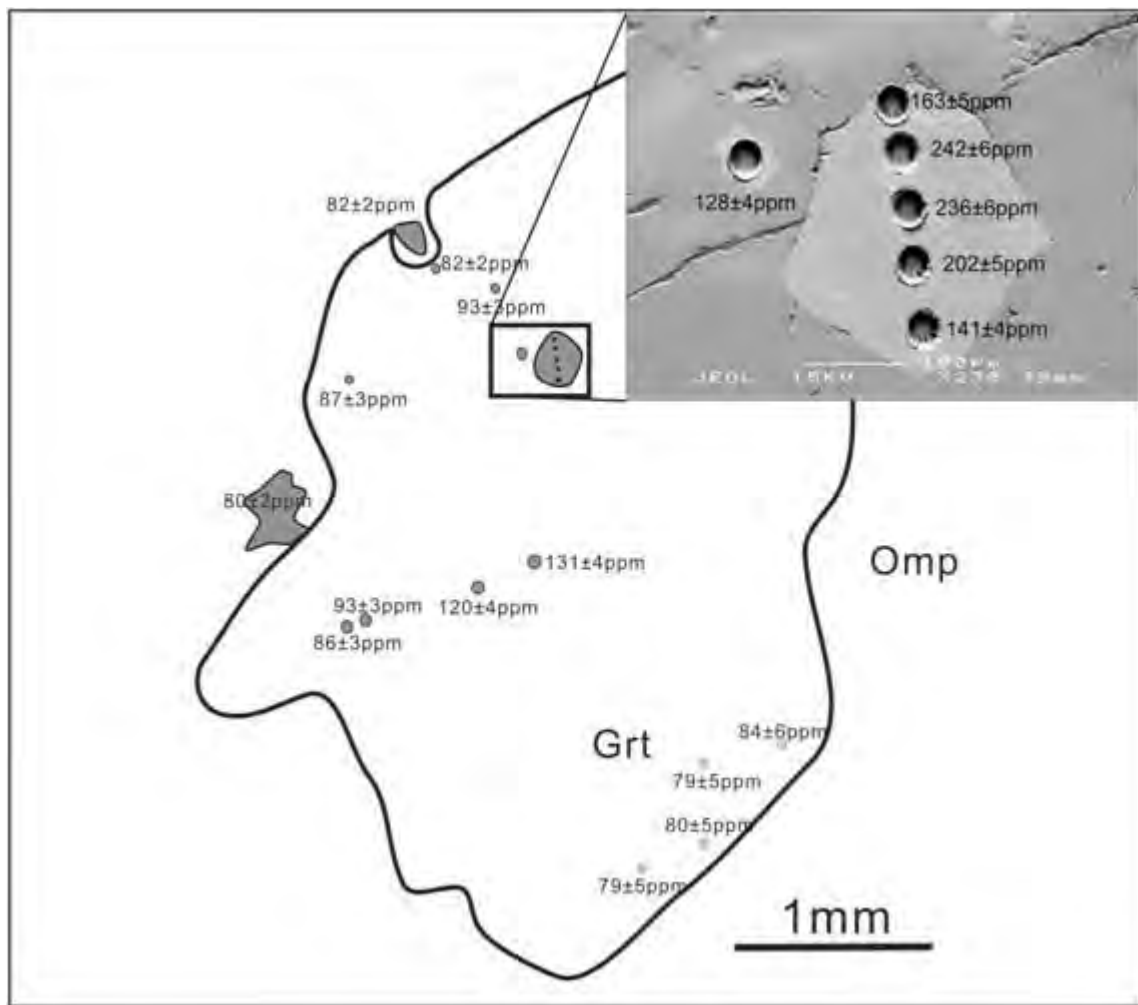


Figure 5. Sketch of distribution of rutile Zr contents in a garnet porphyroblast from north Dulan. Insert shows micrograph of one of the larger rutiles and Zr zonation within rutile. Finewhite lamellae are late ilmenite exsolution.

Major Element Zonation in Garnet from the Wesselton Kimberlite pipe, South Africa

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We are investigating the relationships between metasomatic enrichment processes and changes in redox conditions in the cratonic lithosphere. Analysis of a suite of garnet peridotite xenoliths from the Wesselton kimberlite pipe in South Africa has been performed using the electron microprobe for major elements and laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) for trace elements. Lherzolitic and harzburgitic garnets are present with Cr-pyrope garnet being the dominant type; other phases present include Cr-spinel, Cr-diopside, orthopyroxene and olivine.

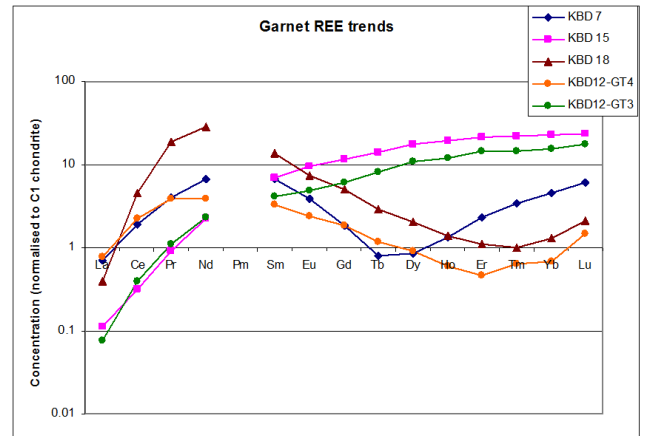


Figure 1. Rare earth element (REE) patterns for some of the garnets from the Wesselton Kimberlite, the two different patterns indicate multiple metasomatic events.

Rare earth element patterns indicate that two different metasomatic events may have affected the Wesselton kimberlite (Figure 1). The 'sinusoidal' patterns correspond to harzburgitic (low $\text{CaO}/\text{Cr}_2\text{O}_3$) garnets whilst the 'normal' patterns are observed for lherzolitic (higher $\text{CaO}/\text{Cr}_2\text{O}_3$) garnets. Cr-rich clinopyroxene (diopside) was found in association with most of the lherzolitic garnet samples. Symplectitic alteration rims are also present on most of the garnets.

One garnet sample (KBD12-GT4) was found to have a harzburgitic core and a lherzolitic rim with the concentrations of Mg, Fe, Ca, Ti, and Cr all changing; the distribution of Mg, Fe and Ca was mapped using the electron microprobe (Figure 2). This suggests that a harzburgitic precursor lithology was metasomatised to lherzolite by a Ca-enriched agent, as previously suggested by Griffin et al. (1999). Microprobe data suggests that the rim is relatively enriched in Fe^{3+} compared with the core, consistent with oxidation during metasomatism, as was previously observed by McCammon et al (2001).

Further work will be performed on this sample, including Fe K-edge X-ray Absorption Near-Edge Structure (XANES) spectroscopy, a synchrotron based technique to determine Fe^{3+}/Fe (Berry et al. 2010) and to map the Fe^{3+} distribution across the grain, as well as trace element mapping. Initial Ni in garnet geothermobarometry (Canil 1994; Ryan et al. 1996) indicates that the outer rim formed at a higher temperature than the core whilst the XANES measurements will help establish the change in oxygen fugacity ($f\text{O}_2$) during metasomatism.

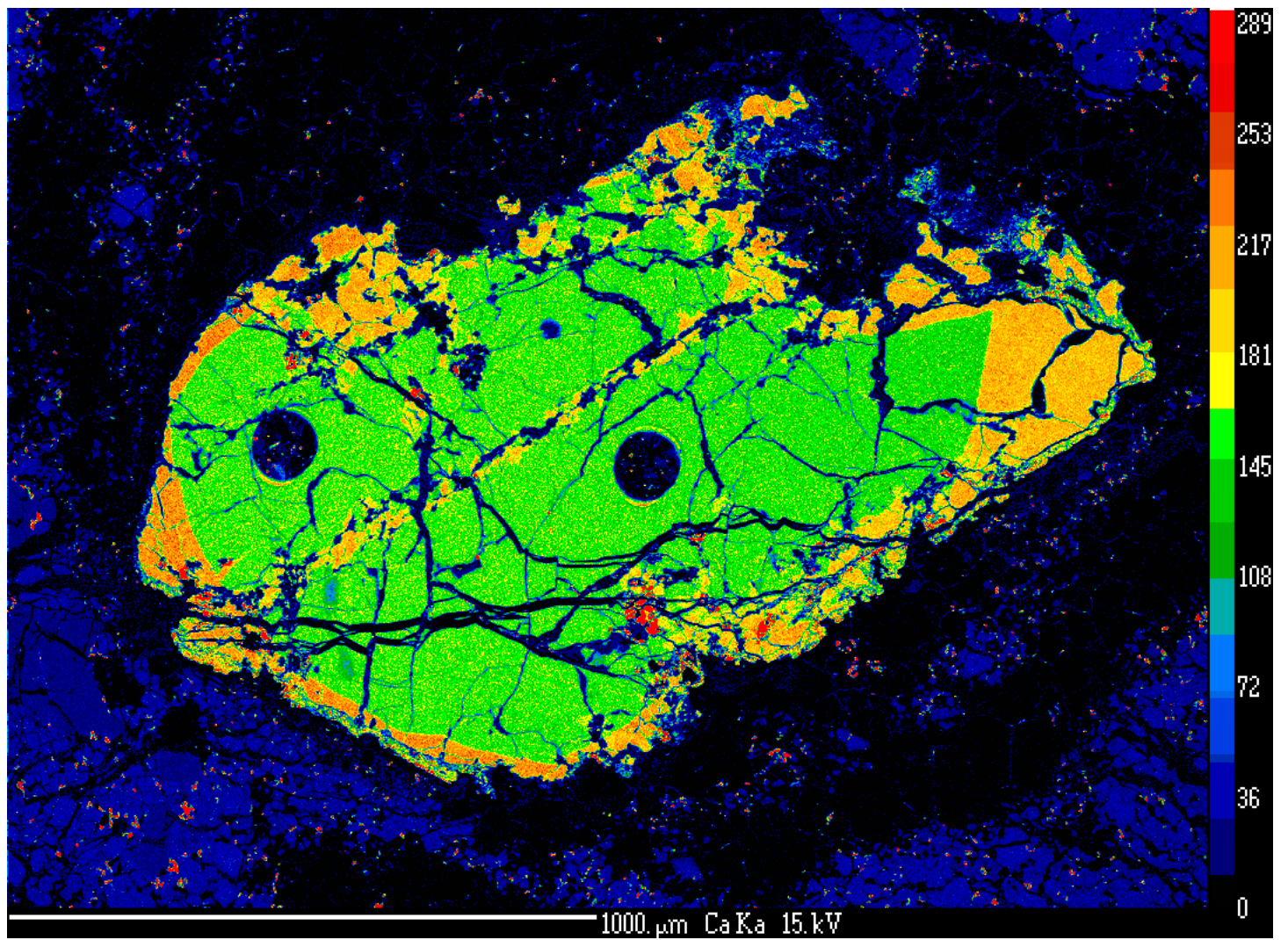


Figure 2. Ca X-ray map of garnet KBD12-GT4 produced using the electron microprobe at a resolution of 2µm. Th black circles are laser ablation pits, the background is mainly olivine.

Continent Formation in the Archean and Chemical Evolution of the Subcratonic Lithospheric Mantle

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Despite indirect evidence for the presence of continental crust on the Earth at ~ 4.2 – 4.4 Ga (e.g., Hadean zircons), no granitoid rocks older than ~ 4.0 Ga survive, and so the question of when and how Earth's first true continents formed remains a matter for continued speculation and debate. Archean cratons, the nuclei for the continents, have been attached to deep roots or 'keels' in the cratonic lithosphere since their initial formation more than 3.0 Ga ago. The physical and temporal juxtaposition of the oldest preserved granitoid rocks with old, cold roots extending deep into the underlying subcratonic lithospheric mantle (SCLM) implies a coeval evolutionary history; preservation of this oldest continental crust may in fact be contingent upon the development of these deep roots in the cratonic lithosphere. Understanding the genetic relationship between Archean continental crust and the SCLM may therefore be crucial to understanding how physically and chemically stable continental nuclei (cratons) formed on Earth.

The vast majority of continental crust of early to mid-Archean age (~ 3.8 – 3.0 Ga) is composed of granitoids of the TTG (tonalite-trondhjemite-granodiorite) suite of plutonic rocks. A number of experimental studies have shown that the chemical compositions of TTG granitoids are consistent with an origin by low to moderate degrees of dehydration melting of garnet-bearing metabasalt (garnet amphibolite-eclogite). A survey of all Archean granitoids in terms of a simple geochemical parameter, the Mg-number (defined as the molar ratio of $[\text{Mg}/(\text{Mg} + \text{Fe})]$, which in the present context reflects the extent of direct mantle contributions to granitoid petrogenesis), shows that Archean granitoids with Mg-numbers greater than ~ 0.50 are relatively rare in the rock record prior to ~ 3.5 Ga, but become increasingly more common between 3.5 and 3.0 Ga (Fig. 1). By 3.0 Ga, late- to post-tectonic granitoids of the sanukitoid suite (Shirey & Hanson, 1984; Stern & Hanson, 1991), with Mg-numbers of ~ 0.55 and above, have become prevalent. The compositional transition in granitoid magmatism c. 3.0 Ga represents the establishment of a clear genetic link between rocks of the silica-rich continental crust and ultra-mafic rocks of the SCLM. In this study, this relationship is considered from two perspectives: first, the nature of the reaction between TTG liquids and peridotitic (cratonic) mantle and its effect on the composition of the hybridized melt; second, the role of TTG melts as metasomatic agents within the cratonic lithosphere. Our focus is on reactions between TTG-sanukitoid melts and mantle peridotite in the juvenile root zones of a maturing Archean craton.

A series of multi-anvil experiments were conducted at 3–4 GPa in which "pristine" TTG melts react with mantle peridotite over a range of pressure, temperature, and melt:rock (TTG:peridotite) ratios. The resulting "mantle-hybridized" melts and residual crystalline reaction assemblages have been fully characterized for major- and trace-elements using electron probe microanalysis (EPMA) and laser-ablation ICP-MS, respectively. Our experimental results demonstrate that liquids similar to typically late- to post-tectonic sanukitoid intrusions can form by hybridization of initial TTG melts by assimilation of olivine-bearing peridotite, and that these primitive granitoid melts are in equilibrium with reaction residues consisting of olivine-free garnet websterite or garnet pyroxenite (Fig. 2). The experimental melts retain the distinctive trace element signature of TTGs, overprinted by a 'primitive' mantle signature (i.e.

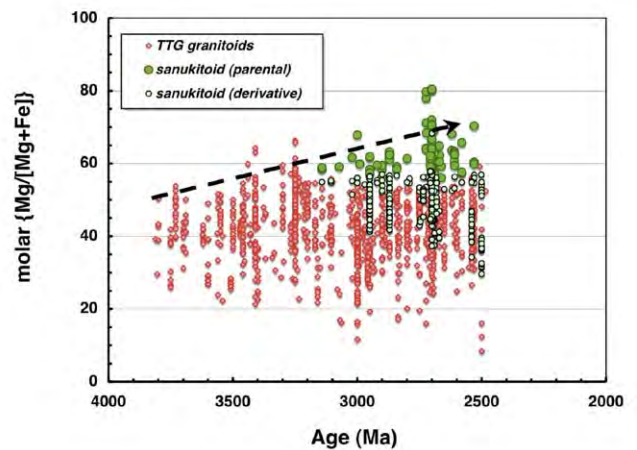


Figure 1. Mg-number vs age for Archean granitoids, including tonalite-trondhjemite-granodiorites (TTG), 'parental' sanukitoids with Mg-numbers 40–58, and 'derivative' sanukitoid suite granitoids formed by crystallization differentiation of 'parental' sanukitoids.

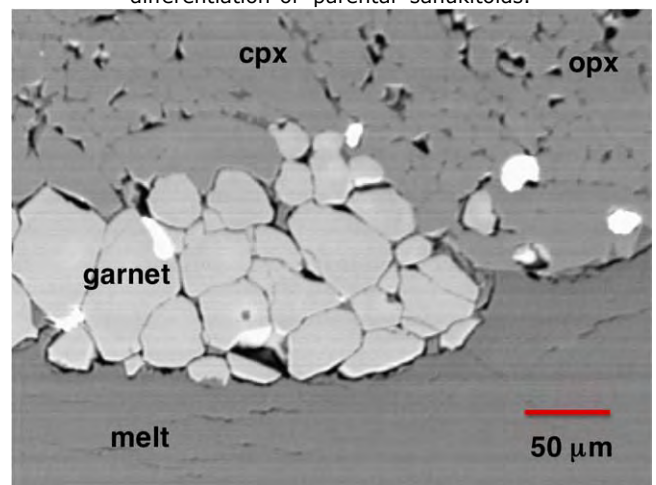


Figure 2. Backscattered-electron photomicrograph of experimental phase assemblage at 3.5 GPa, 1200°C, showing "mantle-hybridized" TTG melt ("sanukitoid") coexisting with garnet-websterite reaction residue (opx=orthopyroxene; cpx=clinopyroxene).

high Mg-number, elevated Cr and Ni abundances), whereas the various phases of the crystalline residues acquire trace element signatures reflecting equilibration with Mg-rich granitoid melts. At low melt:rock ratios, metasomatism by TTG melts may be responsible for the silica enrichment and high modal orthopyroxene content of some cratonic peridotites and cryptic trace element overprints in garnet, clinopyroxene, and orthopyroxene. Our results demonstrate that the lithospheric keel of Archean cratons represents the product of reaction between TTG melts and previously depleted mantle peridotite at relatively low melt:rock ratios, as evidenced by the trace element signature in garnet pyroxenite and orthopyroxene-enriched garnet peridotite xenoliths, whereas Late Archean sanukitoids represent the products of these same reactions at relatively high melt:rock ratios.

Journal Article:

<http://petrology.oxfordjournals.org/cgi/reprint/51/6/1237.pdf>

Rubidium isotopes constrain the Earth's volatile budget and its Pb isotope evolution

Figure 1.

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In a model with a C1-meteorite composition of the bulk Earth, the bulk silicate Earth (BSE) exhibits a substantial deficit in volatile elements. This deficit is considered to be the cause of volatile loss of a Proto-Earth in an early stage of our planet's evolution, possibly related to a putative Moon-forming Giant impact. This interpretation is predominantly based on observations of progressive volatile depletion trend of the BSE relative to C1 chondrites with decreasing half-condensation temperatures of the elements. This trend is often referred to as the Earth's volatile depletion trend. A complication of a simple volatile depletion is further introduced by the siderophile and chalcophile behaviour of some volatile elements such that a volatile-loss from the Earth in the aftermath of core formation was accompanied by previous core storage of these elements. As a consequence, absolute constraints on the timing and degree of volatile loss remain elusive. A prominent example for this complication is the Pb deficit of the BSE, where the timing and degree of Pb depletion strongly influences absolute age information on the Earth obtained from the U-Th-Pb isotope decay system.

An ultimate test for volatile depletion in a high energetic event is the analyses of isotope distributions of elements that are lithophile and moderately volatile, making them independent to core formation but susceptible for evaporation during planetary collisions. High energy impact events can be considered to have caused substantial isotope fractionation, which acts as a 'smoking gun' for one or more giant impacts that were accompanied by volatile loss. In order to test the volatile-loss theory and to constrain the Pb isotope evolution of the early Earth, we analysed the Rb isotope composition in primitive meteorites. Rubidium is a semi-volatile element that was not affected by core formation and has a half condensation temperature that is close to that of Pb. The Rb isotope composition of 17 primitive meteorites was analysed by MC-ICP-MS using Zr and standard-sample bracketing for mass bias correction, yielding a reproducibility of ± 0.2 per mill on the $^{87}\text{Rb}/^{85}\text{Rb}$. Small variations in the stable isotope composition of Rb between the analysed early solar system objects and the Earth in the order of 1 per mill are far too small to account for impact driven volatile loss, and argue for a pre-accretionary volatile depletion history. It is suggested here that the Earth was accreted from almost volatile free material with a later gain of volatiles prior to a Moon forming event. Mass balancing with a 90% depleted Proto-Earth (Wänke & Dreibus, 1988) and gain of $\sim 10\%$ C1-like material at a time after core-mantle equilibrium was achieved can account for the Rb isotope distribution and abundance in the present day BSE. In analogue, the Pb concentration of the BSE requires an additional Pb depletion event, probably by protracted core formation in the aftermath of a Giant impact (Wood & Halliday, 2005, 2010). This model is consistent with the Pb isotope evolution of the BSE with a final $\mu=9$ and places the secondary Pb loss event at ~ 110 Myrs after start of the solar system.

Reference:

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A new synchrotron-technique for measuring Fe³⁺ in mantle garnets – implications for diamond stability in cratonic lithosphere

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The synchrotron-based spectroscopic technique **X-ray Absorption Near Edge Structure (XANES)** spectroscopy has been applied previously to the determination of abundances of elements present in multiple oxidation states in natural volcanic glasses and in some minerals. We have developed a new empirical Fe K-edge XANES technique specifically for determining Fe³⁺/Fe in mantle garnets. Our technique uses the intensity ratios of certain spectral features for a series of natural garnet standards (with Fe³⁺ abundance previously determined from Mössbauer Spectroscopy). Fe³⁺ determinations can be made with precision similar to that of the standard technique Mössbauer Spectroscopy.

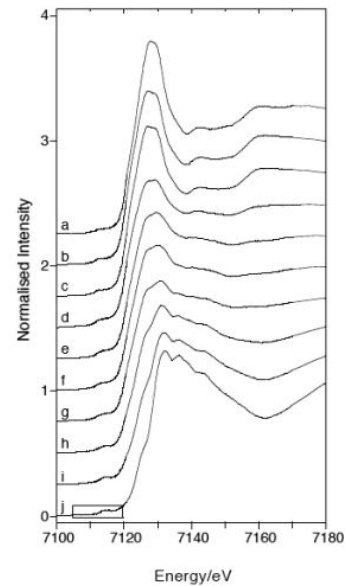


Figure 1. Figure 1: Representative Fe K-edge XANES spectra, recorded at the Australian National Beamline Facility, Photon Factory, Tsukuba, Japan. These spectra are mostly from a series of synthetic garnets with Fe³⁺/Fe increasing from b to j. Spectrum a was taken from a natural mantle garnet.

The main previous technique is Mössbauer Spectroscopy. This is essentially a bulk technique with no or poor spatial resolution and data acquisition times of days to weeks. The principle advantages of the new XANES technique over Mössbauer Spectroscopy or other techniques are that measurements can be made in air, on a polished section, with better than 3 µm spatial resolution, with acquisition time of a few minutes and with the possibility of grain scale Fe³⁺ mapping.

Fe is the most common element in the Earth that exhibits a variable oxidation state, occurring as both Fe²⁺ and Fe³⁺ in minerals and melts. The Fe³⁺/Fe ratio of geological samples can be used as an indicator of the redox conditions (oxygen fugacity = fO_2) at which the samples equilibrated. Knowledge of lithospheric redox conditions is extremely important as fO_2 controls the speciation of CHO-fluids, which in turn can profoundly influence the nature of partial melting of the mantle, and other processes. In addition, fO_2 is an important control on diamond stability relative to carbonate.

Garnet peridotite is the dominant rock-type in the cratonic lithosphere, the relatively cold and brittle upper mantle beneath ancient stable regions of continental crust. It can be accessed because fragments of lithospheric material (xenoliths) are occasionally accidentally entrained in and transported to the surface by deep-seated magmas such as kimberlites. Garnets in peridotite xenoliths contain Fe in both oxidation states and their Fe³⁺/Fe ratios record the fO_2 in the lithosphere. In conjunction with determinations of pressure and temperature of origin of the rocks using calibrated mineral geothermometers and geobarometers, this allows the mantle's fO_2 to be profiled as a function of depth. For depths >150km, corresponding to pressures greater than the graphite to diamond transition, the mantle's fO_2 is sufficiently reduced for diamond to be stable. However, post diamond formation metasomatic enrichment processes may impose significantly higher fO_2 s leading to diamond breakdown or resorption. Because kimberlites sample potentially diamondiferous lithosphere, and transport diamonds

to the surface, this new technique may have important applications in diamond exploration and targeting of particular kimberlites for expensive bulk sampling to determine diamond grade.



Figure 2. Figure 2: Photomicrograph of a thin section of a garnet lherzolite xenolith from a kimberlite at the Diavik Diamond Mine, northern Canada. The xenolith is about 5 cm across. Redox conditions in the lithosphere represented by this sample are recorded by the Fe^{3+}/Fe ratio of the pink garnets.

White mica $^{40}\text{Ar}/^{39}\text{Ar}$ data - the key to the thermal evolution of faults

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A new method has been developed and applied for deriving not only time constraints but also other physical properties of an extensional fault in the Central European Alps from high quality white mica $^{40}\text{Ar}/^{39}\text{Ar}$ data.

Extensional structures, such as low angle detachment faults or high angle normal faults, are responsible for major changes to the thermal structure of the affected lithosphere. This is mainly caused by the exhumation of hotter rocks from lower parts of the crust and its juxtaposition against cooler rocks from the upper crust and/or melt formation initiated by a pressure drop during extension related crustal thinning and subsequent melt migration through the crust. Timing, duration and extent of these thermal disturbances is of major importance for the reconstruction of any geological system that involves extensional episodes during its evolution.

High quality $^{40}\text{Ar}/^{39}\text{Ar}$ data was gained in the argon laboratory of the RSES from different microstructurally controlled white mica samples (Figure 1) that were collected next to (<50 m) the fault line of the Forcola fault in the Central European Alps. This data was used to model the thermal history of the samples and with it the thermal evolution of the fault. The latest release of the MacArgon software

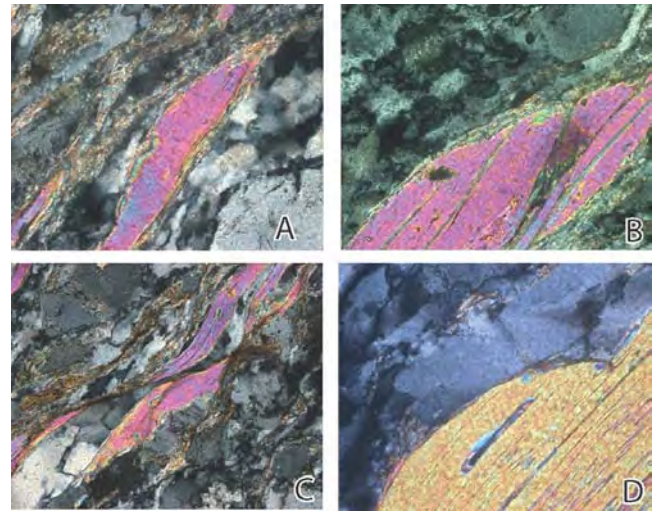


Figure 1. White micas from the footwall (A, B and C) and the hanging wall (D) of the fault. Note the difference in grain boundary shape and absence of fine grained micas in the hanging wall sample. Picture widths: A, B and D = 0.33 mm; C = 0.66 mm.

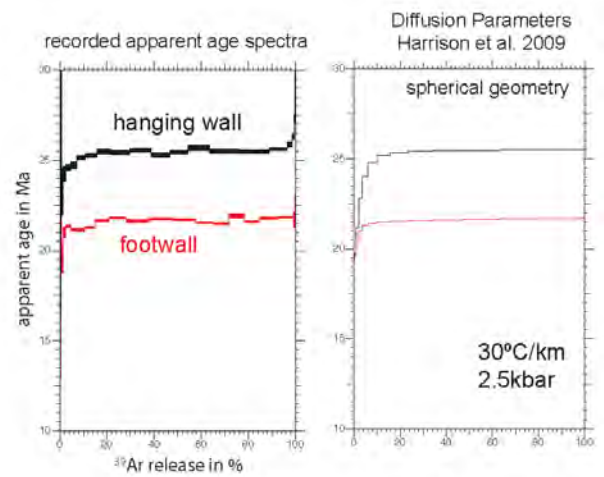


Figure 2. Recorded apparent age spectra from the Forcola fault in the Central European Alps (left) and modelling results from MacArgon software's MacSpectrometer (right) with the best fit parameters for fault depth (i.e. depth of hanging wall sample) and ambient geothermal gradient.

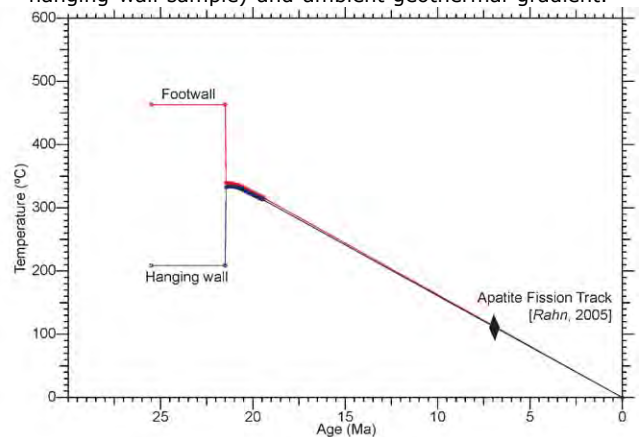


Figure 3. Temperature time path for the best fit model from a new release of the MacArgon software. Time path commences at the oldest age recorded in the hanging wall, fault movement for this model is set to be instantaneous at the main age recorded in the footwall, exhumation starts at the youngest age recorded in the footwall.

(<http://rses.anu.edu.au/tectonics/programs/MacArgon/index.php>) was utilised to reconstruct a temperature-time path for rocks from the fault's hanging- and footwall, starting before presumed fault

activity and ending with the joint exhumation of hanging- and footwall (Figure 2 & 3).

Modelling results show that high quality white mica $^{40}\text{Ar}/^{39}\text{Ar}$ data can be used to determine parameters such as timing of fault activity, fault depth and ambient geothermal gradient. Experiments with different argon diffusion parameters for white mica (Figure 4) resulted in only minor variations in the derived fault parameters (2 °C difference in ambient geothermal gradient and 0.2 kbar difference in fault depth). These small variations between results gained with published white mica diffusion parameters (Harrison et al., 2009) and diffusion parameters deduced directly from our $^{40}\text{Ar}/^{39}\text{Ar}$ data (after principles described by Forster and Lister, 2010) emphasise the reliability and practicability of this new method. Hence, $^{40}\text{Ar}/^{39}\text{Ar}$ data from white mica provides not only time constraints for cooling or recrystallisation events, but can, combined with diffusion modelling, high quality furnace step heating and detailed microstructural work, also help in resolving complex thermal events as they occur in (syn-orogenic) extensional systems.

The next step of our research will be focused on investigating the effects of multi-domain diffusion on the gained results and on the improvement of the relatively simple model for fault activity.

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Latest release of the MacArgon diffusion modelling software that was used for the presented work.
<http://rses.anu.edu.au/tectonics/programs/MacArgon/index.php>

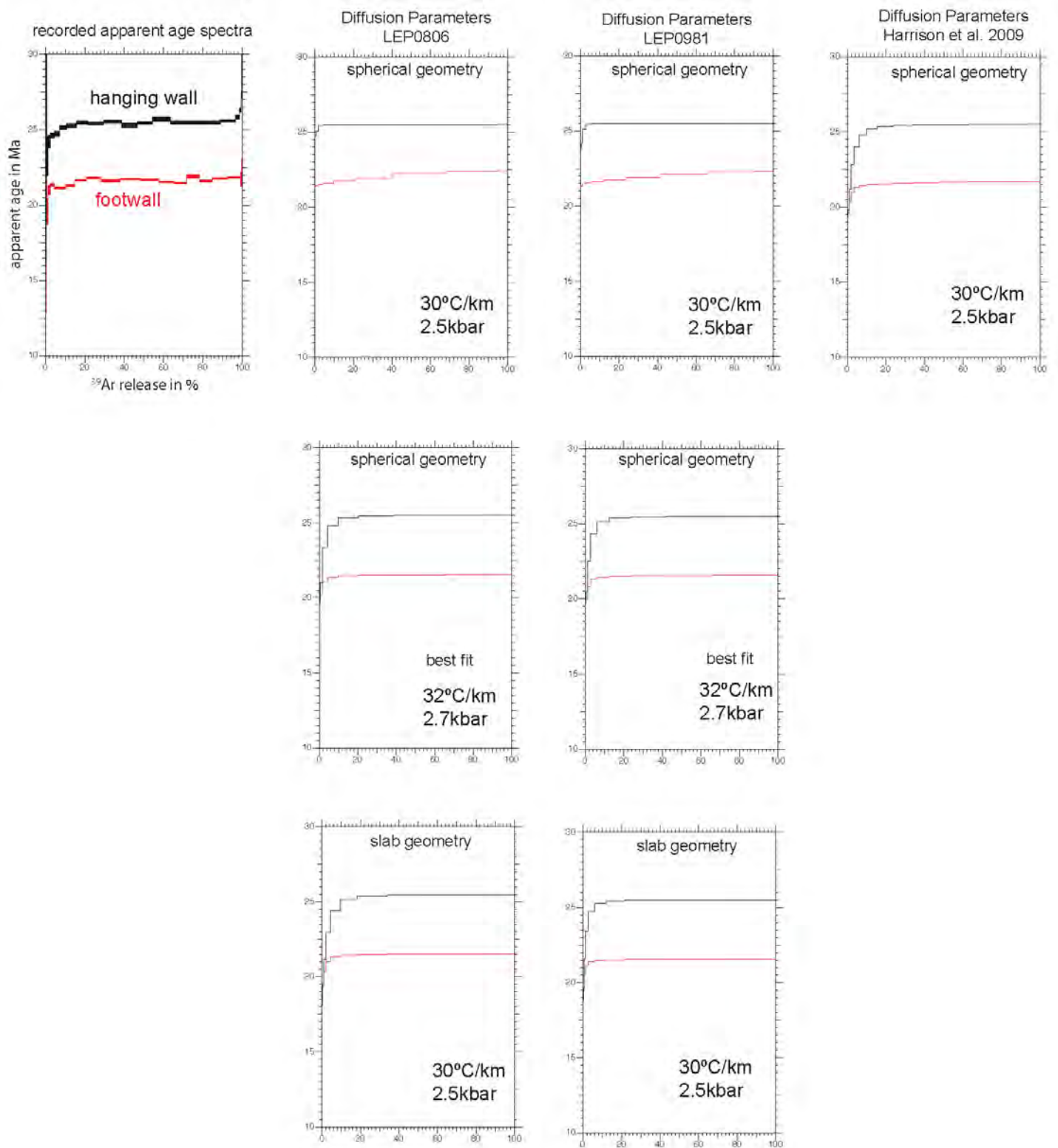


Figure 4. Comparison of results gained with different diffusion parameters and different diffusion domain geometries. Please note the small variation in modelled fault depth (kbar) and ambient geothermal gradient despite the changes in diffusion parameters.

Geodynamics of the New Britain Trench

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We have utilised the Pplates application (written by the Structure/Tectonics team at RSES) to develop an updated tectonic model and plate motion database for the Melanesian region. We have used published kinematic data in conjunction with constraints provided by the extent of seismic activity associated with subducted lithosphere. This model is analysed within various reference frames in an attempt to constrain the elaborate interplay between the numerous microplates that characterise the region. We also consider how the kinematics of the region has influenced subduction hinge migration, development, and the subsequent morphology of subducted lithosphere.

We propose that the evolution of the New Britain Trench is one characterised by trench advance, which in turn implies that subduction at the North Solomon Trench is likely to have operated under trench retreat. The currently observed retreat at the New Britain Trench has only recently commenced, concurrent with arc-continent collision in New Guinea and the initiation of collision between the Ontong Java Plateau and the Solomon Islands Arc. Such trench dynamics appear to be reflected in the structural evolution of associated subducted lithosphere, an observation most apparent in the spatiotemporal correlation between New Britain Trench advance and the high slab dips exhibited by subducted Solomon Sea lithosphere.

Home page for the Structure Tectonics Team

<http://rses.anu.edu.au/tectonics/>

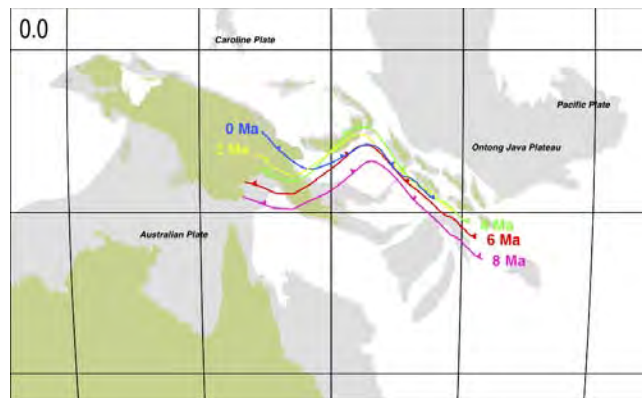


Figure 1. Inferred location of the New Britain subduction zone from 8 Ma to Present created with the Pplates application. Subduction zone location for distinct times is indicated by the blue, yellow, green, red and pink lines, with numbers indicating time in Ma. The model depicted here is referenced within the Pacific hotspot frame of Wessel et al. (2006).

A deformable tectonic reconstruction of Australia's Southern Margin

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Until recently, tectonic reconstructions have been limited by (1) the assumption that tectonic plates do not deform, or (2) the inability of software packages to simulate deformation. The assumption that plates do not deform is based on the earliest ideas about plate tectonics. This assumption has led workers dealing with plate tectonic reconstructions to introduce new micro-plates to explain the inconsistencies observed in different plate circuits (e.g. the Somalian plate). However, we now know from GPS and geophysical datasets that both the oceanic and continental crust deform. Therefore, tectonic reconstructions must begin to address this point, without the need to invoke more and more micro-plates to resolve inconsistencies in rigid plate circuits.

Up until recently there was no tectonic reconstruction software available to simulate plate deformation. However, the Pplates application (written by the Structure/Tectonics team at RSES) addresses this issue. Pplates is a freeware tectonic reconstruction package that allows geologists to build both classical (rigid) plate reconstructions as well as deformable plate reconstructions. To do this, the software uses one or several meshes to move data back and forth in time. Each of these meshes can be deformed in order to simulate deformation of the crust.

Pplates was therefore used to build a deformable reconstruction of the sedimentary basins along Australia's southern margin, as Gondwana supercontinent fractured into the Australian and Antarctic plates (see an animation of this by clicking on the link below). This reconstruction shows that some of the misfits between the Australian and Antarctic plates that are predicted in traditional rigid-plate reconstructions can be reduced after accounting for crustal extension (Figure 1). The ability to simulate extensional deformation associated with continental break-up has implications for both global tectonic reconstructions as well as reconstructions of individual sedimentary basins.

An animation of the reconstruction of Australia's southern margin

<http://rses.anu.edu.au/tectonics/projects/p-plates/examples/Aus-Ant/>

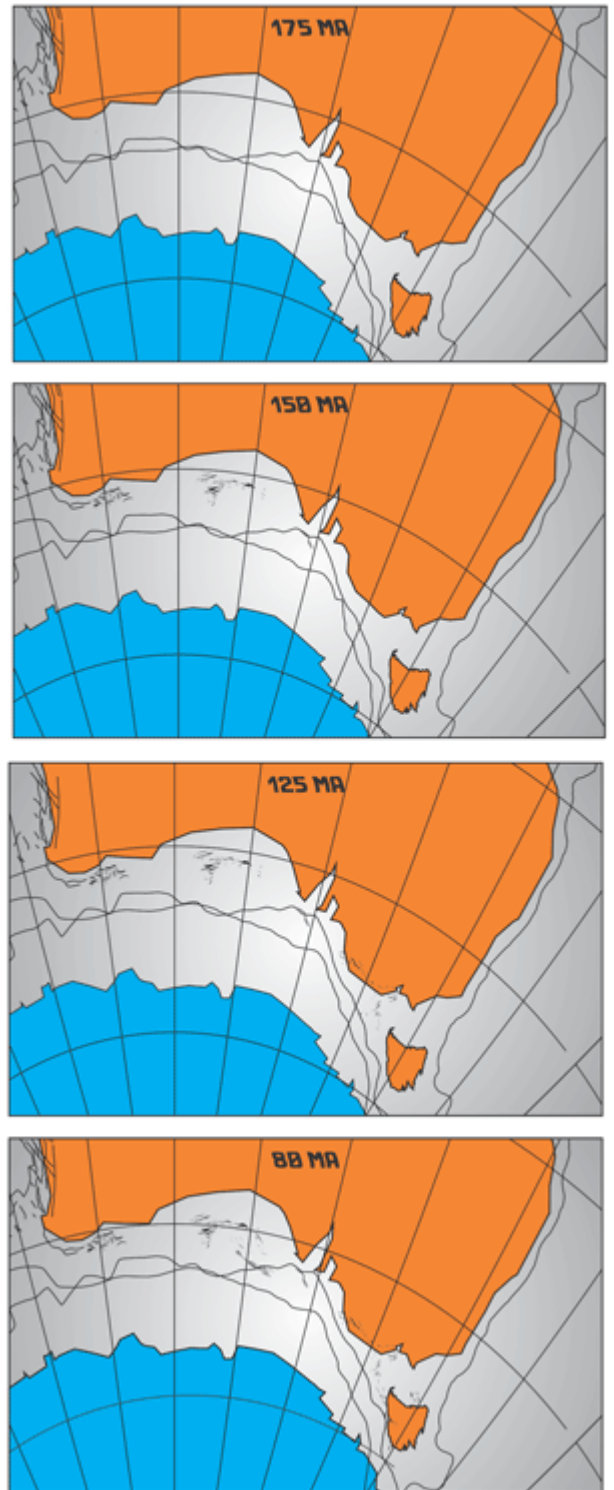


Figure 1. A sequence of snapshots of the early rifting and eventual break up of the Australian and Antarctic plates. The amount of deformation looks negligible at this scale. However, this deformation modifies the shape and extent of the Australian continental-oceanic boundary (COB). This modification is relevant to previously published rigid plate reconstructions that try to fit the outline of the continents together.

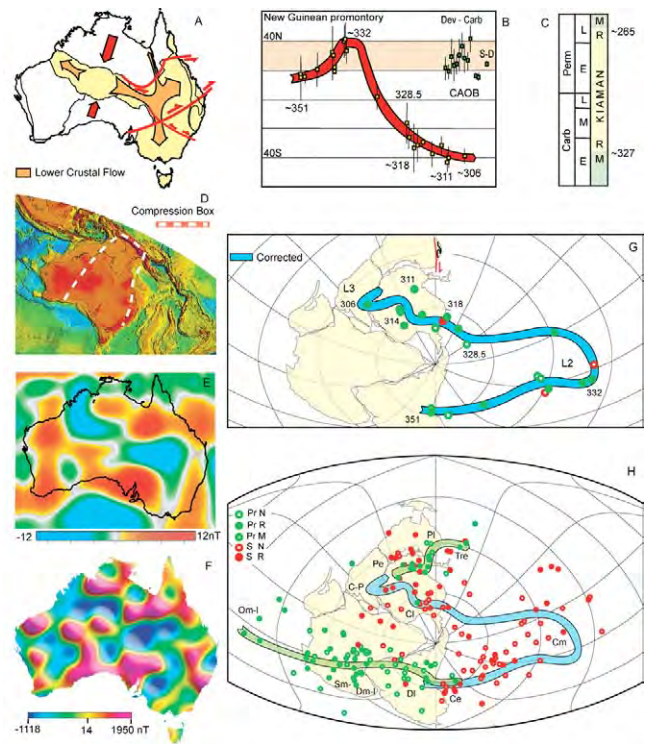
Pervasive remagnetisation of Australian crust: Variscan tectonic extrusion

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The Middle-Late Paleozoic pole path for Gondwana is crucial for Pangea reconstructions, yet its shape is enigmatic. Australian paleomagnetic poles feature prominently in Gondwana pole paths. However, the primary or overprint origin of poles for many Australian Middle-Late Paleozoic rocks is disputed. This has led to two opposing Middle-Late Paleozoic pole paths for Australia. Most Australian paleomagnetists tend to support the established SLP path over the alternative KG path. The two pole path alternatives are largely based on the same poles, but different interpretations for the age of remanence acquisition, primary or overprint, have widely different implications for global reconstructions. The SLP path implies persistence of a substantial latitudinal gap between north-western Gondwana and southern Laurentia till Late Carboniferous, whereas the KG path implies Early Carboniferous convergence and collision of north-eastern Gondwana with southern Laurasia. The former implication contradicts geological evidence for Late Devonian-Early Carboniferous tectonism in western Pangea, whereas the latter implication questions prevalent global reconstructions showing an eastward open "Paleotethys" in eastern Pangea prior to Late Carboniferous.

A solution to the controversy may come from a new Carboniferous pole path for the Southern New England Orogen (SNEO) (Fig. 1G). This path is based mainly on ignimbritic volcanics. Their deuteric oxidation gives them superior prospects over most lithologies to retain a primary magnetisation under pervasive overprinting conditions. The SNEO path conforms at large to the Carboniferous segment of the KG path for cratonic Australia and represents a substantial refinement. The SNEO path details an extensive Early Carboniferous northwards excursion that brought the central New Guinean promontory of the Australian craton at moderate northern paleolatitudes, overlapping with the western Central Asian Orogenic Belt (CAOB) (Fig. 1B). The excursion ends at the middle-late Visean, Sudetic, peak of the Variscan Orogeny, just prior to the long Kiaman interval of continuous reverse polarity of the earth's magnetic field (Fig.1C). Implications of the northward excursion for Devonian-Carboniferous convergence and collision of Australia with the CAOB, confinement of collision-related deformation within a "compression box" behind the central New Guinean promontory (Fig. 1D), and Alice Springs Orogeny-related tectonic extrusion (Fig.1A), have been summarized in contributions to previous RSES Annual Reports (2008, 2009). The contributions describe widespread Kiaman reverse polarity remagnetisation of Australian deeper crust as expressed in satellite (Fig. 1E) and aeromagnetic (Fig.1F) maps. Collision-related tectonic extrusion ended at the start of the Kiaman (Permo-Carboniferous Reverse Superchron, ~327-265 Ma), and tectonic extrusion-affected deeper crust thus began to cool down at the start of a ~60 million year period of reverse polarity. This led the deeper crust to acquire a reverse polarity remagnetisation component that characterises the Larapintine Graben and the interior Tasman Orogenic System (Fig. 1E, F).



(Figure 1 Klootwijk RSES AR 2010)

Figure 1. A) Tectonic extrusion model. B) Overlapping paleolatitudes for the cratonic promontory of central New Guinea (Early Carboniferous) and the western Central Asian Orogenic Belt (Devonian-Carboniferous). C) Approximate duration of the Kiaman (Permo-Carboniferous Reverse Superchron). D) Outline of "compression box" containing Alice Springs Orogeny-related compressional deformation. E) Lithospheric magnetic anomaly pattern at 400 km altitude (Sabaka et al. 2004). F) Long wavelength component of aeromagnetic anomaly map (Milligan & Franklin 2004, courtesy Peter Milligan [Geoscience Australia] 2008). G) Carboniferous pole path for the Southern New England Orogen (SNEO), corrected for 500 km northward displacement relative to the Australian craton leading to the Texas and Coffs Harbour Oroclines. L2= apex (~330 Ma) of pole path loop related to Australia-Asia collision. L3= apex (~305) of loop related to onset of sinistral shear between Gondwana and Laurasia. G) Compilation of reinterpreted Paleozoic primary (green) and overprint (red) poles for locations within the "compression box", with polarity (N, R, M-mixed) indicated. Primary pole path segments are indicated for Ordovician to Devonian and for Permian. Carboniferous primary poles seem lacking. The displacement-corrected SNEO path has been transferred to the "compression box" (cratonic) paths for tentative dating of overprint poles. Interpreted overprint ages range from Devonian to Permian. There is no clear separation between a Devonian to Late Carboniferous range of poles related to Australia-Asia collision and tectonic extrusion (L2), and a Late Carboniferous-Permian range of poles related to onset of sinistral shear within Pangea (L3). See previous annual report contributions.

Tectonic extrusion-related pervasive remagnetisation was not restricted to deeper crustal levels. It also affected the paleomagnetic signal of the uppermost crust, albeit over different time ranges. Tectonic extrusion-related cooling progressed differently for lower and uppermost crust. Cooling of the deeper crust below the Curie temperature of magnetic carriers, “freezing-in” remagnetisation, was delayed till middle-late Visean ending of tectonic extrusion ended lower crustal advective heat transfer. In contrast, low ambient temperatures at the crust-atmosphere boundary ensured that paleomagnetic overprinting continued during tectonic extrusion and shortly thereafter. With this time duality in mind, paleomagnetic data from Paleozoic rocks within the tectonic extrusion-affected compression box have been reinterpreted in terms of primary or overprint origin, using the Carboniferous SNEO pole path segment (Fig. 1G) as a guide. This has led to recognition of primary pole path segments for Cambrian to Devonian and for the Permian (Fig. 1H), but not so for the Carboniferous that is lacking in primary poles. Instead a Carboniferous segment, broadly reflecting the SNEO path, seems outlined roughly by a dispersed group of overprint poles. Overprint ages of this group range more widely from Devonian to Permian. This may reflect two successive phases of overprinting of different causes and with unclear separation. A first phase of remagnetisation, related to tectonic extrusion, extended from Devonian up to middle-late Visean, petering out in Late Carboniferous. A second, unrelated, phase of remagnetisation started with a prominent latest Carboniferous (~305 Ma) change in Gondwana movement, leading to Permian-Triassic reconfiguration of Pangea.

Recent insights in tectonic extrusion-related pervasive remagnetisation, progressing at different rates for the lower and upper crust, have considerable implications for interpretation of lithospheric magnetic anomalies, Australian and Gondwanan paleomagnetic poles paths, and Pangea reconstructions.

Contribution to RSES Annual Report 2008

<http://rses.anu.edu.au/research/annrep/ar2008/visitors/index.php?p=klootwijk>

Contribution to RSES Annual Report 2009

<http://rses.anu.edu.au/highlights/view.php?article=47>

Observations of element concentration profiles surrounding ilmenite inclusions in garnet from the Barrovian Metamorphic series, Scotland

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The garnet-ilmenite system has the possibility to be utilised to determine timescales of thermal events using diffusion modelling. The Cameca NanoSIMS 50 at the Centre for Microscopy, Characterisation and Analysis, University of Western Australia was used to image the distribution of elements surrounding ilmenite inclusions within garnet to determine if diffusional features are evident. From previous computer modelling of the system it is expected that there are bimodal diffusion profiles preserved in the garnet surrounding ilmenite inclusions, due to exchange of elements during thermal events. Proof of this phenomenon would be valuable in garnet diffusion modelling techniques already used for determining timescales of thermal events.

Two samples from the Barrovian metamorphic series, Scotland were analysed that are from the staurolite and sillimanite zones. Both samples showed diffusional features in Al, Mg, Mn and Fe concentration profiles in garnet adjacent to ilmenite inclusions.

The results cleared up ambiguity associated with Ti concentration profiles that have been observed in electron microprobe transects in garnet adjacent to ilmenite inclusions. These profiles have been confused with diffusion profiles. However, Ti concentration profiles obtained from the NanoSIMS show no Ti in the garnet. This is indicative of the Ti profiles seen in electron microprobe transects being analytical artefacts, as previously suggested by Feenstra and Engi, (1998). In electron microprobe transects these profiles can often be seen up to $\sim 30\mu\text{m}$ from the grain boundary.

This study was successful in measuring diffusional features within garnet adjacent to ilmenite inclusions. However, the bimodal profiles that were obtained from diffusion modelling of the system were not found. What was found was a peak in Mn, Mg, Al and Fe in garnet adjacent to the ilmenite inclusion; a profile for Mn can be seen in Figure 1 for sample DV06-21. Profiles obtained from image analysis software, imagej, for Mg, Ca, Al and Fe can be seen in Figure 2.

These diffusional features observed in this study are important because ultimately they may lead to a new method of determining the timescale over which metamorphism occurs which in turn allows for determination of the source of heat. If modelled, the concentration profiles can be used to determine timescales of Barrovian metamorphism in Scotland. The garnet-ilmenite system has not been previously used in diffusion modelling however, the ability to treat it as a closed system and the strong dependence of the systems partition coefficient on temperature makes it a useful model. The garnet-ilmenite system can also be calibrated against other methods already in use such as major element in garnet diffusion models.

Feenstra, A., Engi, M. 1998, An experimental study of the Fe-Mn exchange between garnet and ilmenite. *Contributions to Mineralogy and Petrology*, v. 131, p. 379-392.

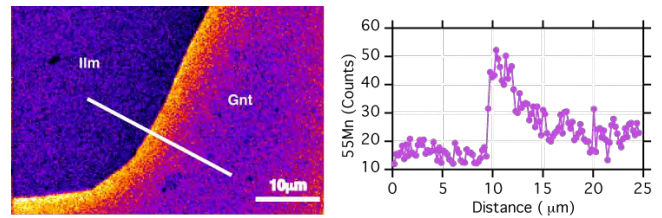


Figure 1. Elemental map of a grain boundary between an ilmenite inclusion and the surrounding garnet. This shows a Mn diffusion profile in the garnet adjacent to the grain boundary in sample DV06-21 from the staurolite zone of the Barrovian metamorphic series, Scotland.

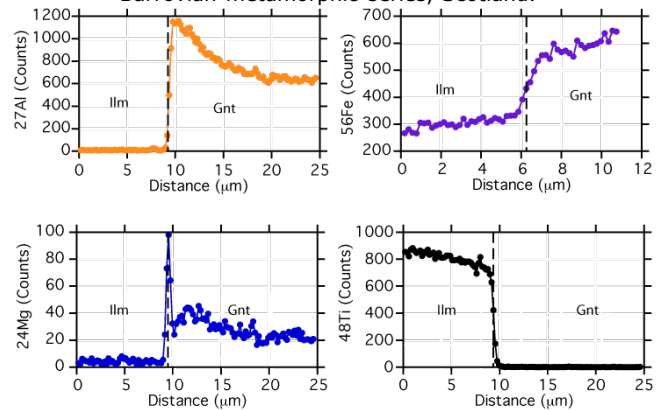


Figure 2. Elemental concentration profiles showing the distribution of elements close to an ilmenite boundary within garnet for Fe, Mg, Al and Ca. The grain boundary is marked with a dotted line in all plots.

Geodynamics of the 2010 Chilean Great Earthquake

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The rupture that caused the 2010 Great Chilean Earthquake demarcates a distinct segment of the Andean margin, transitional between the Pampas flat slab segment and the ruptured zone from the 1960 Great Earthquake. An investigation as to these two geometries was conducted using hypocentre data from the various earthquake catalogues. Cross-sections illustrate significant differences between subduction geometry in the region affected by the 1960 event in comparison to the subduction geometry along the line of the Juan Fernández Ridge, through the Pampas flat slab segment. The northern cross-section shows that the subduction zone dips relatively steeply down to ~100 km and then runs flat for ~200 km before the dip steepens and the slab plunges to greater depths. A relatively strong, and relatively buoyant, chain of thick basalt accumulations is being subducted and rammed over by the westward migrating South American lithosphere. The compression required by this "push-over" leads to a relatively steeply dipping megathrust (~25°) in the west, and back-thrusting and east-directed reverse-faulting at the eastern end of the compressed zone. The southern cross-section is marked by the trench-lip normal faults that define the western extent of the continental crust and, by implication, the western extent of the rupture from the M_w 9.6 1960 Great Earthquake. In contrast to the northern cross-section the slab steepens smoothly with depth. The history of normal faulting implies that the over-riding lithosphere is also being extended, and overall this segment may be subject to ~E-W horizontal extension. This is consistent with the transtensional right-lateral Gastre fault zone that separates this part of South America from the rest of the continent. In this case the 1960 event may have been a "collapse-driven" megathrust, with a geometry that compares with that of the Andaman Sea segment of the 2004 Great Sumatran Earthquake. If this is the case then the 2010 earthquake ruptured a zone that marks a transition from "push from behind" over the Pampas flat slab segment to gravity driven collapse of the southern margin driven by slab roll-back.

Home page for the Structure Tectonics Team

<http://rses.anu.edu.au/tectonics/>

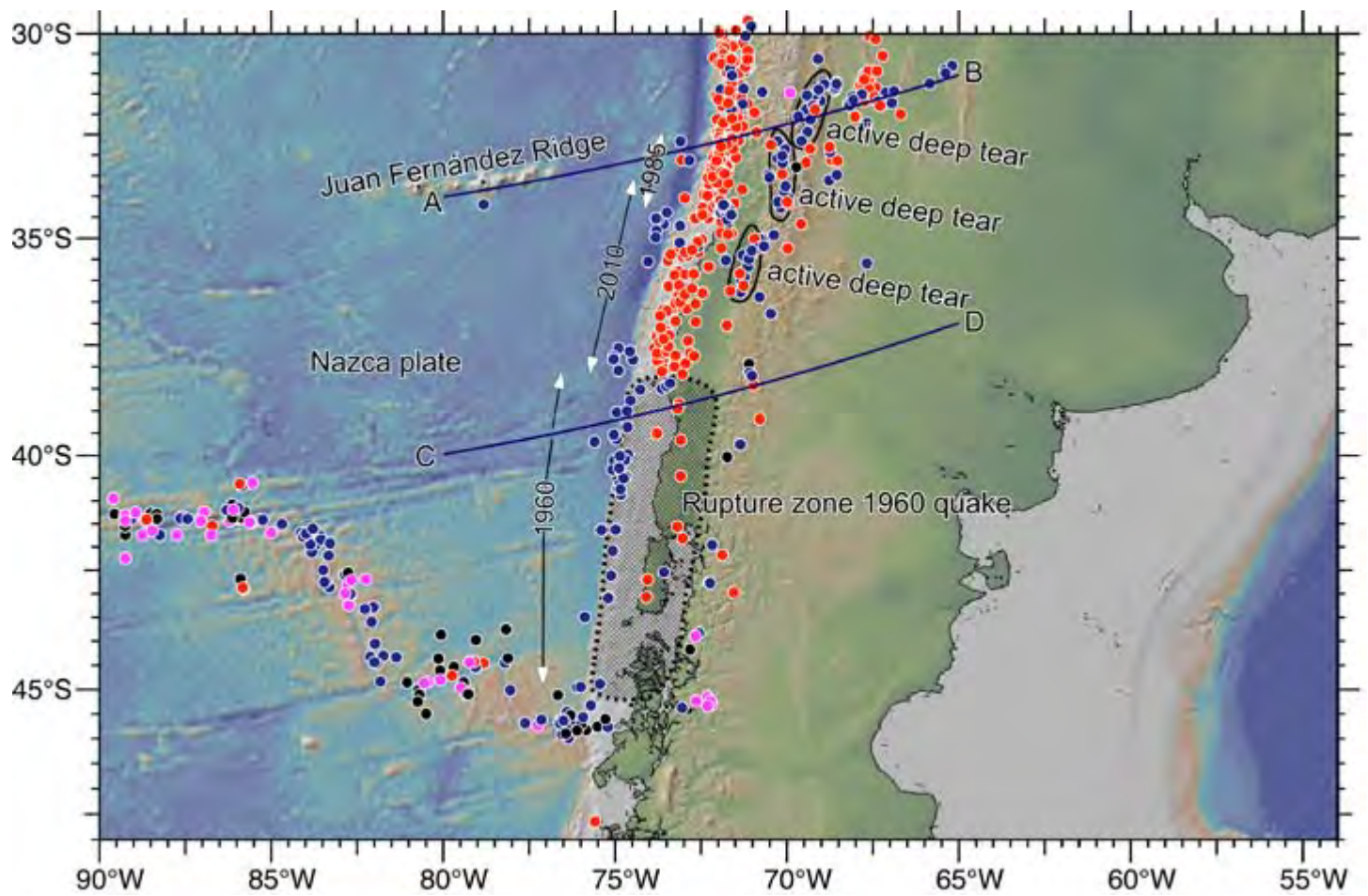
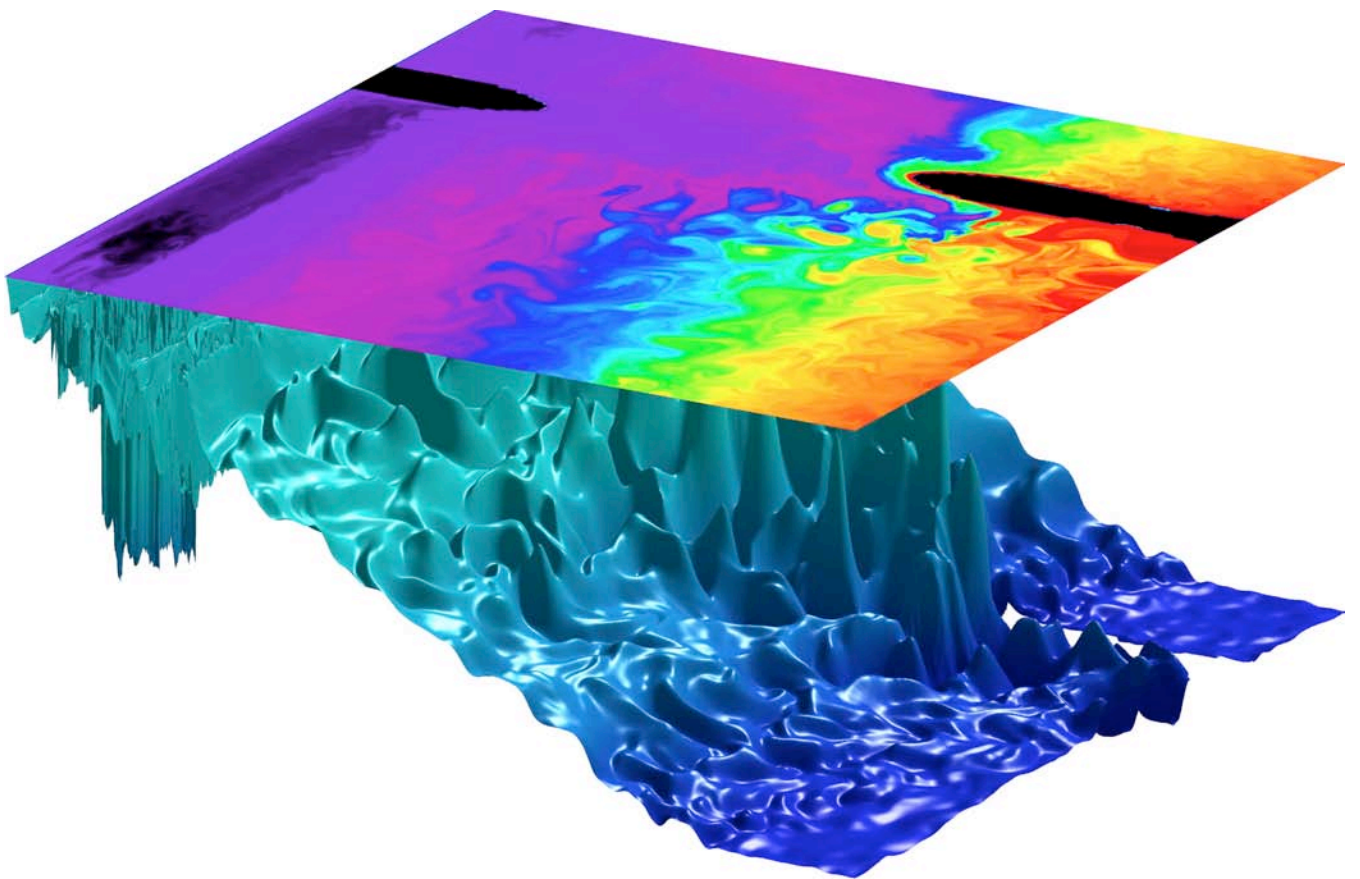


Figure 1. SRTM image of South America showing the geodynamic context of the 1960 and 2010 Great Chilean Earthquakes. PDE hypocentre solutions from the Global CMT project are shown for earthquakes from 1976 until August 2010. Red dots show PDE solutions for thrusts and reverse faults, while blue dots are for normal faults. The ruptured area from the Mw 9.6 1960 Great Earthquake is delineated, and the segments affected by the 1985 and 2010 earthquakes. Note the steeply east dipping normal faults that bound the subduction trench lip west of the 1960 rupture.

Research School Of Earth Sciences (Earth Physics)

Research Activities 2010



Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.

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 2010 Prof. B. Kennett was awarded the 2011 Flinders Medal, the highest award in the Physical Sciences, from the Australian Academy of Science. Prof M. Sambridge was elected a Fellow of the American Geophysical Union. Prof. Griffiths was elected an inaugural Fellow of the Australasian Fluid Mechanics Society and also delivered a plenary lecture to the American Physical Society. Prof. P. Cummins was awarded the Stillwell Award by the Geological Society of Australia. Dr. G. Davies was honoured upon his retirement with a special session at the Fall meeting of the American Geophysical Union. Dr. H. Tkalčić was awarded a JSPS Fellowship from the Japanese Government. Dr. G. Hughes was awarded a Future Fellowship for research in ocean dynamics and solar energy systems. During the year it was announced that Earth Physics will host the ANU node of the new ARC Centre of Excellence in Climate System Science, with Drs M. Roderick and A. Hogg as Chief investigators and Profs. R. Griffiths and G. Farquhar (Research School of Biology) as Associate Investigators.

RSES Earth Physics 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 with absolute and relative gravity measurements being made at several sites across Australia, and the investigations of crustal deformation continued through the analysis of GPS observations and space gravity analysis. The Terrawulf II cluster computer at RSES 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. This year saw the awarding of a second phase of AuScope activities through the Federal Governments Education Infrastructure Fund (2011-2014).

Seismology fieldwork in 2010 was undertaken primarily in New South Wales and Queensland. The WOMBAT transportable array experiment in southeast Australia, which began in 1998, now comprises 12 separate subarrays of between 20 and 70 instruments each deployed for periods of between 6-12 months. In 2010, the 53 station EAL2 array was deployed in central NSW, bringing the total number of WOMBAT station locations to over 550, making it one of the largest experiments of its type in the world. These passive arrays mainly detect signal from large distant earthquakes that take place in regions such as Indonesia, Fiji, New Zealand. This information can be used to image the structure of the crust and upper mantle using a variety of methods including seismic tomography, receiver functions and shear wave splitting. The background noise (or Earth's hum) can also be used to image the crust in high detail. Recent results from Tasmania show that the transition between the Eastern and Western Terranes is marked by a very distinct region of low Rayleigh wave group and phase velocity, which appears to correlate with elevated crustal heat flow and conductivity. On the mainland, teleseismic tomography results show evidence of the signatures of Palaeozoic orogenic events, as well as more recent tectonic activity associated with the break-up of Gondwana and the opening of the Tasman Sea.

In the Mt. Isa region of Queensland, two 25 instrument short period arrays have been sequentially deployed as part of AuScope Earth Imaging. These arrays are designed to complement recent seismic reflection transect work undertaken in northern Queensland, and will help unravel the complex tectonic history of the Mt. Isa Inlier and surrounding regions.

Data recorded by a temporary seismograph deployment was used to infer constraints on the state of crustal stress in the Flinders Ranges, one of the most intense concentrations of intraplate seismicity in the world. Earthquake first motion measurements show that the direction of principal stress is consistent with the E-W shortening inferred from geological observations of fault movement.

Research into tsunami generation by megathrust earthquakes has highlighted the potential threat to Tonga's capital, Nuku'alofa, which lies on a low-lying peninsula facing the Tonga Trench and is home to 35,000 people, (~ 1/3 of Tonga's population). It was shown that the challenge of modeling tsunami propagation over the shallow reef platform offshore Nuku'alofa can be met using high-precision bathymetry models derived from multispectral remote sensing data. In contrast to previous results, tsunami simulation using the new high-precision model shows that earthquakes commensurate with historical events along the Tonga Trench pose a serious threat to Nuku'alofa's population.

In the area of deep earth studies a new model of inner core consisting of a conglomerate of anisotropic domains has been proposed to reconcile travel time and normal modes data. Work has continued on an automated real time regional seismic moment tensor inversion using full 3D structural models of the Australasian region. A collaboration with the ANU's Research School of Information Sciences and Engineering has led to new java software IRFFM2 for interactive simultaneous modelling of receiver functions and surface wave dispersion. In the area of data processing and archiving, the new Seismic Data Centre (SDC), which facilitates user-friendly access to all current and past seismic data collected by RSES via a Java-based GUI and Seismomap Tool has now reached the final stage of development. About three-quarter of all digital data from past experiments has now been converted into continuous miniseed format accompanied by metadata files.

In Geophysical Fluid Dynamics research has continued to tackle the dynamics of the Southern Ocean and of the global overturning circulation of the oceans. The forces balances and energy budget of the Antarctic Circumpolar Current have been examined using high resolution eddy-resolving computations. These studies have indicated that surface buoyancy forcing (heating/cooling at the ocean surface) play a greater role on the ACC than previously thought. Further experimental investigations of overturning circulation driven by surface buoyancy forcing have been carried out. Also completed are studies of the role of topographic sills between ocean basins and marginal seas in determining the density of abyssal ocean waters, and of the behaviour of circulation forced by a 'see-saw' oscillation of surface heat fluxes between hemispheres, and continuing a study of the adjustment of overturning circulation to changes in surface buoyancy forcing. An experimental investigation of the combined roles of mechanical mixing (due to energy from sources such as tides, winds or biological activity) and surface buoyancy forcing was commenced.

In Mathematical Geophysics research has been directed to the study of nonlinear inverse problems and development of new ensemble based approaches for seismic imaging. In lithosphere dynamics attention has focused on the dynamics of the Indian plate over the past 10 Myrs. Recent reconstructions of the ocean-floor spreading allow identifying a peculiar counter-clockwise rotation of the Indian plate, resulting from accelerated convergence across the eastern India/Eurasia margin as opposed to the western end. Global models of mantle/lithosphere dynamics have been employed to link this plate motion change to the dynamic evolution of the Himalayan topography.

Numerical models of mantle/lithosphere dynamics have been employed to explore the possibility that global plate tectonics carries a signature of the amount of heat transferred at the core-mantle boundary (CMB). Efforts have also been undertaken to explore the effect of lateral variations of mechanical coupling along the Andean convergent margin on the evolution of the trench morphology.

Geodynamics research has focused on using temporal gravity changes from the GRACE mission, with progress made in the development of in-house software to account for gravitational variations independent of the hydrological cycle and glacial isostatic adjustment. These effects include ocean and atmospheric tides, planetary gravitational effects, satellite attitude control and manoeuvres and atmospheric pressure effects. In a study of comparisons between GRACE-derived hydrological changes and soil moisture models across the Great Artesian Basin they showed both strong agreement suggesting that the models are accurate and that the dominant geophysical process sensed by GRACE is related to soil moisture variations.

The ongoing investigations into errors in GPS analysis have shown that some of the periodic variations remaining in GPS time series are related to the mismodelling of the solar radiation pressure forces acting on satellites. Work is continuing in collaboration with colleagues at MIT to improve the existing models and reduce the spurious signals.

A new study in conjunction with Ecole Normale Supérieure Cachan (Paris) derived a relation between Love loading number ratios and a spherical harmonic field that can be used to approximate the present-day response of the Earth to melting events that occurred over 10,000 years ago. This relation is independent of both the rheological model for the Earth and the ice history model used.

The gravity gPhones purchased in 2009 were deployed at Tennant Creek, Jabiru and Katherine and have operated normally for the required 6 month period.

AusMoho: A new Moho map of the Australian Continent

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The Moho is a seismological boundary that represents the base of the Earth's crust. We present a new Moho map of Australia estimated from the compilation of seismic receiver functions, tomography, seismic reflection and refraction profiles. This map represents the current status of the AusMoho project, which ultimately aims to image the Australia continental crust with a 50 km resolution.

The current Moho map includes over 5000 km of deep seismic reflection profiles and 400 data points from permanent seismic stations, 3-component broadband and short period stations deployed over the last 15 years and large-scale refraction profiles conducted in the last 35 years. Seismic data coverage of the Australian continent has greatly increased over the last 10 years, doubling the number of data points that were available for previous maps.

The new Moho map provides information about the present day large scale crustal structures that define the geological provinces of Australia and will supply much needed constraints for use in tomographic imaging of the Earth below. The most striking feature of the new Moho depth map is the short wavelength transition from the thickest Proterozoic crust (>50 km) in central Australia to the thin crust (~30 km) of Phanerozoic eastern Australia.

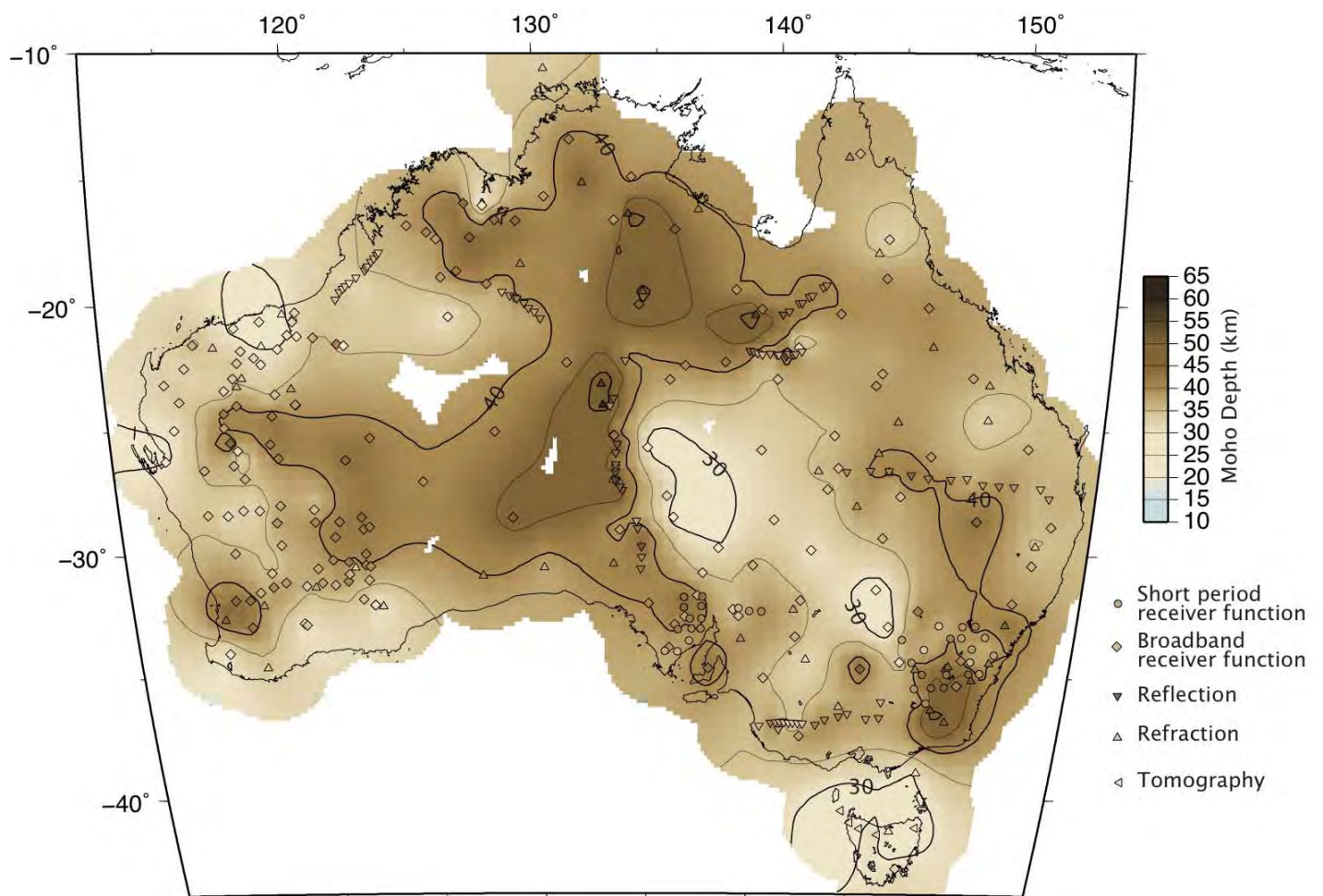


Figure 1. Moho depth data points from reflection and refraction data and receiver functions. The depths are averaged over 50 x 50 km blocks and a surface is fitted through. Where there is no data within a 250 km radius the surface has not been plotted. Data points are colour coded using the same depth scale as the plotted surface to highlight any differences. The regions of thickest crust are found in the North Australia and Central Australia. The Moho extends to a depth of > 55 km depth where the Central Australia is sandwiched between the North and South Australia. This is a region of Mesoproterozoic suturing and is characterized by crustal scale thrust faulting (Korsch et. al 1998). A region of thicker Phanerozoic crust, in southeastern Australia coincides with the Lachlan Fold Belt.

Benford's law of first digits: a universal phenomenon

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More than 100 years ago it was predicted that the distribution of first digits of real world observations would not be uniform, but instead follow a trend where measurements with lower first digit (1,2,...) occur more frequently than those with higher first digits (...8,9). This idea was first described by an astronomer, Simon Newcomb in 1881. Newcomb noticed that the pages of logarithm tables were more thumbed for low digits than higher ones. He argued that this was because scientists had more need to look up logs of real numbers with smaller first digit than larger. He produced a mathematical formula predicting the distribution of first digits. The result has long been regarded as a mere mathematical curiosity and largely ignored across the sciences. It was rediscovered in 1938 by an engineer called Benford. Despite a waning of interest the latter name is now associated with the first digit law.

Our new study shows that Benford's first digit rule is a natural phenomenon which is likely to hold universally. We test 15 sets of modern observations drawn from the fields of Physics, Astronomy, Geophysics, Chemistry, Engineering and Mathematics, and show that Benford's law holds for them all. The data sets used in our study consist of more than 750 000 values which vary over 19 orders of magnitude and differ in origin, type and physical dimension. These include the rotation frequencies of pulsars; green-house gas emissions, the masses of exoplanets; as well as numbers of infectious diseases reported to the World Health Organization.

Figure 1 shows predictions of the occurrence frequency of first digits according to Benford's Law together with digit distributions of three of our data sets. A particular focus of our study has been Earth Science observations and here we have shown that the first digit rule applies to the strength as well as timing of reversals of the Earth's geomagnetic field, seismic tomographic models of the Earth's elastic properties and the depth distribution of Earthquakes.

Our results suggest that Benford's Law is a universal feature for data sets with sufficient dynamic range raising the question of how it might be exploited. Use in a forensic mode, e.g. to detect fraud or rounding errors, is possible by simply looking for departures in the frequencies of individual digits. There have been previous applications of this type to detect fraud in financial data. A more intriguing question is whether it can be used to detect signals in contrast to background noise, e.g. in time series data such as seismic signals.

Figure 2 shows an example of how seismic energy from an earthquake follows Benford's law which means that earthquakes can be automatically detected from just the first digit distribution of displacement counts on a seismometer. Our study led to the first ever detection of an anomalous seismic disturbance (assumed to be a small local Canberra earthquake) using first digit information alone.

We have also managed to extend the mathematical description of Benford's law to account for situations where the range of observables is arbitrary. As awareness of this novel phenomenon grows across the natural sciences we expect new applications will appear, one possibility is in checking the realism of computer simulations of complex physical processes, such as in the climate or oceans. If the natural processes are known to possess the first digit property then any computer simulation of that phenomenon should do also. Another is in the detection of rounding errors or other anomalous signals in data. We hope this work will encourage others to look at their digits more closely.

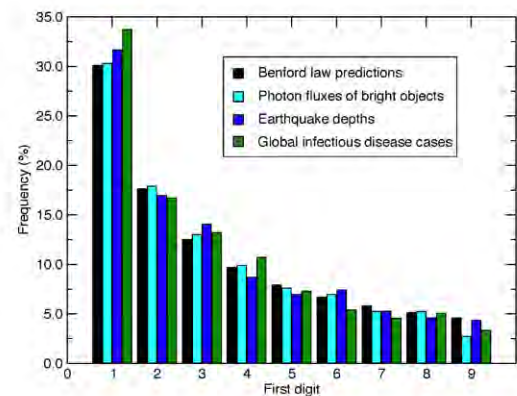
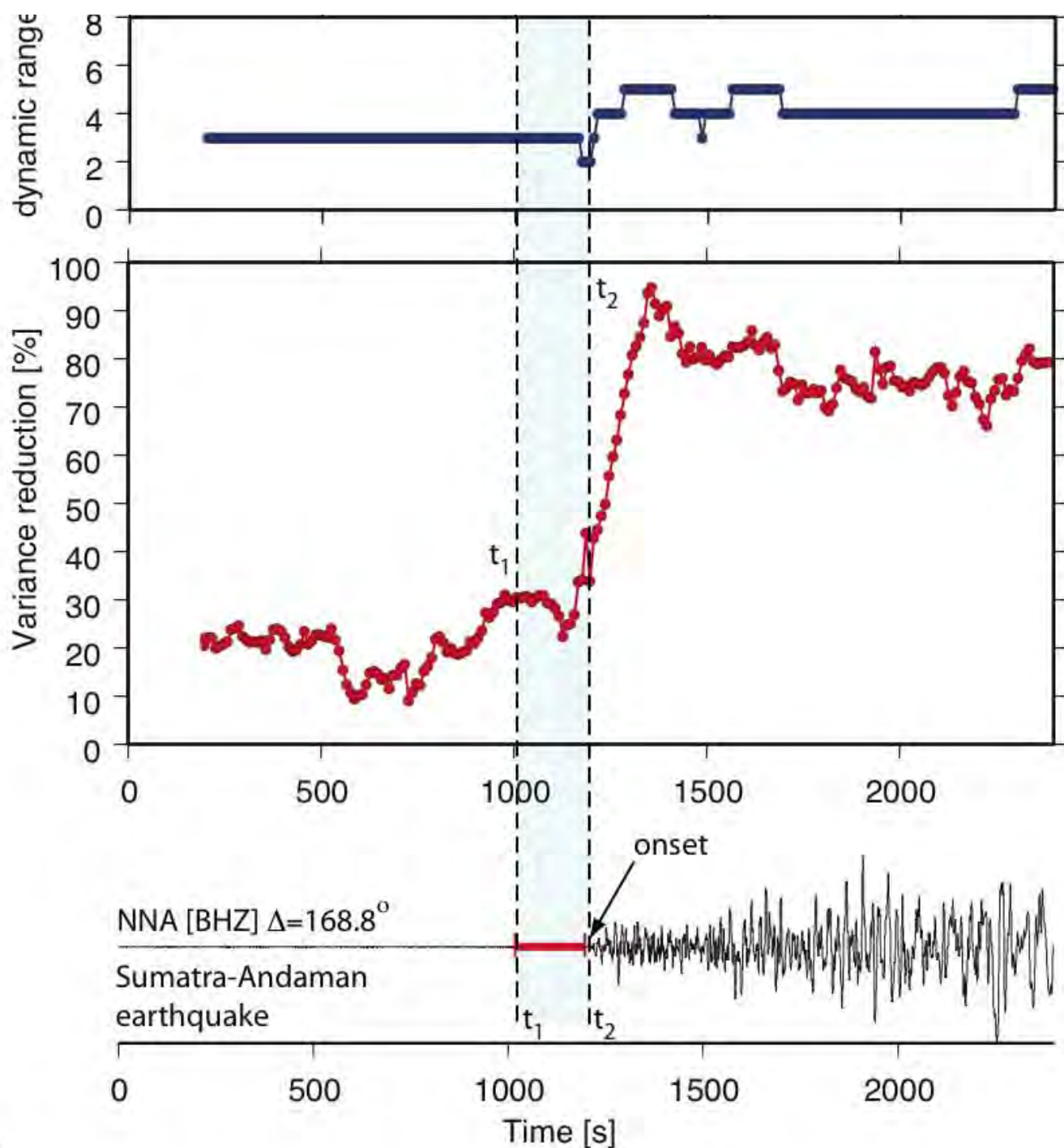
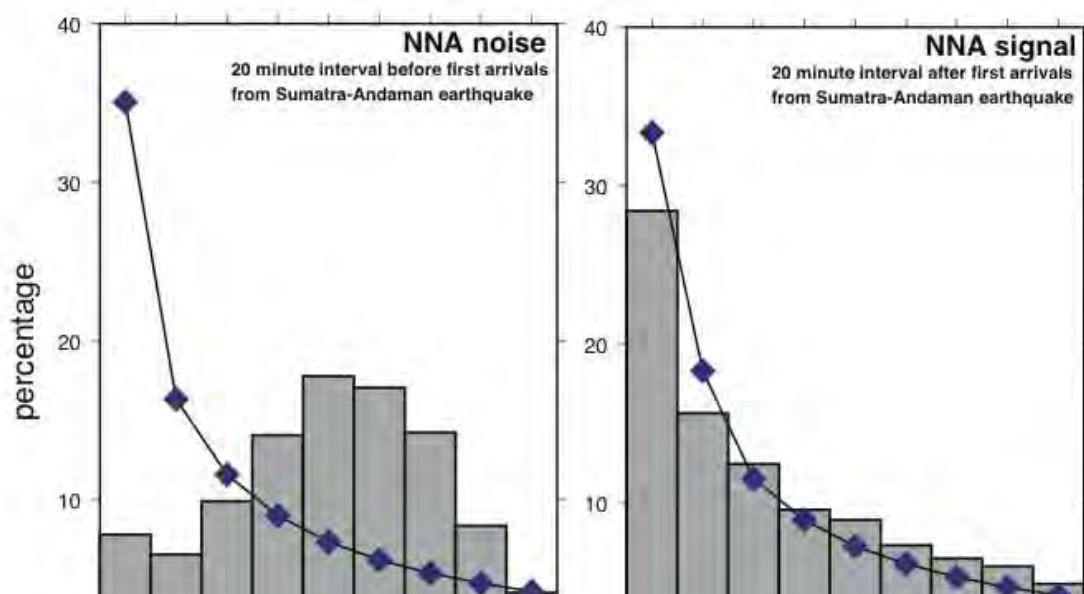


Figure 1. Benford's law predictions for distributions of 1st digits compared to three data sets. Columns represent photon fluxes for 1452 bright objects identified by the Fermi space telescope, depths of 248915 globally distributed earthquakes in the period 1989-2009, and 987 reports of infectious disease numbers to World Health Organization in 2007.



b)



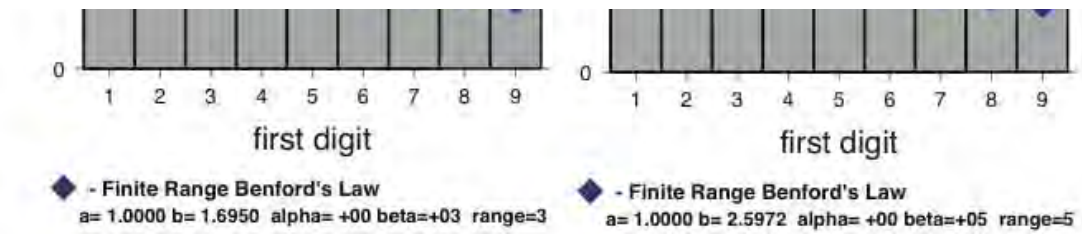


Figure 2. Lower panel. Seismogram of the Sumatra-Andaman earthquake recorded at seismic station NNA in Peru. The onset of seismic waves is marked at time t_2 . Shading shows the 200-second sliding time-window in position t_1 to t_2 . The earthquake signal enters the moving time-window at t_1 . Central panel. Goodness of fit to Benford's law (as defined in the text) as a function of time. Upper panel. Dynamic range as a function of time. b) Distribution of first digits for the 20-minute period before time t_2 (left panel) and after time t_2 (right panel) versus those predicted by Benford's law (blue diamonds).

Earthquake location and source determination using coda waves

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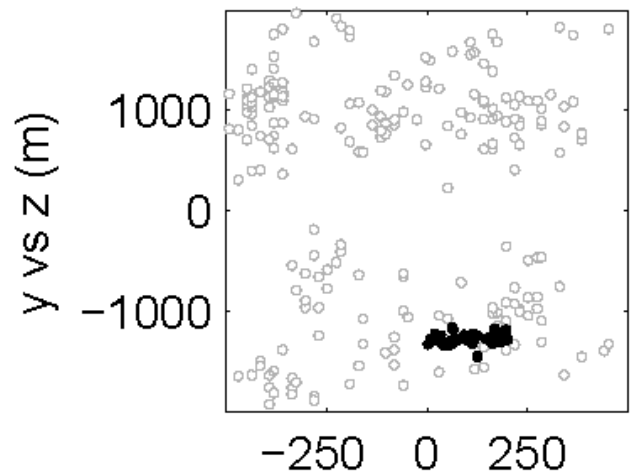


Figure 1. Cluster of earthquakes (black) located using coda wave interferometry. Open circles illustrate scattered nature of locations for neighbouring events when absolute travel times are used.

The majority of existing seismological techniques ignore high frequency coda that result from scattering and focus on early onset body waves to model earthquake location and source properties. A recent technique known as coda wave interferometry utilises the cross correlation of coda waves to constrain changes in source properties between earthquake pairs.

Our work focuses on extending coda wave interferometry by designing mathematical frameworks and practical algorithms which enable the use of coda in studying the properties of earthquake clusters. We have demonstrated how to construct a probability density function (PDF) for the location of a cluster of earthquakes using either coda waves by themselves, or in combination with early onset body waves. This joint PDF is studied using direct search, ensemble inference and optimisation under a range of conditions for earthquakes in Western Australia and California. Combining coda and travel times leads to the best solution in most cases.

We have shown however, that coda waves significantly enhance location constraints when the uncertainty associated with travel times exceeds half the event separation. Furthermore, coda waves are demonstrated to provide valuable information in poor recording situations with few stations and can be used with as little as one station. In contrast, travel time techniques require multiple stations and good azimuthal coverage. This feature of coda waves to succeed with limited data is its greatest strength, lending itself to use in intraplate regions where station density is sparse.

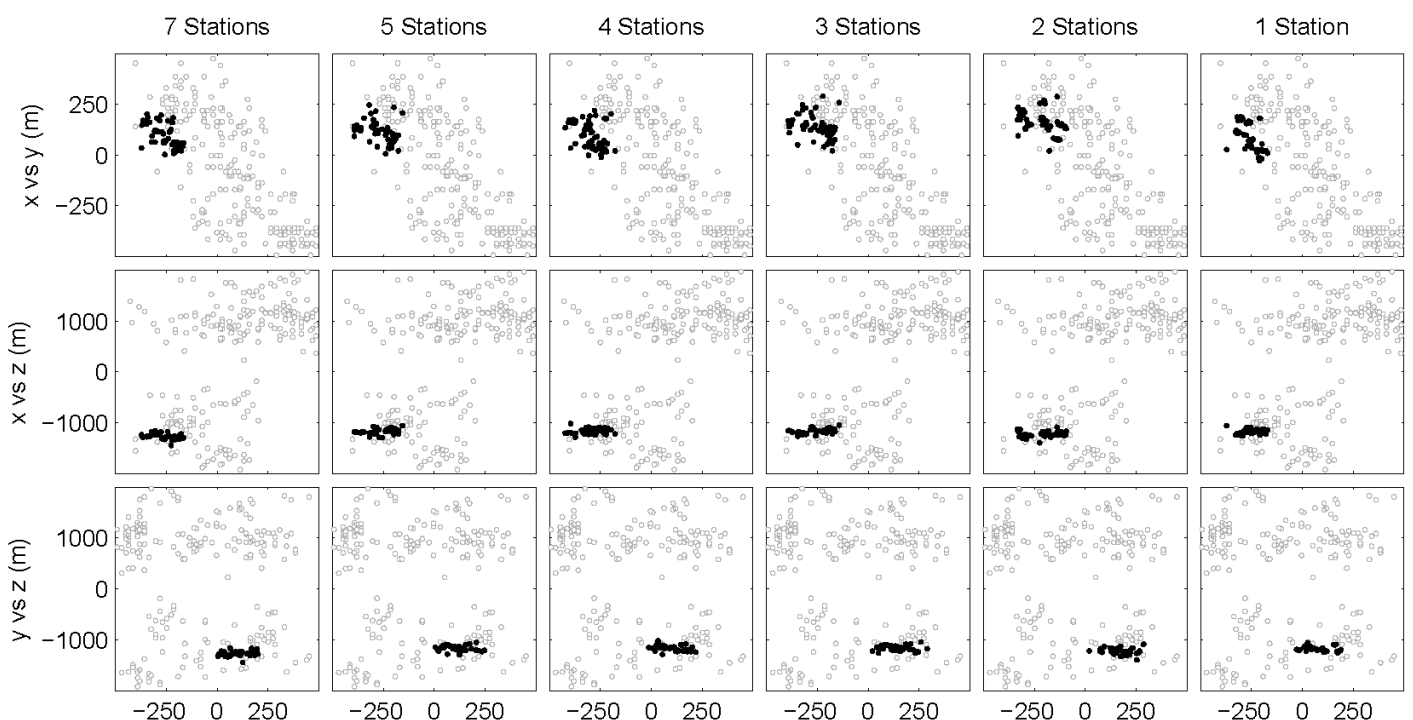


Figure 2. Sequence of images illustrating the similarity of locations obtained for a cluster of earthquakes (black) using coda wave interferometry with a reducing number of stations. Open circles illustrate scattered nature of locations for neighbouring events when absolute travel times are used.

Crustal Stress in the Flinders Ranges, South Australia

Stress inversion using earthquake first motion data

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Compared with other stable continental regions, Australia has a relatively complex crustal stress field which is thought to result from orogenic forces acting at the boundaries of the Australian and Indian Plates. At the same time, with very few well-recorded large earthquakes, Australia's stress field is poorly constrained. The Flinders Ranges in south-central Australia is one of the few places in Australia where there is clear and abundant evidence of neotectonic deformation, and it is one of the most intense concentrations of intraplate seismicity in the world. This makes it an ideal location to study active intraplate deformation.

We used data recorded by a temporary seismograph deployment conducted in 2003-2005, to infer constraints on the state of crustal stress in the Flinders Ranges. Earthquake first-motion measurements were inverted for constraints on the direction of principal stress and the stress regime. These data also allowed us to estimate 65 focal mechanisms that are consistent with our preferred solution for the stress, which corresponds to an oblique thrust regime with S_{Hmax} oriented roughly east-west. This contrasts with the pure thrust and pure strike slip regimes suggested by earlier studies. We found that, although the data from shallow earthquake's reflect velocity and/or stress heterogeneity, our new estimate of stress is more consistent with the E-W shortening inferred from geological observations of fault movement than previous estimates. This study also demonstrates the effectiveness of temporary, concentrated seismograph deployments in constraining the stress field in intraplate environments.

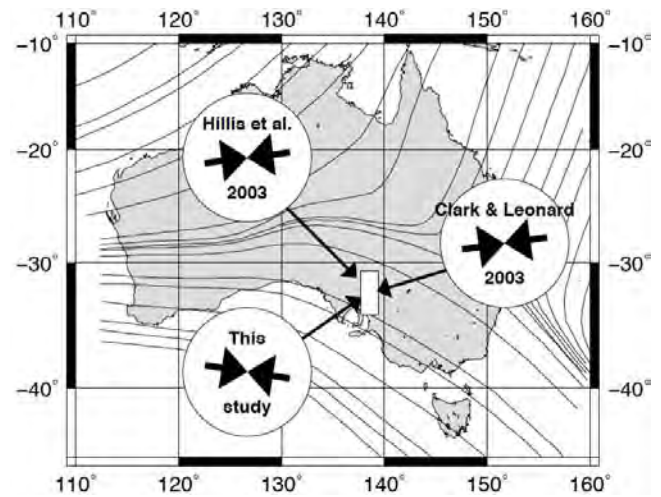


Figure 1. Australia and the counters of S_{Hmax} inferred from elastic modeling of collisions at the plate boundaries in New Zealand, New Guinea and India. The rectangle in indicates the study area in the Flinders Ranges shown in Fig. 2, and the estimates of the S_{Hmax} directions from this and previous studies are indicated.

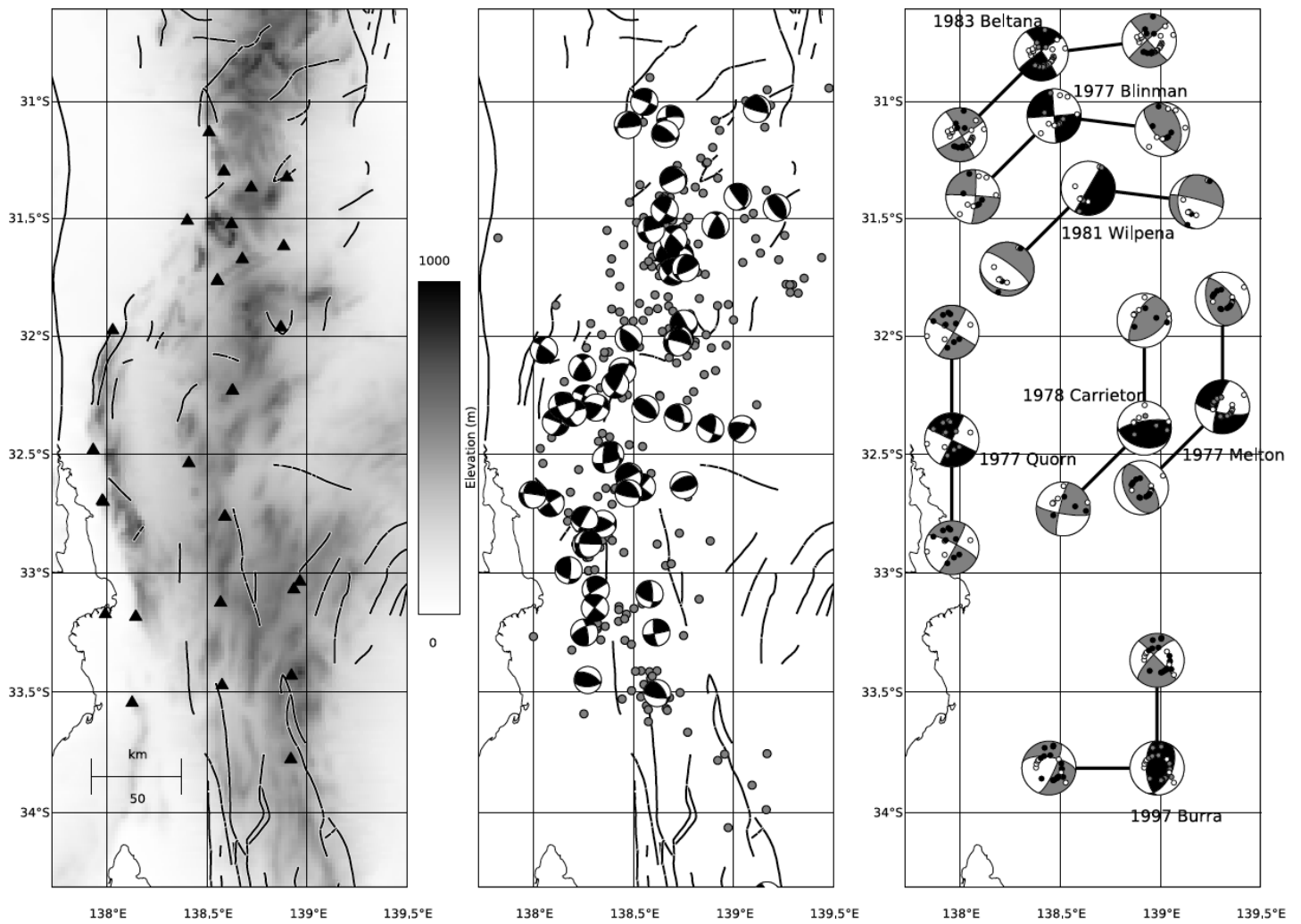


Figure 2. The Flinders Ranges study area in South Australia (see box in Fig. 1), with (left) indicating the location of temporary seismographic stations whose data were used in this study, along with topography and the surface expression of faults thought to have been active since the Quaternary. (center) indicates focal mechanisms for the 65 earthquakes used in the stress inversion of this study, which best match the data subject to the constraint that they are consistent with our preferred solution to the stress orientation shown in Fig. 3. (Grey circles indicate epicenters for the approximately 500 earthquakes recorded during 2003-2005). (right) shows historical focal mechanisms and first motion data plotted at the earthquake epicenter, while to its left/below is plotted the best-fitting focal mechanism that takes into account potential errors in the first motion data, and to the right/above is plotted the best-fitting mechanism that is consistent with our preferred solution to the stress orientation.

The Threat from Tsunamis Generated on the Tonga Trench

Use of Satellite-derived Bathymetry for Inundation Modeling

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In this study we have investigated the use of nearshore bathymetry models estimated using multispectral remote sensing data for tsunami inundation modeling. The technique used here was a per-pixel, physics-based approach (SAMBUCA) used with Quickbird imagery. Tsunami inundation results using this approach were compared with a previous model obtained via an empirical approach with Landsat data. The main difference in these methods is that the SAMBUCA/Quickbird approach produces models with much finer (2.4 m) horizontal resolution, whereas the empirical/Landsat approach has a 30 m horizontal resolution. In addition, the SAMBUCA/Quickbird approach appears to be applicable to greater water depths than the empirical/Landsat one (about 20 m vs. 5m, respectively).

We compared numerical models of tsunami inundation in Tonga's capital, Nuku'alofa, using the two different bathymetry models. The scenario used was a tsunami generated from a hypothetical magnitude 8.25 earthquake commensurate with historical activity elsewhere along the Tonga Trench. Such an earthquake has yet to occur so near to Tongatapu, so in terms of earthquake location this is a worst case scenario. There was a stark contrast between the results: the modeling using the coarse, empirical/Landsat shallow bathymetry predicted inundation only of a narrow coastal strip along Nuku'alofa's shoreline, while the modeling using the fine, SAMBUCA/Quickbird shallow bathymetry predicted that most of Nuku'alofa would be inundated.

These results show that data of 30 m horizontal resolution is insufficient for modeling tsunami shoaling on coral reef platforms such as those surrounding many Pacific islands. It seems more likely to us that data having resolution closer to that obtained using the SAMBUCA/QuickBird approach (i.e., 2.4 m) is required, but further studies are needed to establish the required resolution with precision. The results also tentatively suggest that the SAMBUCA/QuickBird approach provides data of sufficient accuracy that can be used where better data (such as LiDAR) are not available, but this is likely to be true only in shallow water of exceptional clarity. Fortunately, this situation exists offshore many Pacific island communities.

Although the inundation modeling results presented here for a plausible maximum earthquake size on the Tonga Trench suggests that such an event presents a substantial threat to Nuku'alofa, these results should be interpreted with caution, since only poor topography data were available for the study. In particular, these results are not of sufficient accuracy to form the basis of an evacuation plan. However, since Nuku'alofa is home to 35,000 people, roughly 1/3 of Tonga's population, it would make sense to consider better inundation modelling that can support evacuation planning. We are in the process of collecting better topography data so that this modeling can be repeated, in order to better assess the threat and help disaster managers develop an evacuation plan.

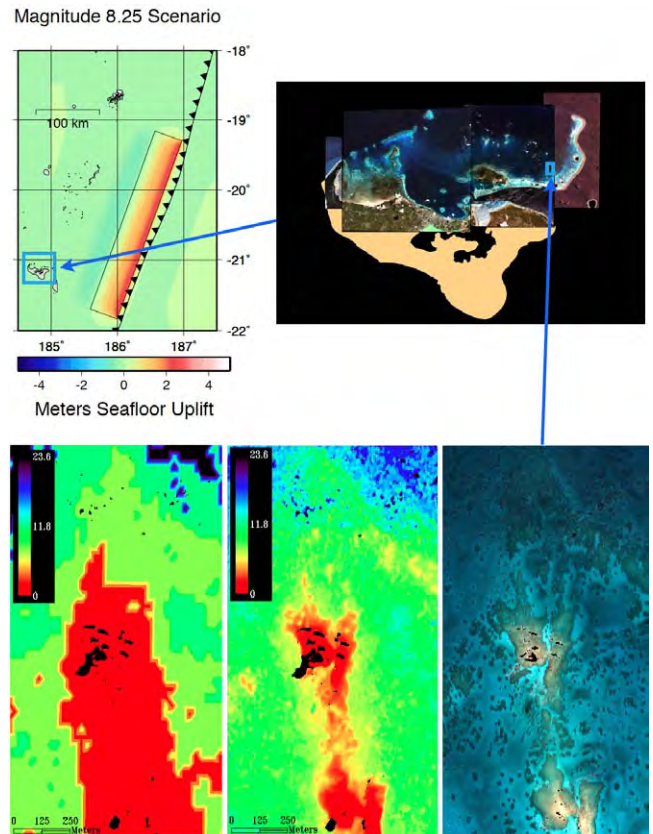


Figure 1. Above Left: Seafloor uplift associated with the magnitude 8.25 earthquake scenario on the Tonga Trench east of Tongatapu used in the tsunami modeling. Above Right: Coverage of Quickbird imagery used to cover the gap in bathymetry north of Nuku'alofa. Below: Comparison of bathymetry models - an empirical approach based on 30 m Landsat imagery (left); A model derived using SAMBUCA's per-pixel, physics-based approach with 2.4 m Quickbird (center); and the original QuickBird imagery.



Figure 2. Tsunami inundation modelling results for a magnitude 8.25 scenario earthquake on the Tonga Trench, compared using two different bathymetry models: (left) a previous model obtained using an empirical method with 30 m Landsat data, and; (right) a new model obtained using a physics-based approach (SAMBUCA) with 2.4 m QuickBird data.

Imaging Turkey's Crust

Hunting for the Moho

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Earthquake signals at detected teleseismic distances, approximately 300 to 900 kilometers away from the physical recorder, provide a valuable resource to image the Mohorovicic discontinuity (the Moho), which denotes the boundary between the Earth's crust and mantle. The Moho is characterized by a large jump in seismic velocity that causes teleseismic P-waves to generate P to S converted waves; the time difference between these seismic phases is indicative of the thickness of the crust. To highlight this conversion and its associated reverberations, we use receiver functions in our analysis.

Turkey is currently instrumented with over 250 3-component broadband stations from both temporary and permanent deployments (Figure 1). To date, we have conducted a preliminary analysis of event data between 2008 and 2009. The calculated receiver functions are analyzed with both H-k and depth stacking techniques. The former allows the V_p/V_s ratio to vary whereas the latter employs a set 1-D velocity model to determine the depth of the Moho (Figure 2). The weighted results of both these methods have been used to generate a preliminary Moho map of Turkey (Figure 3). The calculated Moho depths are to the first order consistent with the tectonic structure of Turkey. The thin lithosphere in the southwest is associated with regional extension, and a "sharp" transition near 37°E between deeper 40+ km Moho depths to shallower Moho depths may delineate the Arabian block. Mapping Turkey's Moho is and will continue to be a useful tool in understanding the ongoing geological processes of the region as more data is analyzed and more details of the complex Moho structure become apparent within the study region.



Figure 1. Distribution of temporary and permanent seismic stations available for analysis in Turkey. Yellow triangles denote the National Seismic Array of Turkey (TU); purple triangles denote the Kandilli Observatory Array (KO). Red triangles denote other deployments.

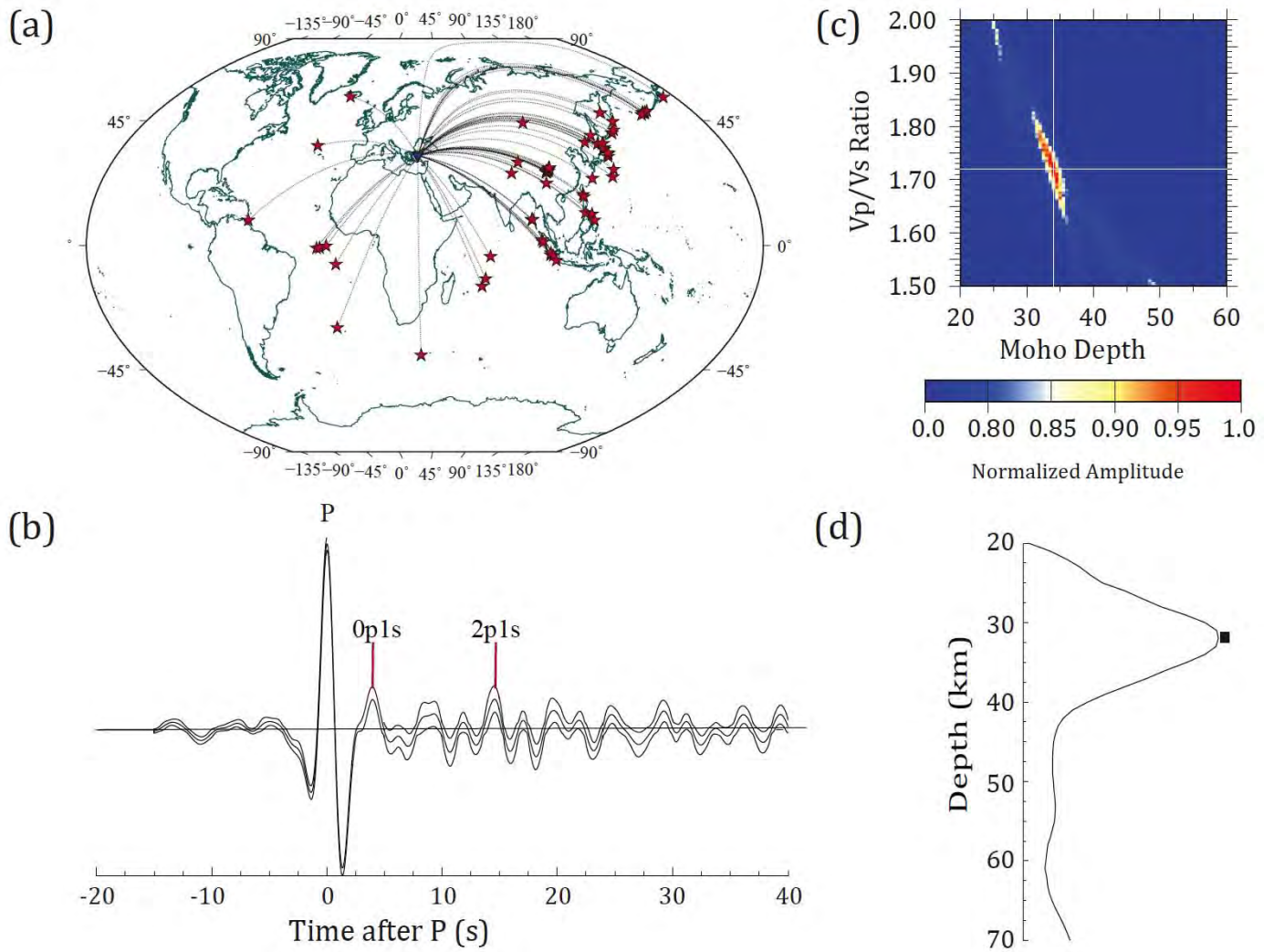


Figure 2. Example of results of the receiver function analysis for the station ALT (39.06°N, 30.12°E) located in western Turkey. (a) Distribution map of the 44 teleseismic events used in the receiver function analysis. (b) The average receiver function generated by the radial and vertical components for station ALT linearly stacked in the time domain with a 95% confidence interval. The converted and reverberated phases are labeled. (c) The H- κ stacking results for the receiver functions; hot colors denote the likely Moho depth and Vp/Vs ratio combination. The white lines denote the automatic pick of Moho depth and a Vp/Vs ratio. (d) The stacked receiver function after time to depth conversion based on the IASP91 model. The square dot indicates the observed Moho depth.

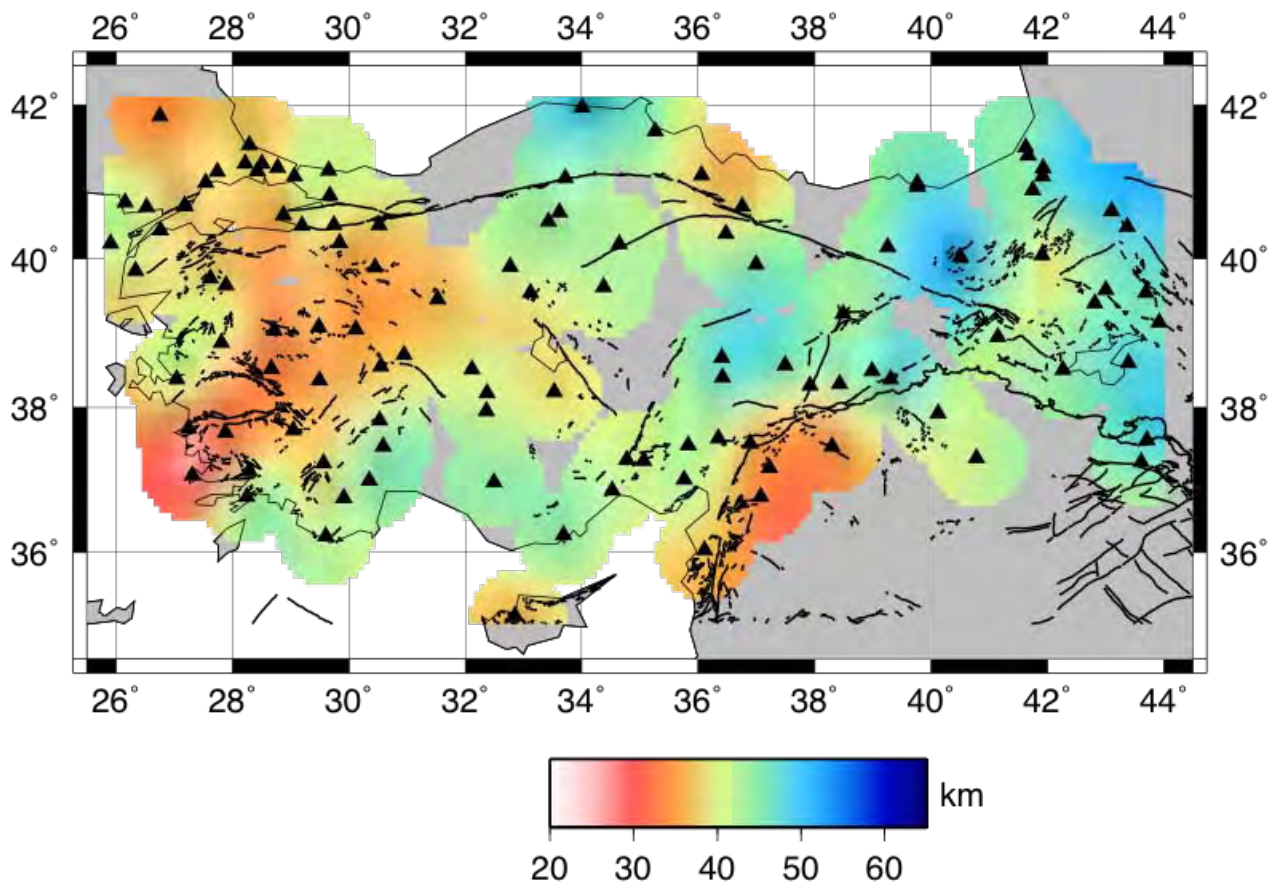


Figure 3. Preliminary Moho depth map of Turkey for the current receiver function data set; warmer colors indicate shallower Moho depths. The used stations are indicated by the triangles and the black lines delineate the major faults.

The Ambient Noise Tomography of Turkey

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The ambient seismic noise correlations is an important tool to understand Earth's internal structure. In this study, we use 5 months of continuous data from the 2 major seismic broadband networks of Turkey (TU, KO) for extracting the interstation Green's functions from the ambient seismic noise (figure 1). The vertical and horizontal components of the stations are used to extract the Rayleigh and Love wave type Green's functions. The other available data from temporary deployments are also included to improve the ray path coverage. The group velocity dispersion of the Green's functions is estimated by applying narrow band filters consecutively over a period range of 1 s to 40 s. The measurements are then inverted with nonlinear tomographic inversion schema to create the Rayleigh and Love maps for different periods. The images presented in figure 2 show the complex geological structure of the region, and matches with some of features shown in figure 1b.

In the centre, the Kirsehir Block is marked with increased velocities. Western Turkey has low velocities for the shallow depths with possibly linked to the elevated heat gradient in the region. The transition from Anatolian block to Arabian plate is marked with high velocities (Rayleigh 3-20 s).

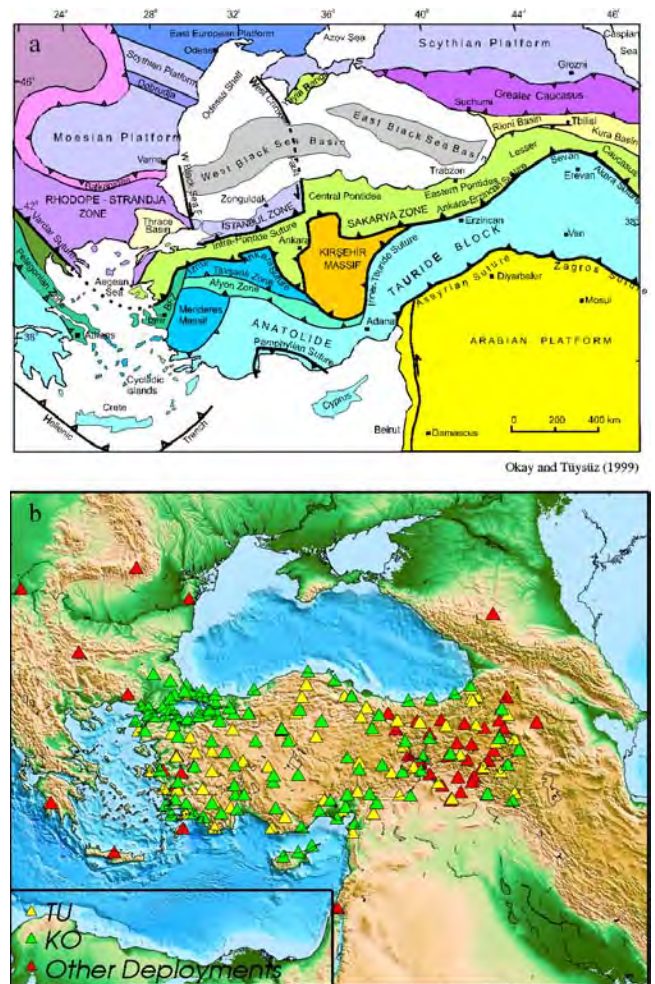


Figure 1. a) Tectonic blocks of Turkey. b) Broadband seismic station distribution.

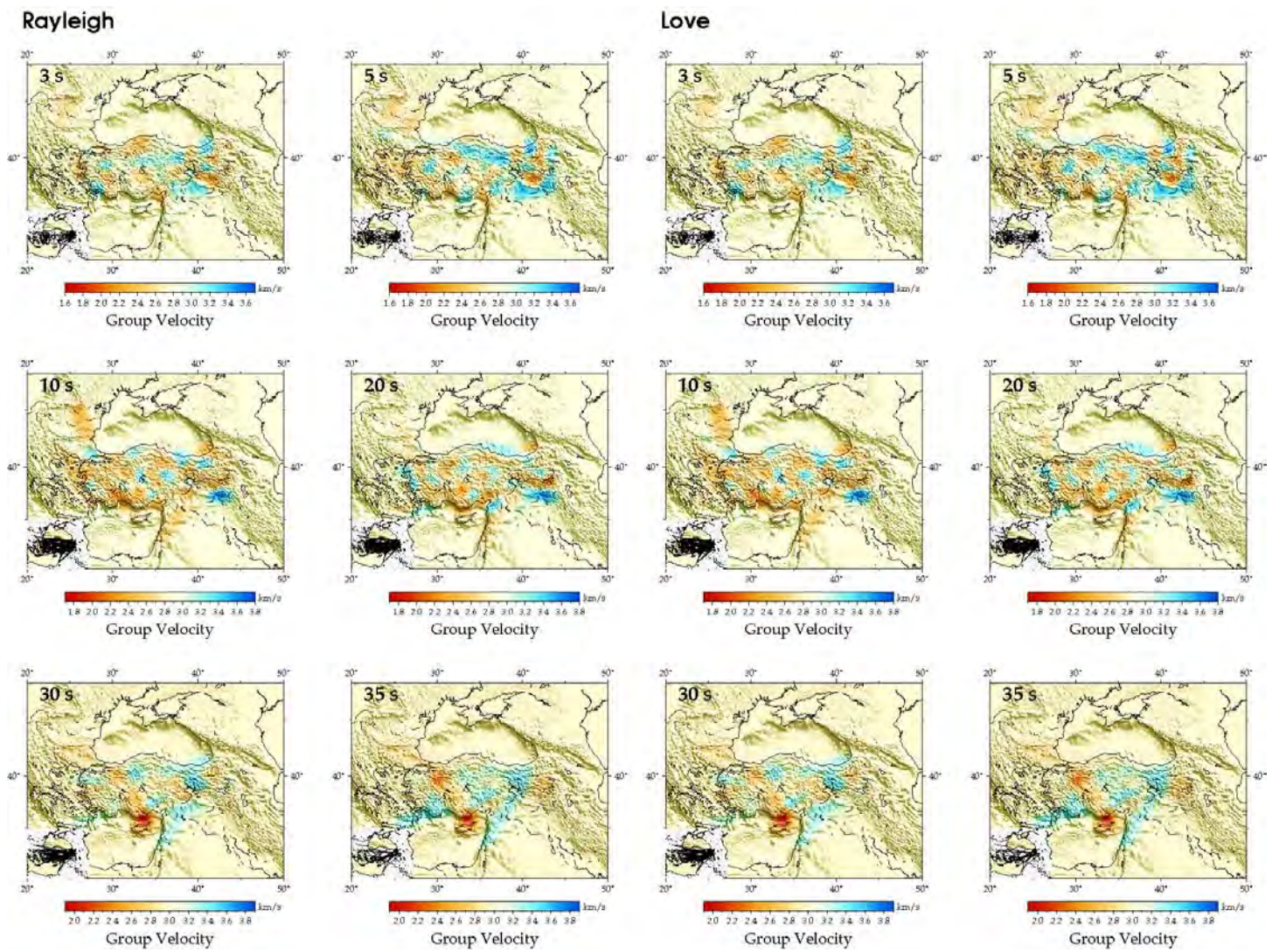


Figure 2. Ambient seismic noise tomography images for Rayleigh and Love waves.

Crustal Structure of Australia from Ambient Seismic Noise Tomography

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The cross-correlation of the ambient seismic noise field recorded at two different seismic stations gives a surface wave type Green's function between the two. The surface wave type Green's function has dispersive characteristics which carries information from different depths of the Earth over a range of periods.

In this study, we use all of the available broadband data from temporary and permanent stations in Australia to extract the Green's functions from the ambient seismic noise field. Then we create a number of tomographic maps from the inversion of the group velocity dispersion of Rayleigh and Love waves (figure 1). As a final step, we merge the results by inverting each point for estimating the 1-D shear wave velocity structure with a nonlinear direct search algorithm.

The tomographic images in figure 1 show complex patterns of seismic velocities for the shallower depths (3-10 s) for both classes of the wave tomography. The thick sedimentary basins of the regions i.e. Canning, Eromanga are well imaged with lowered velocities. The Archaean Cratons in Western Australia show consistently high velocities in compared to other parts of the continent. The rapid change in group velocities from Canning Basin to the Kimberley region corresponds to the terrane change.

In figure 2, the inverted shear wave velocity model from dispersion curves are given for the seismic station TL07 located in central Australia.

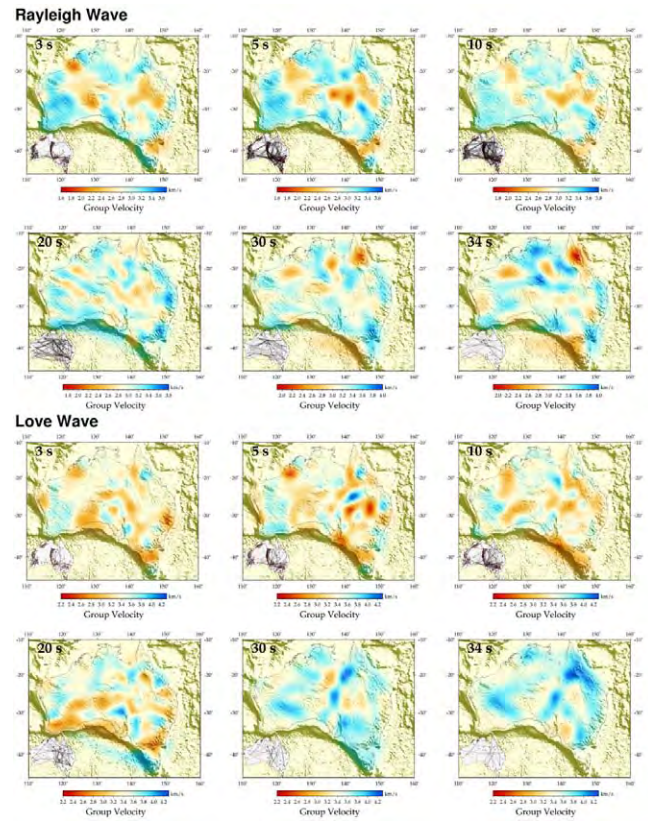


Figure 1. Combined images of Rayleigh and Love waves from ambient seismic noise tomography.

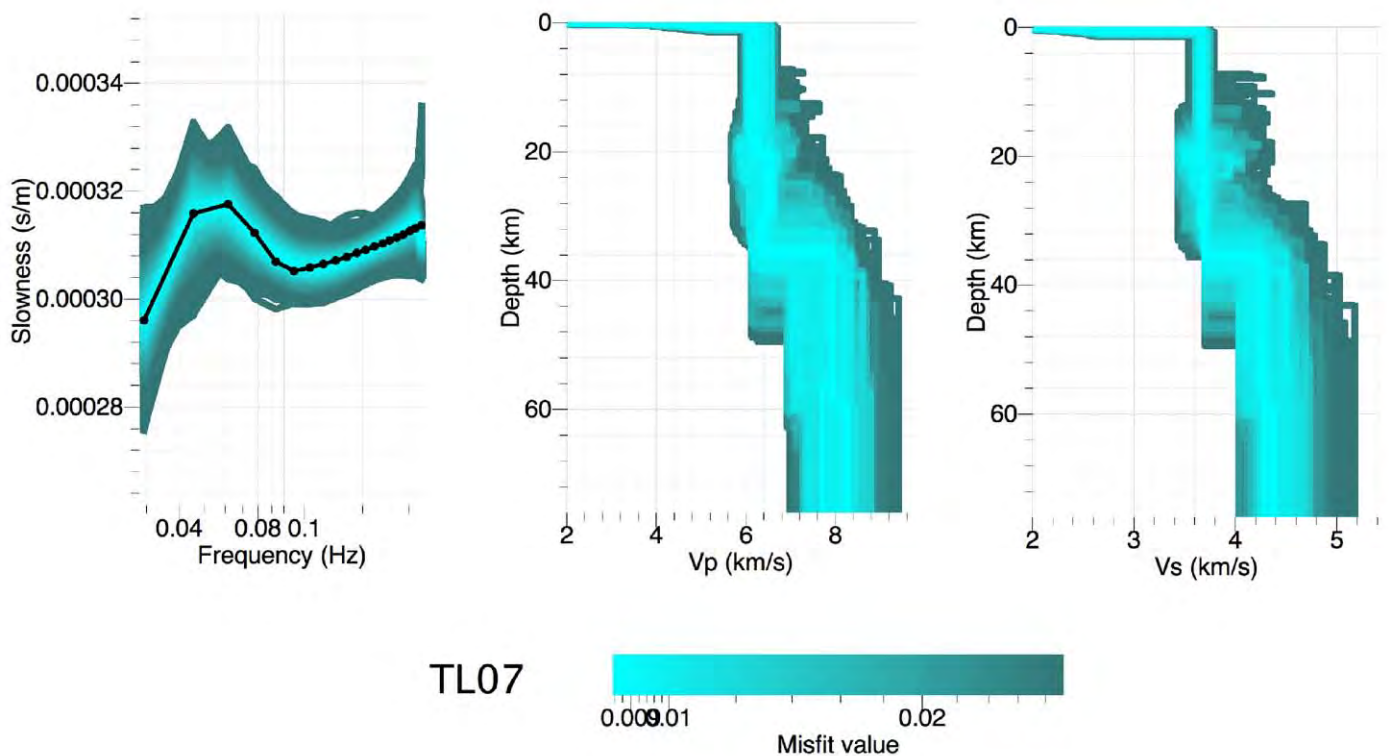


Figure 2. Shear wave velocity structure of station TL07 obtained from the inversion of ambient seismic noise tomography.

Is the Earth's Inner Core a Conglomerate of Anisotropic Domains?

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Cylindrical anisotropy in Earth's inner core has been invoked to account for travel times of PKP core-sensitive seismic waves, such as from the South Sandwich Islands (SSI) earthquakes observed in Alaska (Figure 1), which depart from predictions. Newly collected travel-time residuals from seismic waves from the SSI region that sample only Earth's mantle (PcP and P waves; see inset of Figure 1) have a comparable range to the PKP differential travel-time residuals, yet they are insensitive to core structure. This observation suggests that mantle structure affects PKP travel time residuals more than previously acknowledged and challenges the existing conceptual framework of a uniform inner core anisotropy. The inner core could be a conglomerate of anisotropic domains (Figure 2), and the PKP travel times are most likely influenced by the geometry of inner core sampling and inhomogeneous mantle structure. Spatial and temporal variations of the geomagnetic field and the lowermost mantle heterogeneity via the outer core can contribute to the complex structure of the inner core. Columnar convection and convective heat flux in the outer core result in heat transfer variations, which influences the inner core growth and crystal alignment. Thus, only for certain geometries of sampling, the accumulated travel time anomaly will be strong enough to be detected at the surface. Contrary, if elastic anisotropy in the inner core is weak or cancels out in the domains sampled by body waves, then some very anomalous travel times with respect to spherically symmetric models of Earth for those ray paths are likely to be a result of inhomogeneous or anisotropic structure outside the inner core, such is probably the case for the SSI earthquakes. The inner core as a conglomerate of anisotropic domains reconciles observed complexities in travel times while preserving a net inner core anisotropy that is required by observations of Earth's free oscillations (Figure 2).

Link to the online article:

<http://www.agu.org/journals/gl/gl1014/2010GL043841/>

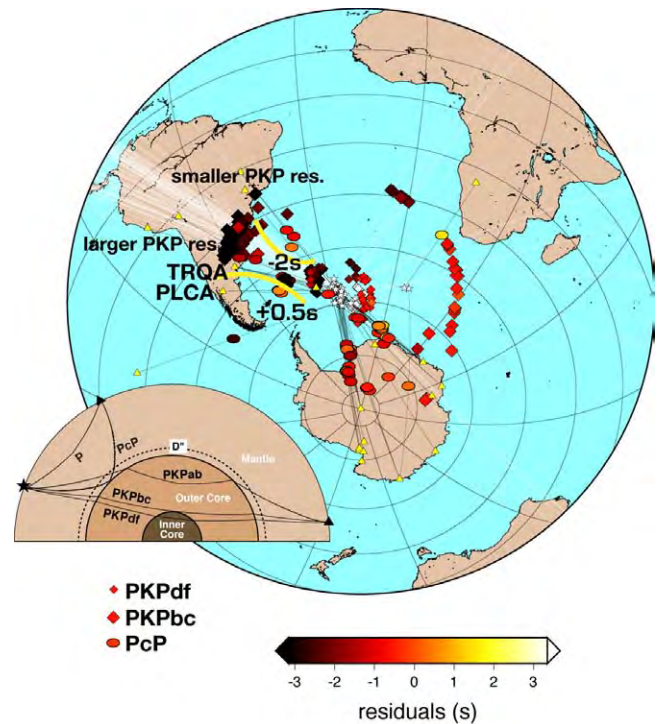


Figure 1. Map of locations of the SSI earthquakes used in this and in the previous study of PKP travel times (stars). Reflection points of PcP waves at the core-mantle boundary are projected to the surface (ellipses) in different colors corresponding to the observed PcP-P differential travel-time residuals. Piercing points of PKPdf and PKPbc waves in the IC are projected to the surface (small and large diamonds) with the corresponding PKPdf-PKPbc differential travel-time residuals using the same color scheme. Travel-time residuals are relative to the model ak135 by Kennett *et al.* [1995]. PKP and PcP ray-paths projected to the surface are shown in white and black lines. GSN stations PLCA and TRQA are highlighted. Yellow lines indicate a corridor in which some of the largest departures from theoretical predictions in PKPdf-PKPbc and PcP-P travel times are observed. A schematic representation of Earth's cross-section and ray-paths of seismic phases PKP, PcP and P waves used in the study is shown in the inset.

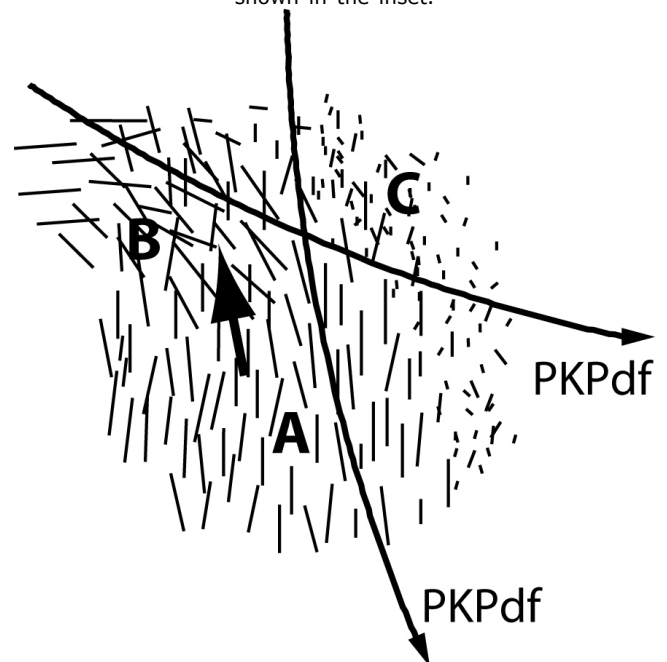


Figure 2. A schematic representation of three distinct anisotropic domains in the IC where the strength and orientation of fast crystallographic axes are shown as straight lines. Two different PKPdf ray paths are shown sampling different domains. A represents a semi-constant

anisotropy domain with a predominant alignment of fast anisotropic axes; **B** is a transitional domain with a mixed orientation of fast anisotropic axes, and **C** is an isotropic or a weakly anisotropic domain. The arrow in the middle represents the net direction of the fast axis of anisotropy.

Monsoon speeds up Indian plate motion

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Short-term plate motion variations, occurring over few Myrs, represent a powerful probe into the nature of forces acting along lithospheric plate boundaries, as mantle-related buoyancies evolve on longer time-scales. New reconstructions of the ocean-floor spreading record reveal an increasing number of such variations, but the dynamic mechanisms producing them are still unclear. In this study we show quantitatively that climate changes may impact the short-term evolution of plate motions. Specifically, we link the observed counter-clockwise rotation of the Indian plate since ~ 10 Ma to increased erosion and reduced elevation along the eastern Himalayas, due to temporal variations in monsoon intensity. By assimilating observations into empirical relations for the competing contributions of erosion and mountain building, we estimate the first-order decrease in elevation along the eastern Himalayas since initial strengthening of the monsoon (Figure 1). Furthermore, we show with global geodynamic models of the coupled mantle/lithosphere system that the inferred reduction in elevation is consistent with the Indian plate motion record over the same period of time (Figure 2), and that lowered gravitational potential energy in the eastern Himalayas following stronger erosion is a key factor to foster plate convergence in this region. Our study implicates lateral variations in plate coupling and their temporal changes as an efficient source to induce an uncommon form of plate motion where the Euler pole falls within its associated plate.

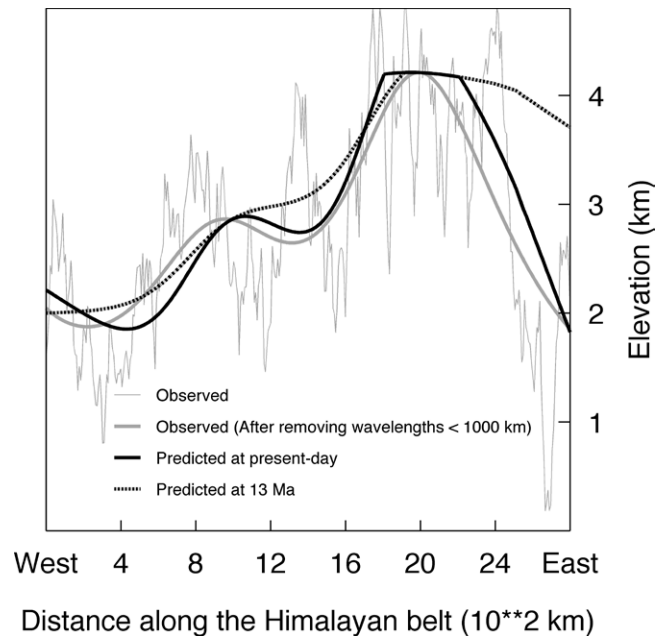


Figure 1. Present-day and past Himalayan elevation as observed and predicted from 2D analytic models. We model relief as the algebraic sum of time- and space-dependent contributions from mountain building and erosion rates, integrated since time of continental collision ~ 50 Ma. Grey thin line is the observed elevation at the present-day. Thick grey line is the observed elevation after short wavelengths have been filtered out to preserve wavelengths longer than 1000 km. Solid black is the prediction of our model at the present-day. We compare it against the observed elevation, filtered for wavelength shorter than 1000 km (thick grey). Based on the good agreement, we trust our model in its prediction of elevation at 13 Ma (dashed black), when the monsoon had reached its first peak. We infer that prior to monsoon intensification, elevation in eastern Himalayas was significantly different from the one at present-day, featuring an average relief as high as 4 km. At the same time, central and western Himalayas are predicted to be very similar to the present-day.

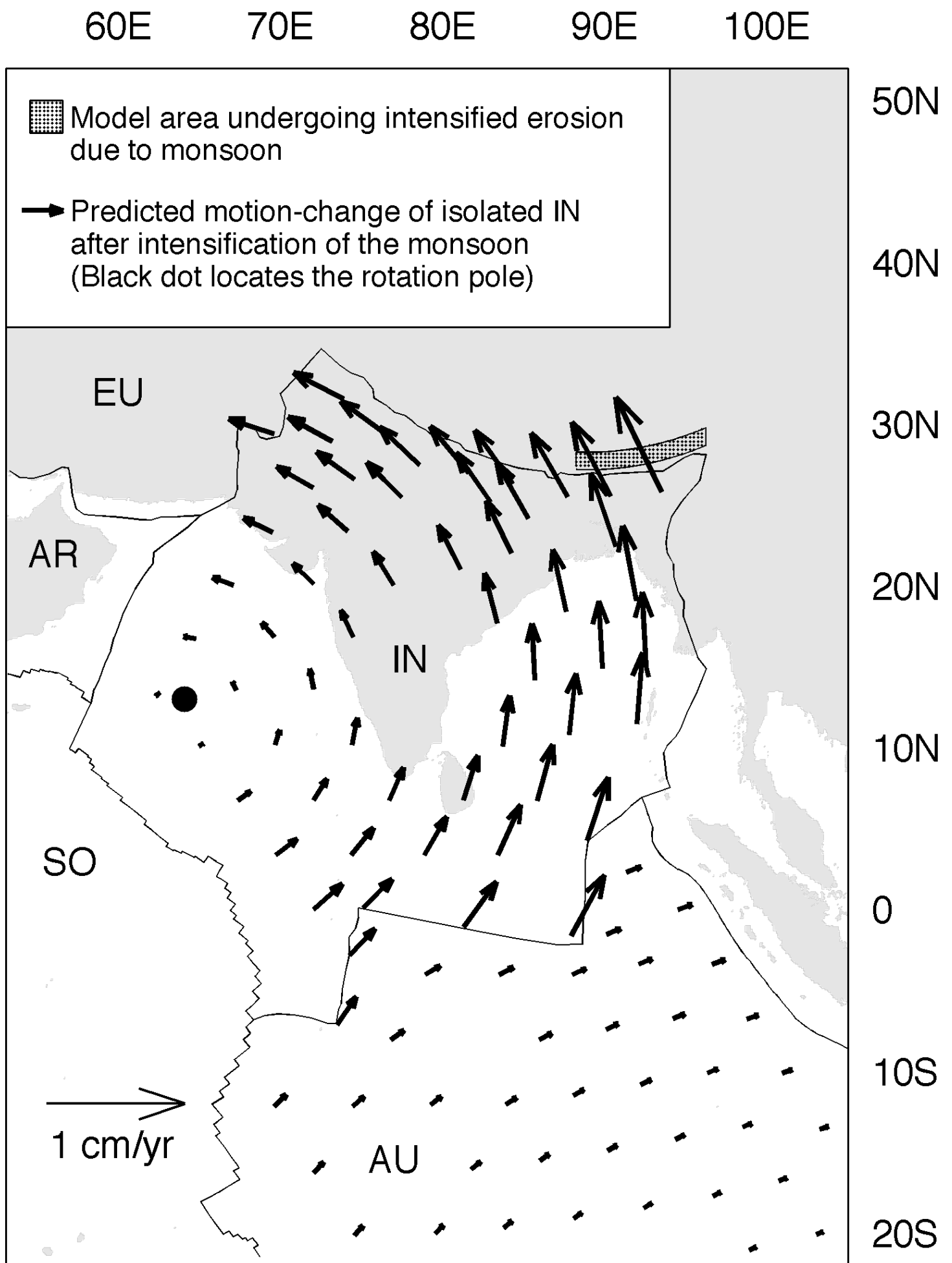


Figure 2. Indian plate-motion change following erosion of eastern Himalayas due to intensified monsoon. Impact of erosion in eastern Himalayas on Indian plate motion is estimated as the difference between the velocity fields computed before and after simulated intensification of the monsoon. We predict a velocity change induced on India as high as 8 mm/yr (black arrows), directed normal to the eastern IN/EU margin. An almost equal increase is predicted for the trench-parallel component along the western margin. Numerical result

compares well with our reconstruction of India/Eurasia kinematics (see Fig. 3-5). Importantly, predicted change of Indian plate motion is well described by an Euler pole located within Indian plate itself (black dot). Oceans are in white, continents in grey. Plate boundaries are in black, plate names as in Fig. 8.

Transdimensional Inversion of Receiver Functions with the Hierarchical Bayes Algorithm

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Receiver functions (Fig 1) are time series that are sensitive to the structure underneath a seismic station. These waveforms can be inverted for a 1D Shear wave velocity model of the crust and uppermost mantle beneath the receiver. In this type of inversion, the number of layers defining the velocity model, the level of smoothing and the required level of data fit are usually arbitrarily determined by the user prior to the inversion. These quantities are often manually 'tuned' by means of subjective trial-and-error procedures, and this represents a recurring problem.

We address these issues by proposing a novel and alternative inversion strategy. Different methodologies recently developed in the area of Bayesian statistics (i.e. transdimensional Markov chains, hierarchical models) are combined to produce an inversion algorithm, which treats the tunable quantities as unknowns to be constrained directly by the data. In this way the number of layers as well as the presumed magnitude and correlation of data noise are variable and treated as unknowns in the problem.

In such a transdimensional approach, the level of data uncertainty directly determines the model complexity needed to satisfy the data. The level of data noise effectively quantifies the usable information present in the data (a very noisy dataset does not contain much retrievable information), and thus it naturally controls the quantity of information that consequently should be present in the model (i.e. the number of model parameters). Here, an Hierarchical Bayes formulation of the problem enables us to estimate the level of data noise while at the same time controlling model complexity in an automated fashion.

The method developed is an ensemble inference approach, where many potential solutions are generated with variable numbers of layers (Fig 2a). This large ensemble of models is distributed according to a probability density function that represents the full state of knowledge we have about seismic structure. At each depth, local information about the velocity model is represented by a complete probability distribution (density map in Fig 2b). It is tantamount to picking a depth and asking the ensemble solution what velocity constraint is given by the data. This density plot is used as a way to visualise the ensemble solution, and it is particularly useful to picture the constraint we have on the Shear wave velocity model. Then, the probability of Shear wave velocity at each depth can be used to construct a solution 1D model. In Figure 2a is plotted the "mean model" (red line) which follows the mean of the distribution with depth.

If one is interested in assessing the number and position of seismic discontinuities beneath the seismic station, it is possible to examine the ensemble solution from a different point of view and to plot the probability distribution on the location of interfaces. Figure 2c shows an histogram of interfaces depth in the ensemble of models. For each depth, this function represents the probability of having a discontinuity, given the data. This provides useful information on the location of transitions, which can be unclear in other plots.

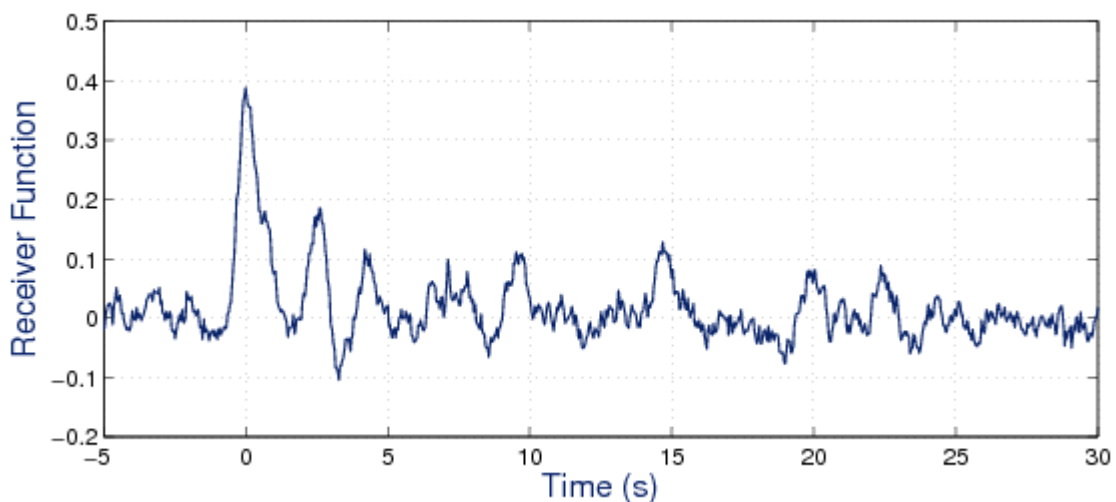


Figure 1. A noisy receiver function. Here, there is no information available about the data uncertainty, and hence it is difficult to separate the signal from the noise.

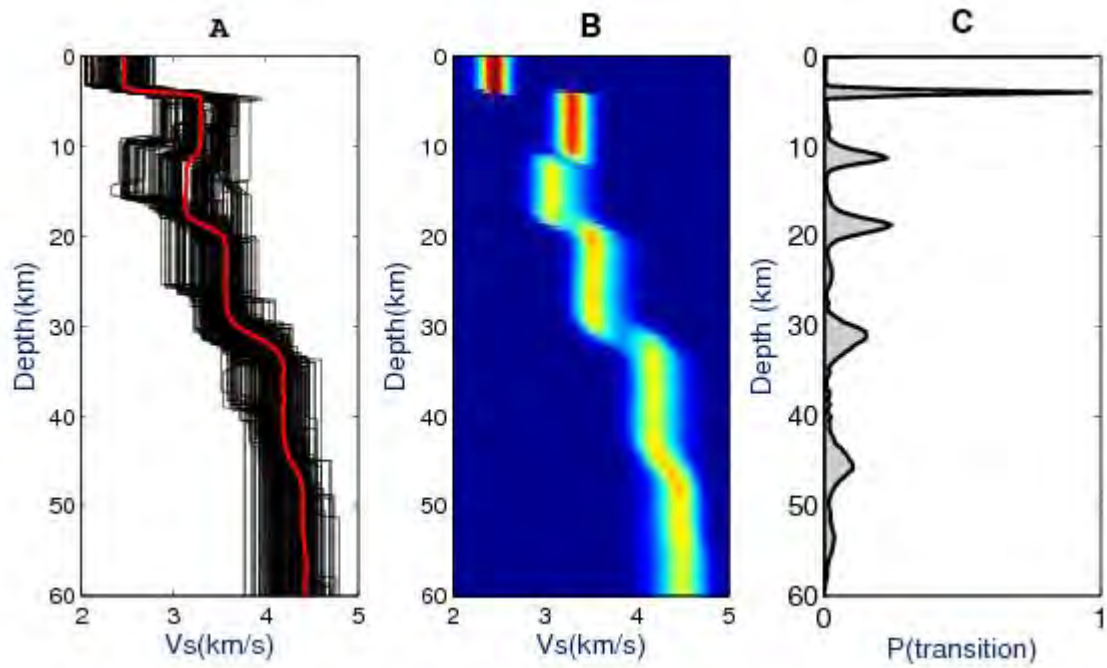


Figure 2. Results given by the transdimensional inversion. A) The models in black have variable number of layers and they represent the complete solution of the inverse problem. The model in Red is the average over the ensemble of models. B) density plot showing the probability density for the Shear wave velocity at each depth. C) Probability distribution for the position of transitions.

Seismic multi-pathing in complex media

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As seismic waves propagate through the Earth, they focus and defocus in response to variations in the physical and material properties of rocks. Even in relatively simple media, wavefronts can distort to such an extent that they eventually self-intersect, which results in more than one energy packet arriving at a receiver. This phenomenon is commonly referred to as multi-pathing, and is distinct from the arrival of multiple phases due to reflections and refractions in stratified media, and scattering. In order to numerically simulate the propagation of seismic waves in the presence of realistic Earth structure, one can solve the full elastic wave equation, but this is extremely time consuming, even on modern computers. A much simpler, but in many cases extremely effective, approach is to invoke the so-called "high frequency" assumption, where it is assumed that the wavelength of the seismic wave is much smaller than the dominant scale-length of the underlying heterogeneity. Under this assumption, principles from geometric optics can be used to track evolving wavefronts via their characteristics, commonly referred to as rays. These rays represent the propagation path of energy between a source and receiver, and in many cases can be computed very rapidly (e.g. by repeated application of Snell's Law). An alternative approach is to directly solve the so-called eikonal equation, which describes the evolution of wavefronts. These eikonal solvers are very efficient and robust, and can rapidly compute the traveltime field (traveltimes from some source to a grid of points that spans the medium) of very complex media. Both wavefronts and raypaths can be readily extracted from the traveltime field. However, one limitation of eikonal solvers is that they only find the first arrival, and provide no information on multi-pathing.

We develop a novel approach for locating multi-paths in complex media which harnesses the speed and efficiency of eikonal solvers. In its simplest form, our method involves computing traveltime fields for the both the source (forward field) and receiver (reciprocal field). By summing the two fields together, it is possible to identify stationary curves, which correspond to segments of later-arriving rays. Complete rays can readily be found by beginning at some point along the stationary curve, and following the traveltime gradient back to the source and receiver through the forward and reciprocal fields respectively. In theory, this approach can be extended to locate all later arrivals. Tests in complex 2-D media show that the new method is rapid, robust and highly accurate.

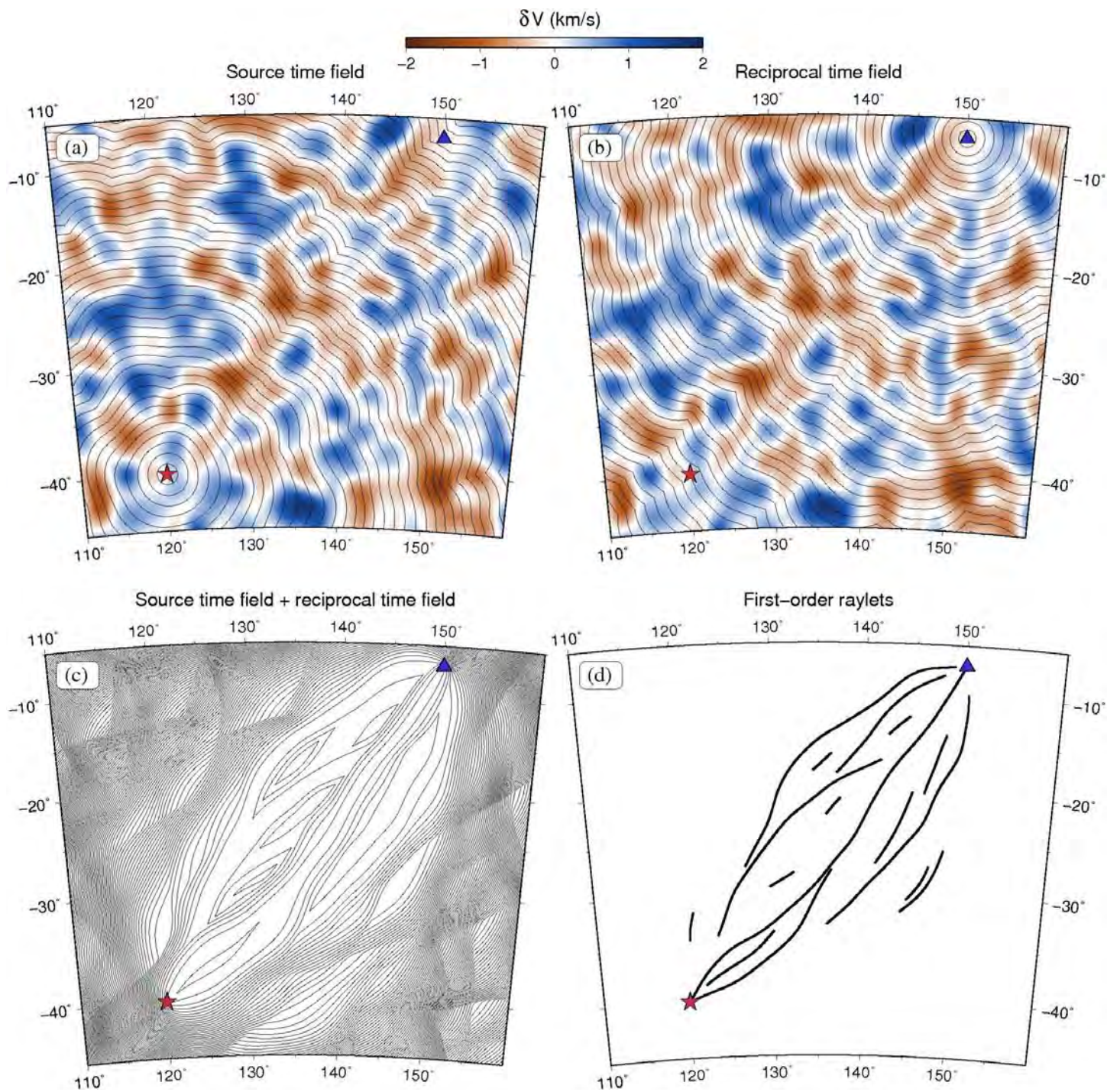


Figure 1. Example showing how the forward and reciprocal traveltime fields can be summed to extract "raylets", which are stationary curves that represent segments of complete raypaths.

Passive seismic imaging of the southern Tasmanides

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The Tasman Orogen or Tasmanides of eastern Australia largely consists of a series of accretionary orogens that formed outboard of the Pacific margin of eastern Gondwana from the Middle Cambrian through to the Middle Triassic. Occupying approximately one-third of present day Australia, the Tasmanides incorporate five orogenic belts, including the Delamerian and Lachlan orogens in the south, the Thomson and North Queensland orogens in the north, and the New England Orogen in the east. The Delamerian Orogen, which incorporates the Adelaide Fold Belt in South Australia, extends southward from the mainland into Tasmania, where it is often referred to as the Tyennan Orogen. It comprises Precambrian and Early Cambrian rock sequences that were subject to contractional orogenesis along the eastern margin of Gondwana between about 514 Ma and 490 Ma. This was followed in the Late Cambrian by the formation of the Lachlan Orogen to the east, which continued through to the Early Carboniferous.

In order to study this fascinating region of Australia, a series of passive array deployments have taken place in Tasmania, Victoria, South Australia and New South Wales over the last twelve years which has resulted in over 550 station locations spaced between 15-50 km apart. The collective array is referred to as WOMBAT, and the large volumes of passive data that have been recorded provide a unique opportunity to image a large region of the Australian continent at high resolution. Teleseismic tomography using relative arrival times from seven of the sub-arrays has been carried out to image the mantle lithosphere beneath most of Victoria, southern New South Wales, and eastern South Australia.

The results from the teleseismic tomography show a marked variation in the strike of dominant P-wave velocity anomalies with depth. Immediately beneath the crust, dominant variations in velocity tend to strike east-west, and share little resemblance to Palaeozoic boundaries inferred in the shallow crust from surface geology and potential field data. A broad region of elevated wavespeed beneath central Victoria may represent the signature of under-plated igneous rocks associated with detachment faulting during the break-up of Australia and Antarctica. A distinct low velocity anomaly to the south of this feature appears to correlate well with the Quaternary Newer Volcanic Provinces. Towards the base of the mantle lithosphere, the dominant structural trend becomes north south, and five distinct velocity zones become apparent. Of particular note is a transition from higher wavespeed in the west to lower wavespeed in the east beneath the Stawell Zone, implying that the Proterozoic lithosphere of the Delamerian Orogen protrudes eastward beneath the Western subprovince of the Lachlan Orogen. This transition zone extends from southern Victoria into central New South Wales (the northward limit of the arrays), and is one of the dominant features of the model. Further east, there is a transition from lower to higher wavespeeds in the vicinity of the boundary between the Western and Central subprovinces of the Lachlan Orogen, which has several plausible explanations, including the existence of a Proterozoic continental fragment beneath the Wagga-Omeo Zone.

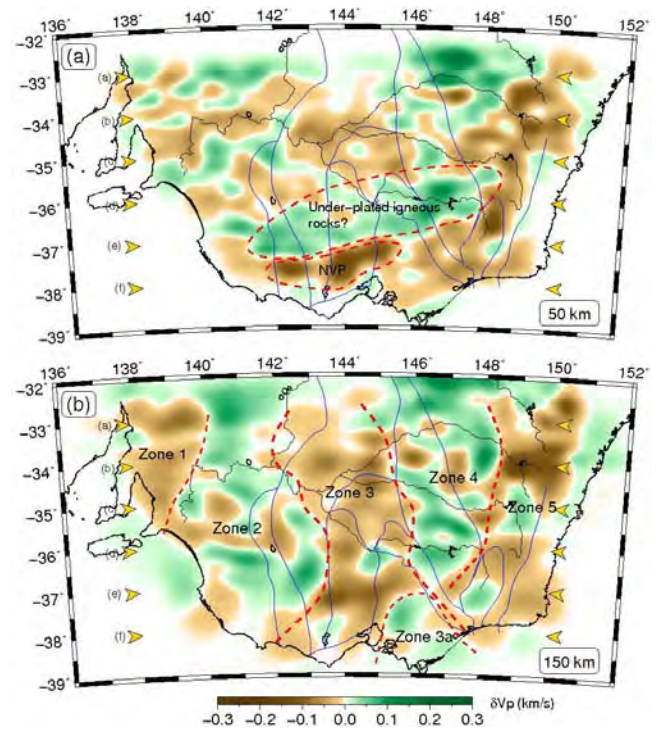


Figure 1. Two horizontal sections through the final tomographic model highlighting features of interest

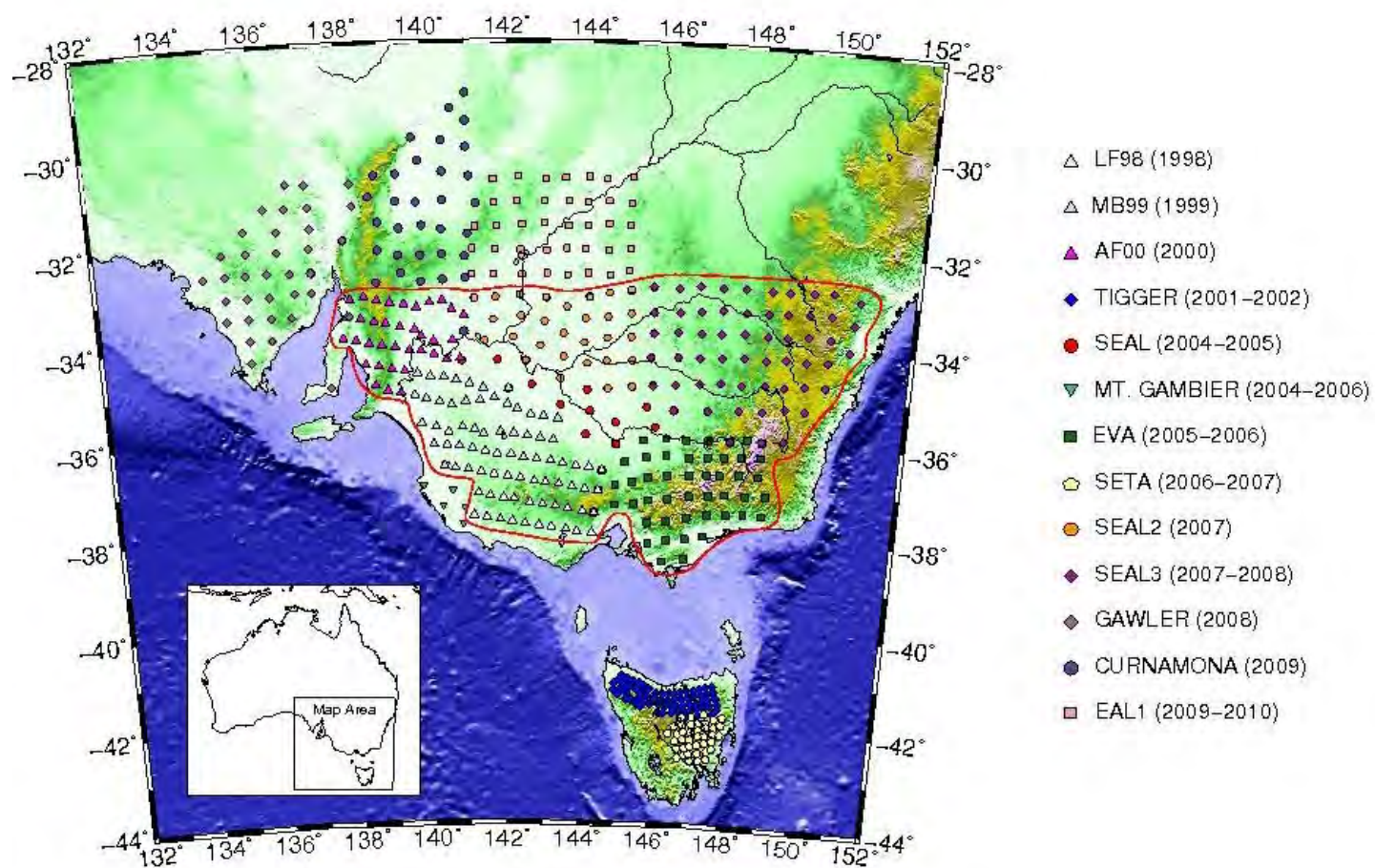


Figure 2. Map showing the locations of all WOMBAT stations. The thick red line encircles only those arrays that were used in this study.

Varying mechanical coupling along the Andean margin: implications for trench curvature.

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The Andean system, where the Nazca plate plunges beneath continental South America, is often regarded as the archetype of convergent margins where spatial and temporal correlations between the trench curvature, shortening, and uplift stand out from the geologic record. These links however remain debated. There is distinctive evidence that the degree of mechanical coupling between converging plates, i.e. the amount of resistive force mutually transmitted in the direction opposite to their motions, may significantly vary along the Andean margin at present-day. In this study we employ laboratory models of subduction to investigate quantitatively the role of the lateral variations of the mechanical coupling between converging plates in controlling the evolution of trench curvature. The analogue of a two-layer Newtonian lithosphere/upper mantle system is established in a silicone putty/glucose syrup tank-model. We perform two models where we monitor the temporal evolution of the trench. In the first one, the central portion of the margin is more strongly coupled compared to the rest, where a lubricant paste has the effect of reducing plate coupling (Figure 1). In the second model we instead maintain plate coupling at a uniform low level along the entire interface by leaving a channel of glucose syrup between the overriding and the subducting plates (Figure 2). We find that the ability of the experimental overriding plate to slide above the subducting one is significantly inhibited by strong mechanical coupling. This inference applies in particular to the central Andean margin, where the overriding plate shortens more than elsewhere along the margin, and the trench remains stationary as opposed to the advancing northern and southern limbs. Consequently, the margin evolves into the peculiar shape observed along the Andes in the present-day.

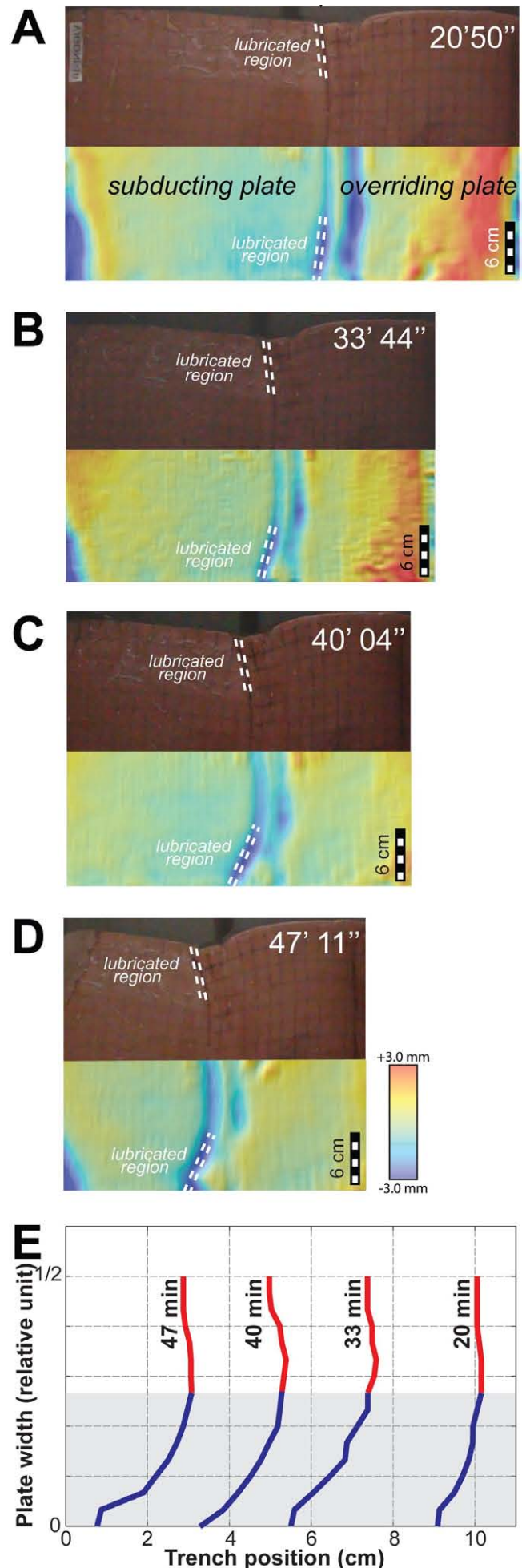
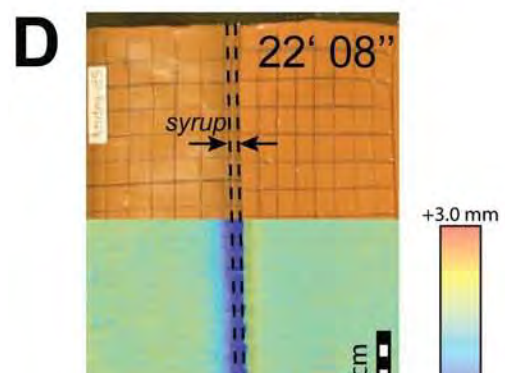
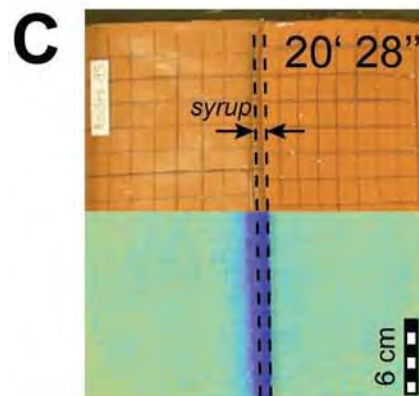
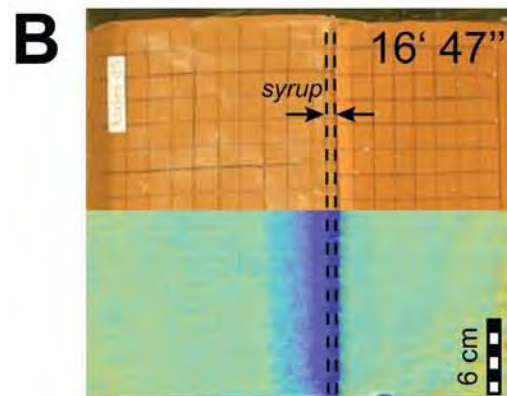
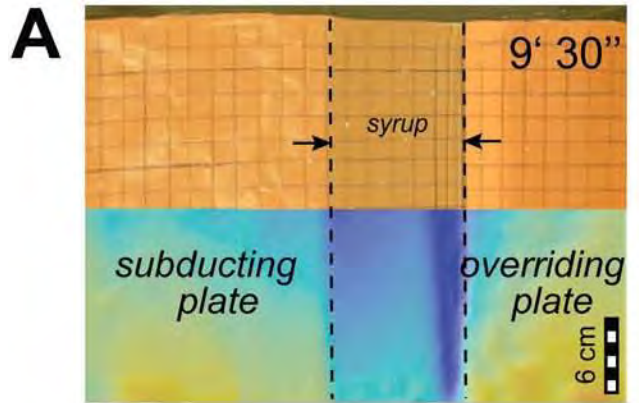


Figure 1. Laboratory model 1. Panels A-D are snapshots of trench evolution; elapsed time from model start is in the

upper-right corner. The subducting plate undergoes the overriding one from left to right. The upper half of each panel is a picture of the plates, where 2 x 2 cm squares are outlined to detect deformation. The lower half is a laser-scanned image of plate relief (offset from the beginning of the model) acquired at the same moment: red represents bulging upwards, blue is bulging downwards. Note that the model plates are manually attached to the pistons, therefore the peripheral regions naturally bulge upwards or downwards, and are thus detected as anomalous. Panel E shows the evolution of half-trench through time, as detected through the laser-scanned images. Red on white is the portion of trench with no lubricant paste, hence featuring high coupling. Blue on gray is one of the lateral edges with lubricant paste, thus featuring average coupling.



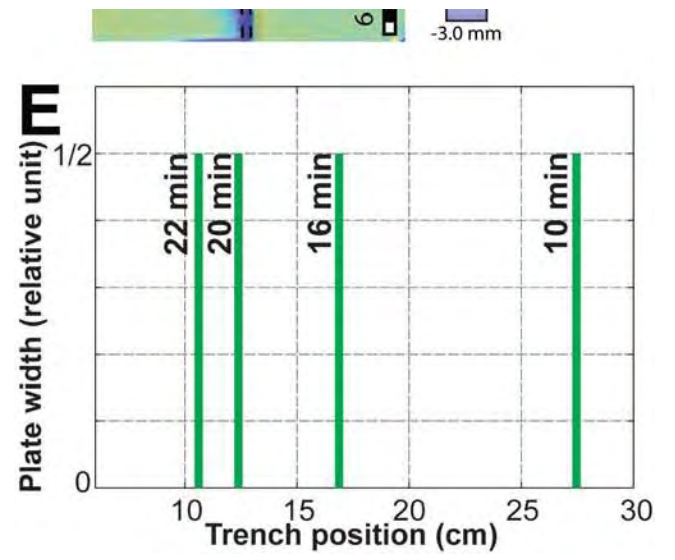


Figure 2. Laboratory model 2: analog subduction featuring uniformly low mechanical coupling along the plate interface, obtained with lubricating syrup (panels A-D). Images are equivalent to the ones in Figure 1.

Tears or thinning?

Subduction structures in the Pacific plate beneath the Japanese Islands

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The nature of a subduction zone at depth is affected by the evolution of its tectonic system, and the geometry of the trench line can change over time due to slab roll-back or the arrival of a distinctive feature with the incoming oceanic lithosphere. The configuration of the plate has to accommodate such changes with buckling, thinning or the formation of tears depending on the rate of influx to the trench.

Tomographic imaging is commonly used to recognise the presence of such tears through marked reductions in wavespeed anomalies in localised zones. A good example is provided by Pacific Plate subduction beneath the Japanese Islands. A horizontal tear in the plate below 300 km depth can be recognised at the southern end of the Izu-Bonin arc associated with the change in slab morphology to the much steeper Mariana arc. Beneath southern Honshu a break in the fast wavespeeds associated with the Pacific plate has been described as a tear based on evidence of converted phases from the edge of the zone and tensional focal mechanisms for seismic events in the tear zone.

In the north, close to the Hokkaido bend in the subduction zone, the reduction in the shear wavespeed anomaly is just as dramatic, so that a slab tear might be inferred. A test of the nature of the slab can be made by using high frequency waves trapped within the subduction zone that are guided by elongate wavespeed variations along the length of the slab. Such waves can travel to the surface from even the deepest earthquakes, but the conditions for trapping energy are quite subtle and can be readily disrupted. In the zone of apparent tear such guided waves propagate but with a reduced high frequency content. This behaviour requires continuity of slab material and indicates a thinning of the subduction zone. The thinned slab has less wavespeed contrast within the affected cells and so appears in the tomographic images as a weakened anomaly.

The various modes of slab deformation represent different ways in which the subducted material accommodates the strains imposed by the evolution of the geometry of the subduction scenario. Not all significant reductions in wavespeed anomalies represent tears and thus it is important that such interpretations be checked against the characteristics of wave propagation through the zone.

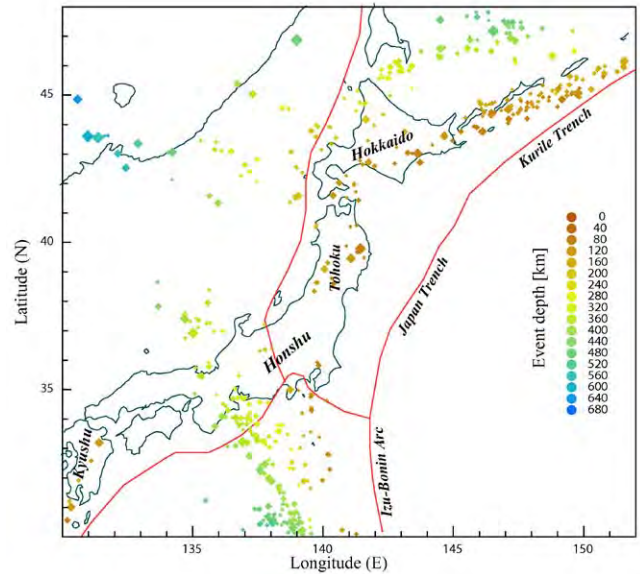


Figure 1. Earthquakes in the Japan region showing the deep events associated with the subduction zone. Seismograms for deep events are analysed at stations along the east coast of Japan to look for high frequency guided waves that would indicate continuity of slab structure.

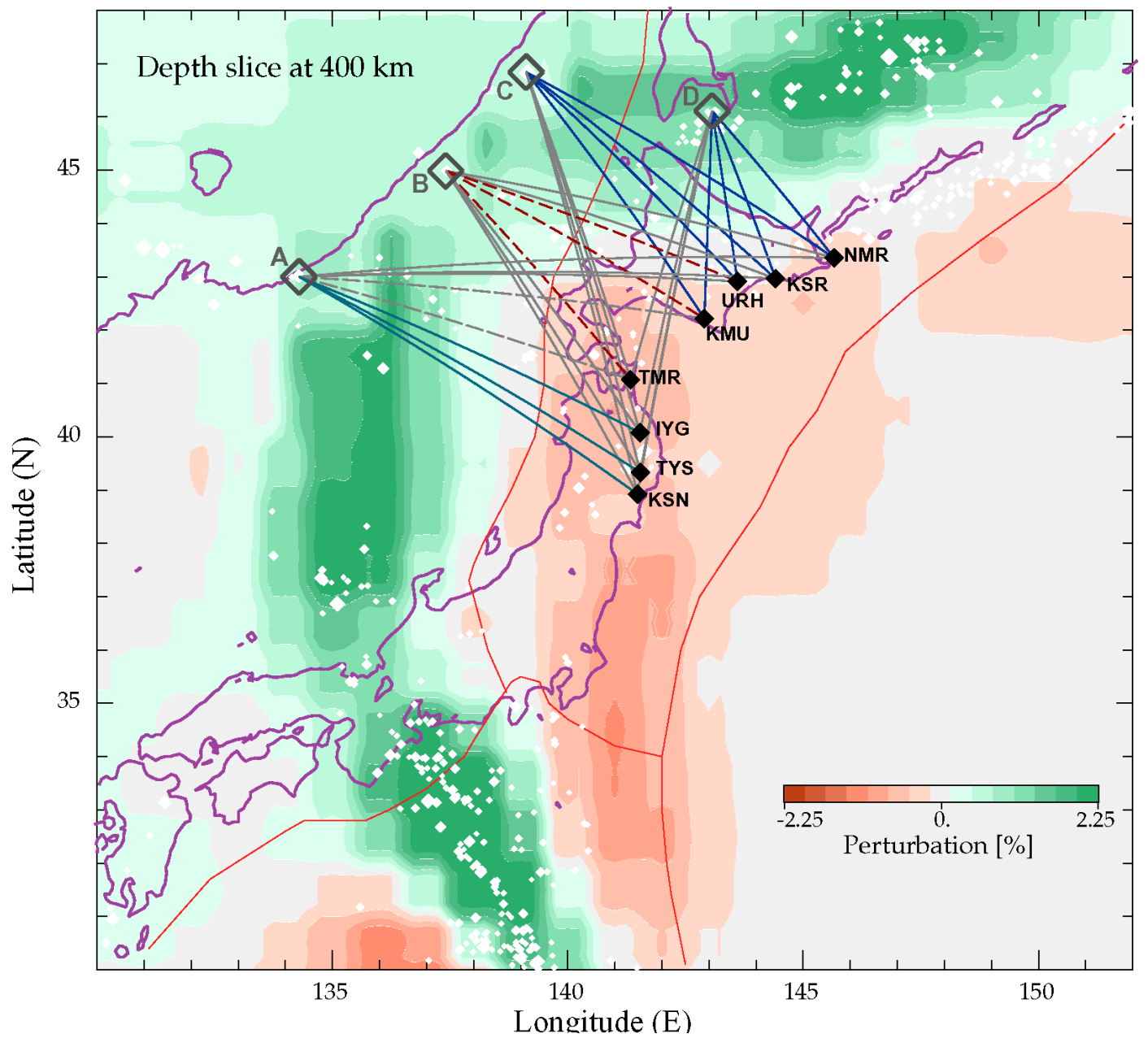


Figure 2. Propagation paths for guided waves superimposed on the tomographic image at 400 km that shows a distinct gap between the fast wavespeed structures associated with the subduction zones beneath Honshu and the Kurile chain. Seismograms from the four marked events A-D observed at stations on the east coast of Japan show clear guided waves indicating continuity of the slab despite the weak signature in the tomographic images. The dashed paths have less high frequency content and suggest thinning of the subduction zone to accommodate the change in geometry from Honshu to the Kuriles.

A Synthesis of Local, Teleseismic, and Ambient Noise Data for High-Resolution Models of Seismic Structure in Western and Southeast Australia.

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The use of ambient seismic noise has become an increasingly popular method of imaging the Earth's crust with high resolution. For example, variations in group and phase velocity in the Tasmanian and Western Australian lithosphere were mapped through the cross-correlation of ambient seismic noise recorded by temporary array deployments. Additional constraints from receiver functions improve the depth resolution and sensitivity to velocity gradients and allow a joint inversion for shear velocities.

The southeast Australia dataset comes from the WOMBAT rolling seismic array project in Tasmania, which in the last decade has seen over 500 stations deployed. The group and phase velocity maps for this area clearly discriminate between regions of hard rock and sediment and indicate temperature differences. One of the prominent features of the maps is a pronounced low velocity zone that coincides with the Tasman conductivity anomaly, a region of elevated conductivity and heat flow, which may reflect the presence of a lithospheric boundary.

These methods were also applied to the 20 CAPRAL stations in Western Australia. Significant improvement in fit between synthetic and regional earthquake waveforms is evident after the shear velocity models of the crust replace those of current earth reference models. Moreover, reliable crustal maps are crucial to the accurate full waveform inversion of regional earthquake source parameters and enable a better understanding of the rupture process.

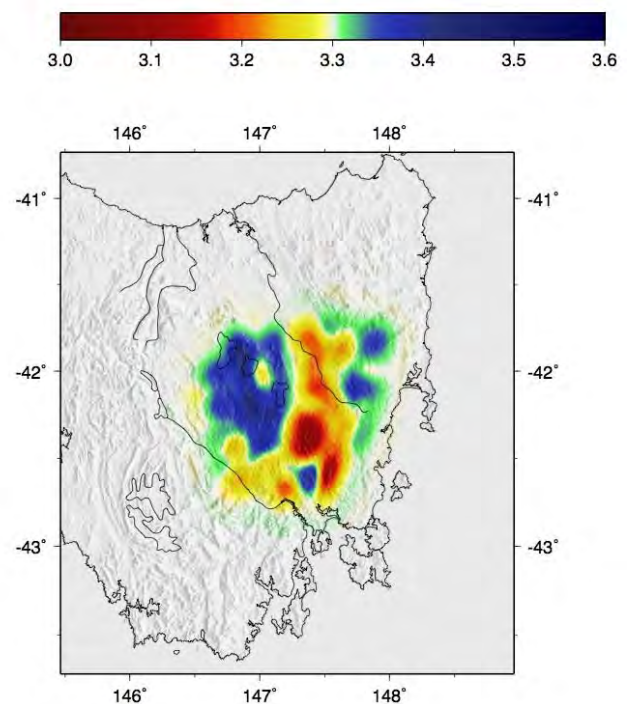


Figure 1. Shown here are the variations in phase velocity (km/s) in eastern Tasmania for a period of 4 seconds as determined from ambient seismic noise.

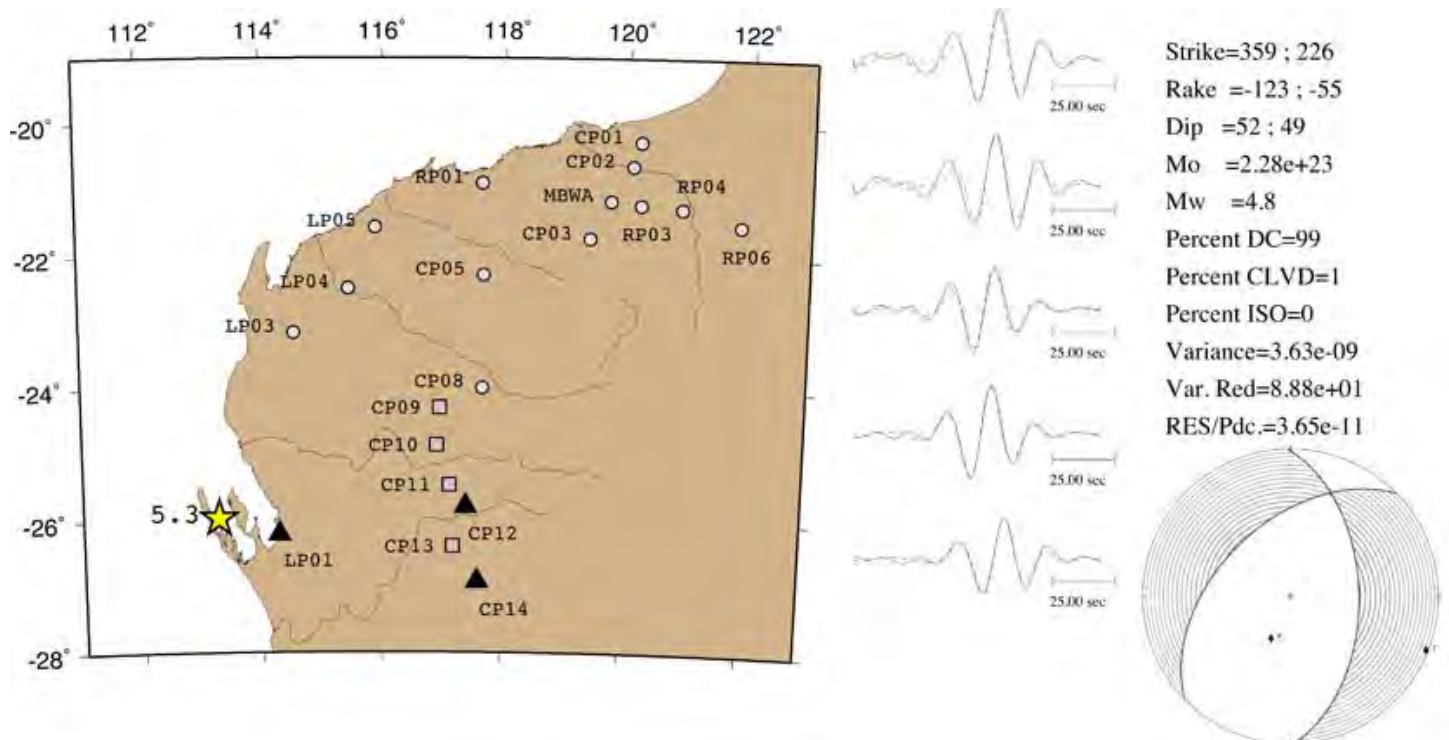


Figure 2. The CAPRAL stations in Western Australia are shown on the left. On the right, you can see the excellent agreement between synthetic and recorded vertical waveforms from a local magnitude 5.3 earthquake. The inverted focal mechanism solution is shown as well.

Balancing the Southern Ocean

Marshall L. Ward and Andrew McC. Hogg

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Intense eastward winds blow perpetually over the waters around Antarctica, injecting a continuous stream of energy and momentum into the Southern Ocean. This leads to the formation of the Antarctic Circumpolar Current, a massive current responsible for the exchange of water between the world's oceans and a crucial component of the Earth's climate. But what determines the eventual circulation? What prevents this current from accelerating endlessly? What balances the surface winds from above?

The answers to these questions depend on subtle interactions between the largest and smallest features of the circulation. The Geophysical Fluid Dynamics group at ANU has been using high-resolution numerical models to simulate the currents of the Southern Ocean. Our calculations show that the winds are largely counterbalanced by the undersea mountains and ridges, which push back against the winds as the current struggles to flow over them. But it is actually the mesoscale eddies, local swirls of ocean currents many times smaller than the ocean, that regulate the flow and determine its equilibrium state.

The currents flowing over the bottom ridges are inherently unstable, and faster currents tend to undulate and create more mesoscale eddies. These eddies emulate the effect of the topography below, pushing back against the current and countering the surface winds. As the winds continue to accelerate the current, the current produces more and more mesoscale eddies, until this pushback completely balances the surface wind forcing.

The details of these eddies are crucial to determining the eventual transport of the Antarctic Circumpolar Current, and our simulations demonstrate that even the smallest scales of the ocean can be responsible for the regulation of the climate in the ocean, highlighting the immense challenges ahead as we continue to improve our understanding of the global climate.

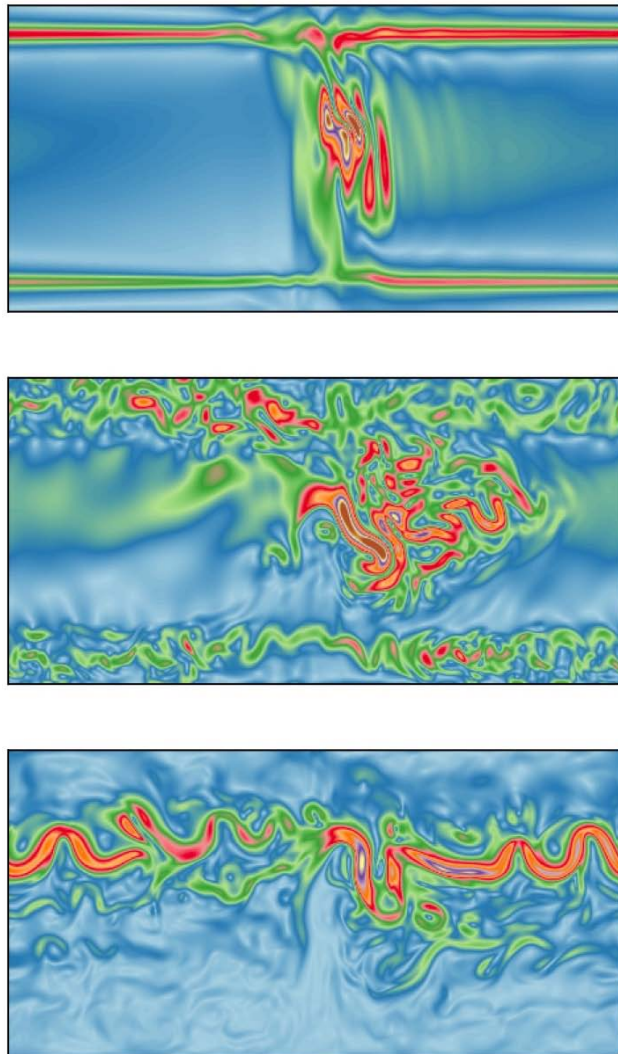


Figure 1. Winds force the model from a state of topographically determined flow (top figure), through an intermediary phase of instability and eddy formation (middle), until finally reaching a state of equilibrium where winds are balanced by the resisting influence of small-scale jets and eddies (bottom).

What drives the Antarctic Circumpolar Current?

Wind vs thermal forcing

Andrew McC. Hogg

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The Antarctic Circumpolar Current (ACC) is the world's strongest ocean current, connecting the three major ocean basins. The ACC is usually considered to be forced by strong westerly winds over the Southern Ocean. However, a comprehensive theoretical prediction of the volume of water transported (around Antarctica) by the ACC as a function of wind stress remains elusive.

In this study, simulations of an idealised, but eddy-resolving, channel model of the ACC are used to investigate the sensitivity of ACC transport to both wind stress and surface buoyancy forcing (heating/cooling). Sample temperature field from the simulations are shown in Fig. 1. The surprising result is that, even without any wind stress, a realistic ACC can be driven by surface heating/cooling along. When wind stress is varied (Fig. 2) the kinetic energy of the entire system increases, but transport around Antarctic is slightly reduced. On the other hand, transport is strongly influenced by change in the surface buoyancy forcing.

The results are consistent with theoretical predictions of the "eddy-saturated limit", where transport is independent of wind stress. In this parameter regime, surface heating/cooling is the primary control over ACC transport.

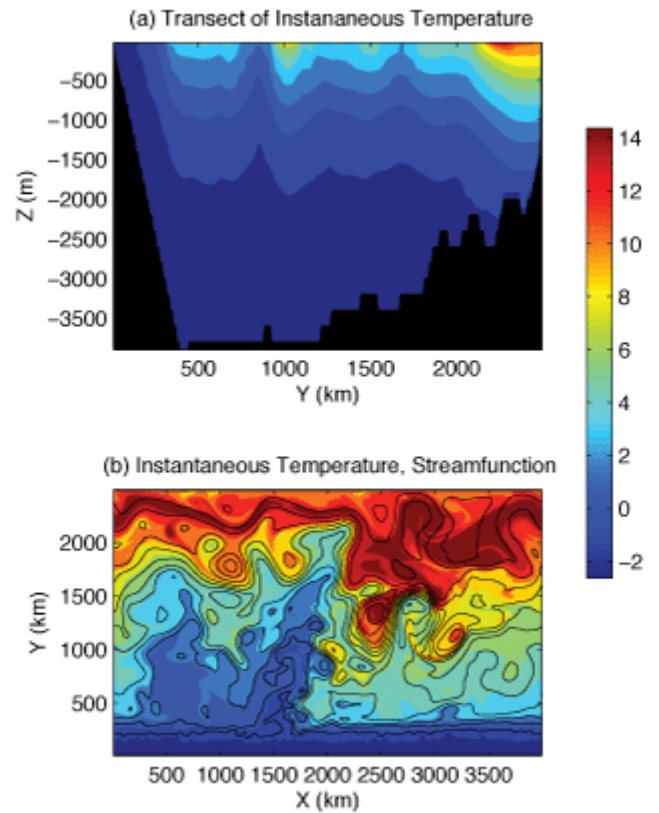


Figure 1. (a) Temperature in a north-south transect through the domain; (b) Plan view of temperature (colour) and streamfunction (lines) of a snapshot of the flow, illustrating the resolved eddies.

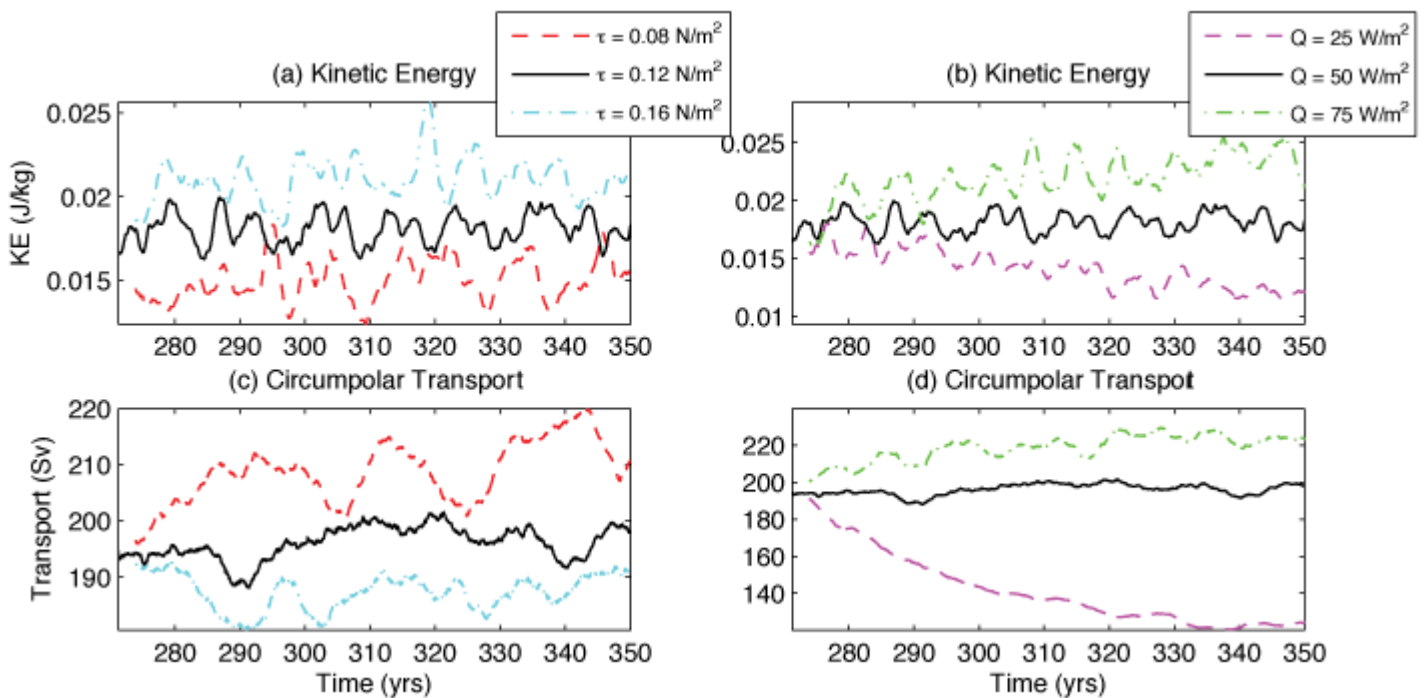


Figure 2. Kinetic energy response to (a) changes in wind stress; (b) changes in surface buoyancy forcing. Transport response to (c) changes in wind stress; (d) changes in surface buoyancy forcing.

Response of Southern Ocean overturning to future climate change

Adele K. Morrison, Andrew McC. Hogg and Marshall L. Ward

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The world's oceans have absorbed around one third of the total anthropogenic CO₂ emissions to date, with the Southern Ocean responsible for ~40% of the global oceanic anthropogenic carbon sink. The overturning circulation, through ventilation of upwelled deep water masses and subsequent formation of intermediate waters in the Southern Ocean, makes the region a dominant player in the exchange of air-sea CO₂ fluxes. Dense upwelled waters, rich in natural dissolved inorganic carbon, result in a significant outgassing band around Antarctica which nearly balances the Southern Ocean anthropogenic sink further north. Any future change in the strength of the overturning circulation has the potential to upset the balance between the outgassing and subduction of carbon, leading to feedbacks on the system.

Currently, the dynamics of the overturning are poorly understood and coarse resolution models fail to simulate the turbulent mesoscale eddy field, which plays a significant role in determining the magnitude and response of the overturning. We use idealised, but high resolution, eddy-resolving models of the Southern Ocean to investigate the sensitivity of the meridional overturning circulation to changes in surface wind stress and heat fluxes. We have found that the overturning is likely to increase under future warming and freshening of the southern hemisphere mid-latitudes. Enhanced westerly winds are also likely to increase the overturning, though the presence of eddies will partially compensate for the wind-driven changes.

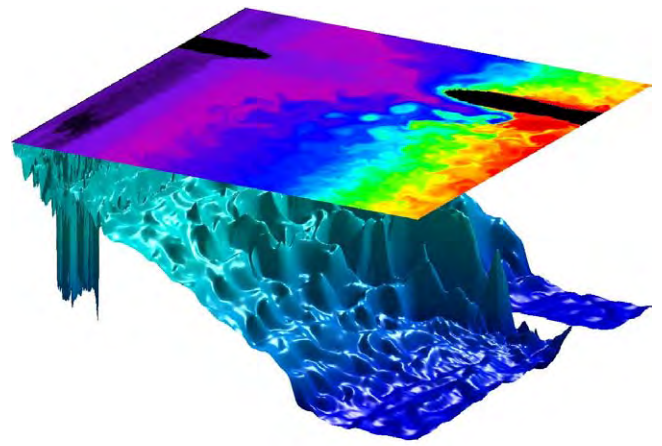


Figure 1. Idealised numerical model of the Southern Ocean overturning at 1/8° resolution. The eddy field shows up clearly in the surface density field (purple represents cold, dense waters; red represents warmer, lighter density waters). One interior constant density layer is shown (this model has twelve in total), depicting the connection between the deep ocean water masses and the surface, via the overturning circulation.

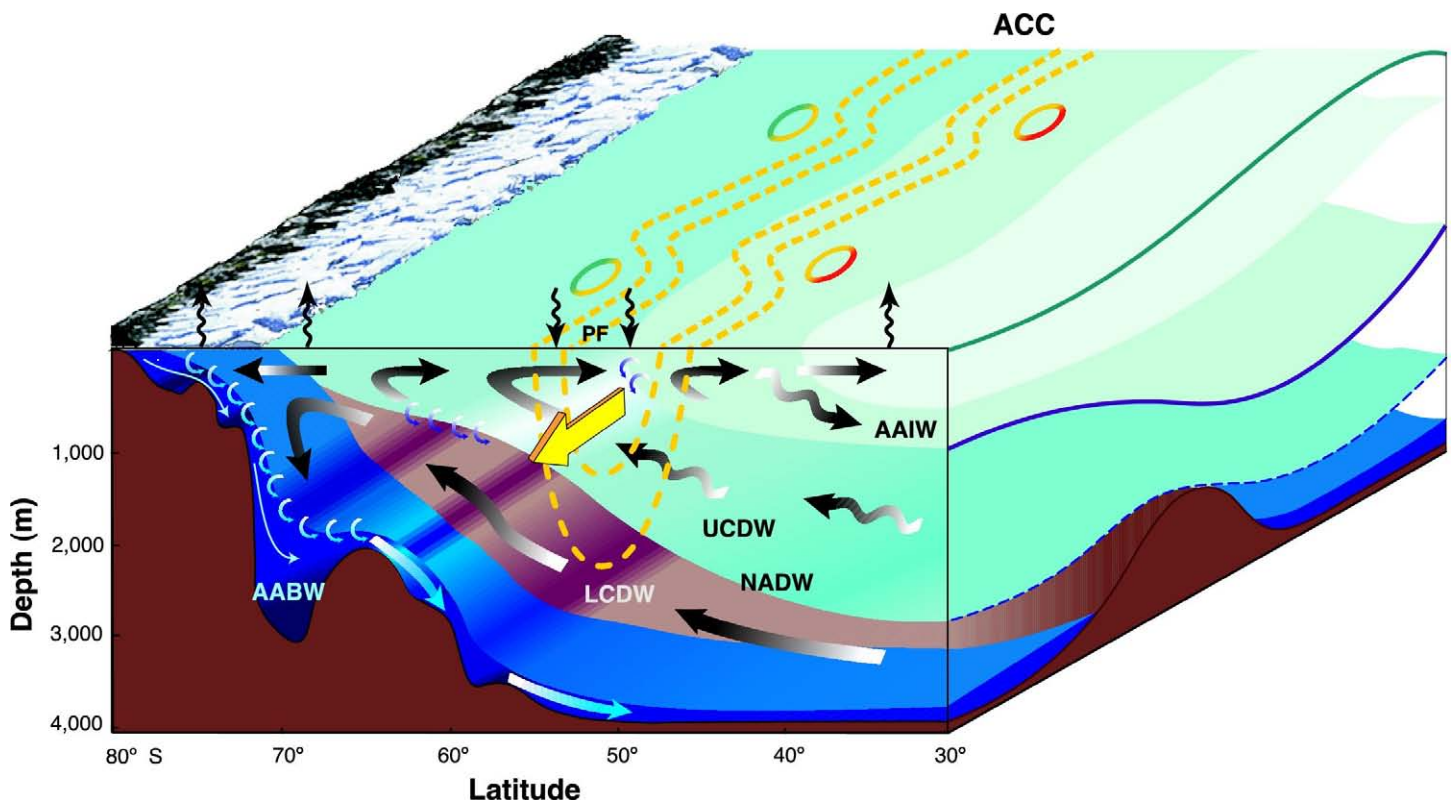


Figure 2. Conceptual model of the Southern Ocean limb of the meridional overturning circulation. From Olbers and Visbeck (2005). North Atlantic deep water upwells from the deep ocean to the surface.

The energetics of ocean circulation: the link between surface buoyancy forcing and the global rate of mechanical mixing

The energetics of ocean circulation

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

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The density of the ocean water can be altered by surface buoyancy fluxes (which tend to produce density differences) and irreversible mixing (which tends to eliminate differences). Hence the energy conversions associated with these two processes must balance when globally integrated (in a steady circulation). Thus we have argued in previous years that both the surface buoyancy (heat and freshwater) fluxes and sources of kinetic energy for turbulent mixing are simultaneously necessary to maintain the observed ocean overturning circulation. These factors have not been widely recognized: the turbulent mixing rate in the oceans is often viewed as independent of surface heat fluxes.

We are examining these concepts further in laboratory experiments with large-scale overturning forced by salt and freshwater fluxes at the surface (in place of heating and cooling) and in which mechanical stirring is imposed. The stirring is generated by horizontal bars, which are gently oscillated while being traversed up and down through the depth of the water column. The stirring causes a vertical mixing rate that can be accurately calibrated and parameterized in terms of an 'eddy diffusivity'. The rate of mixing of density depends on both the diffusivity and the vertical density gradient. Greater mixing rates gives rise to a greater rate of large-scale overturning. The results can be compared with theoretical solutions and with the behaviour of ocean general circulation models. Professor Griffiths delivered a plenary lecture on this topic at the APS-DFD conference, Longbeach California, in November.

A simple demonstration of the concepts of available potential energy produced by surface buoyancy forcing, and irreversible mixing, as illustrated in figure 2, can readily be set-up and would be useful for fluid mechanics teaching.

Figure 1. A diagrammatic representation of energy conversions in 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). We conclude that heating and cooling at the surface of the oceans, as well as external inputs of mechanical energy from the winds and tides, are essential for the maintenance of the overturning circulation in the oceans.

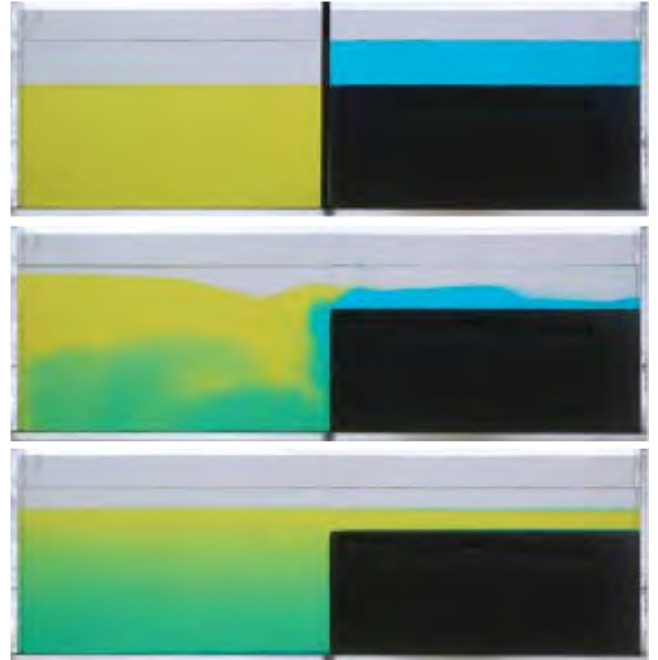


Figure 2. A simple flow designed to illustrate how surface buoyancy fluxes generate available potential energy (APE) upon conversion from background potential energy (without an increase in the total potential energy). The APE is then released in driving a mean flow, and irreversible mixing converts some of the APE back to background potential energy. The first frame shows surface layers of fresh (clear) and salt water (blue), and a volume of mid-density salt solution on the bottom (yellow). The barrier was then removed.

The effects of marginal seas on ocean density

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

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Heating and cooling along one horizontal boundary of a fluid leads to an overturning circulation known as "horizontal convection". Numerical modelling and laboratory experiments with horizontal convection are helpful in understanding the role of surface buoyancy fluxes in the oceans. For instance, the meridional variation of sea surface buoyancy fluxes leads to a poleward transport of heat and to localized sinking plumes at the polar extremities of the oceans. The plumes form the Deep and Bottom Waters that fill the abyssal ocean.

The majority of abyssal waters are formed by outflows from marginal seas or semi-enclosed basins, where submarine topography strongly influences transport. However, the role topography plays in the global meridional overturning circulation (MOC) is largely unknown.

In 2010 we have built on our previous studies of convective overturning circulation and examined the effects of a topographic sill, which defines a simple marginal sea, or smaller basin, at one end of a simple rectangular basin. Laboratory experiments (figure 1) and computer modeling show the presence of the marginal sea influences the global density structure when the sill depth is less than twice the oceanic thermocline depth. In these cases the dense water overflowing the sill interacts directly with the surrounding thermocline water, bringing the properties of the overflow (and thus, deep) water closer to those of the warm surface water. This result is the opposite of the effect expected on the basis that the sill tends to restrict exchange and increase the density of the sill overflow.

Application of the results to the North Atlantic circulation predicts that the Greenland-Scotland Ridge is shallow enough to lead to a significant reduction of the density of North Atlantic Deep Water. This conclusion is consistent with an analysis of North Atlantic water mass properties (figure 2).



Figure 1. Dye visualization of a horizontal convection experiment with a large topographic sill (the field of view includes only the left-hand half of the box). The overturning circulation is forced by surface cooling at the left-hand end of the box ("polar latitudes") and surface heating over the right-hand end ("equatorial latitudes"; not visible). The circulation is in thermal equilibrium. The dye originates at the surface at top right of the tank and marks relatively warm surface water flowing from right to left towards the sill, where some of it mixes with dense water overflowing the sill (from the smaller basin on the left) and sinks to the bottom in the overflow plume. This "short-circuiting" within the main basin warms the deep water in that basin.

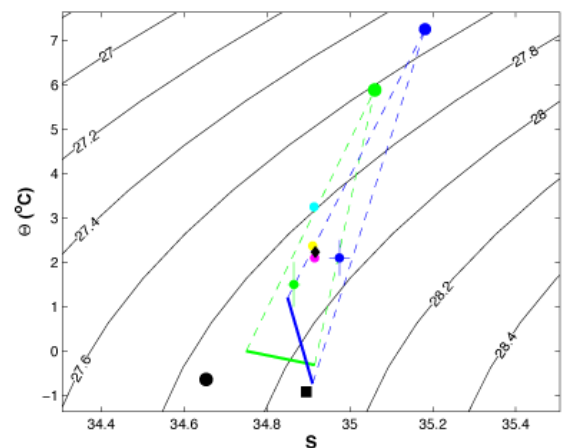


Figure 2. Potential temperature - salinity diagram for the water masses involved in the Greenland-Scotland Ridge exchange. Water properties shown are for the dense southward flowing waters entering the Denmark Strait and Faroe Bank Channel (green and blue bars, respectively), the relatively warmer and saltier overlying thermocline waters (large green and blue circles, respectively), and the overflow plumes sinking beyond the thermocline depths (small green and blue circles, respectively). These overflow plumes entrain North Atlantic intermediate waters (cyan circle) to give the deep western boundary current rounding Cape Farewell (magenta circle) and entering the Labrador Sea (yellow circle), subsequently exiting as North Atlantic Deep Water (black diamond). The dashed lines indicate mixing triangles coloured as per their respective product waters; this mixing is a result of the presence of the sill. Antarctic Bottom Water and Arctic Water are shown by the black circle and square, respectively.

Rayleigh-Taylor instability of an inclined buoyant viscous cylinder

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The Rayleigh–Taylor instability is most familiar as the gravitational instability of horizontal layers of fluid of differing densities when the lighter fluid underlies the heavier. The Rayleigh–Taylor mechanism also applies to linear, rather than planar, buoyant regions and has variously been invoked to explain regularly spaced volcanism above linear regions of buoyant melt production, such as mid-ocean ridges and island arcs. Applications to flow in the Earth’s mantle have also motivated studies of the shape and stability of a very viscous buoyant plume as it rises through a background shear flow that progressively tilts it further and further from vertical.

In the last two years, we have examined the Rayleigh–Taylor instability of an inclined non-diffusing cylinder of one very viscous fluid rising through another, using a combination of linear stability analysis, numerical simulations and laboratory experiments (Lister, Kerr, Russell & Crosby 2010). The stability analysis represents linear eigenmodes of a given axial wavenumber as a Fourier series in the azimuthal direction, allowing use of separable solutions to the Stokes equations in cylindrical polar coordinates. As the angle of inclination increases, the maximum growth rate decreases and the upward propagation rate of disturbances increases; all disturbances propagate without growth if the cylinder is sufficiently close to vertical, estimated as 70° . The results from the linear stability analysis agree with both numerical calculations (for a viscosity ratio of 1) and experimental observations (Figure 1). A point-force numerical method is used to calculate the development of instability into a chain of individual plumes via a complex three-dimensional flow. Towed-source experiments show that nonlinear interactions between neighbouring plumes are important for inclinations greater than 20° , and that disturbances can propagate out of the system without significant growth for inclinations greater than 40° .

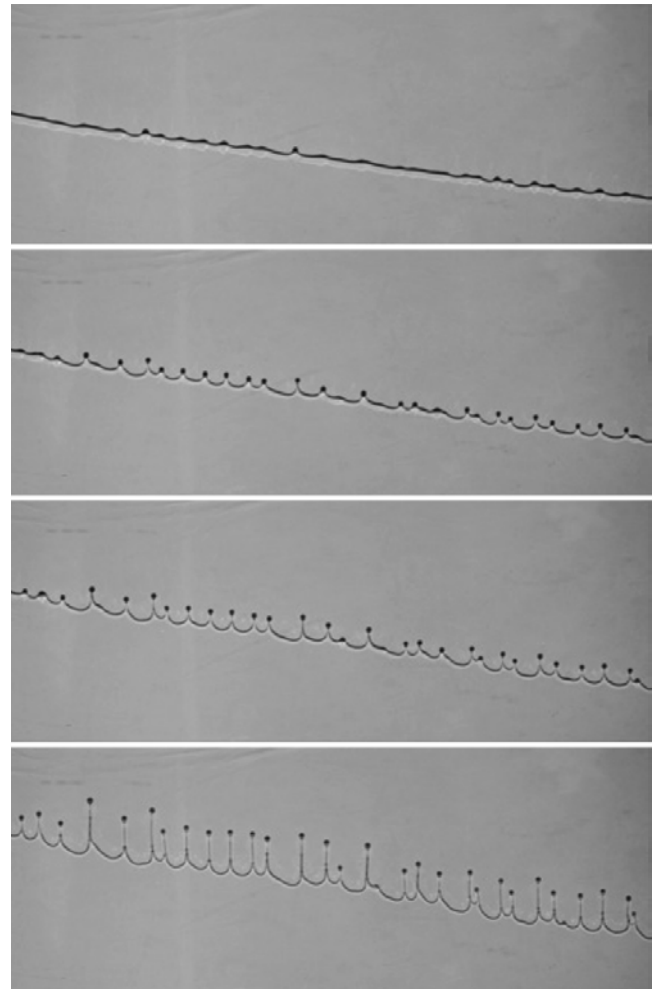


Figure 1. Photographs of the rise of a buoyant cylinder inclined at angle 6.3° to horizontal, after 36 s, 50 s, 64 s, and 102 s. Here the viscosity ratio is 0.011 and the cylinder radius is 0.45 mm. The length of cylinder shown is 29 cm. The developing cavity plumes have a fairly even spacing and growth rate.

Lister JR, Kerr RC, Russell NJ, Crosby A (2010) Rayleigh-Taylor instability of an inclined buoyant viscous cylinder. *Journal of Fluid Mechanics*, in press.

The effects of isolated catchments on calculations of GIA

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Given a model of the ice-loading history through the last glacial cycle, the CALSEA package developed by the ANU Earth Physics groups makes it possible to calculate the corresponding change in sea level, surface deformation, and gravity through time. The accuracy of these calculations depends not only on having a detailed ice sheet history but also on correctly incorporating the corresponding change in water depth across the Earth's surface. Previously, the water-loading calculations have been very limited in their handling of water catchments that are isolated from the ocean basins. Given the scale and complexity of the problem, water-level in these separate catchments has been assumed to rise and fall in time with the water-level in the ocean basins.

We have developed a new methodology whereby the CALSEA program will identify isolated catchments and, at the user's direction, allow the water-level within them to vary independently of ocean-water level. The water-loading effects of these isolated lakes can be included in the calculations of sea-level change, surface deformation or gravity. The user can also suppress water-loading effects in areas where such isolated catchments are water free (such as the Dead Sea and Death Valley). The loading effects of these isolated catchments can be significant, contributing as over 20 m of vertical uplift since the Last Glacial Maximum (22,000 years ago). This increased functionality will allow more precise calculations of sea-level change, and more detailed reconstructions of the major ice sheets and associated peri-glacial lakes.



Figure 1. Plot showing paleotopography for Northern Europe during the Last Glacial Maximum, including the effects of the ice sheet damming the north-flowing river systems. The contours show the difference in sea-level produced by the inclusion of the loading effects due to the quite substantial peri-glacial lakes. The contour interval is 2.5 m.

A technique for estimating GIA effects from observations of the Earth's gravity field

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The ongoing response of the Earth to the exchange of mass between the oceans and ice sheets during the last glacial cycle are collectively referred to as glacial isostatic adjustment (GIA). The resulting surface deformation and perturbation to gravity can be detected by satellite-based observing techniques such as the Gravity Recovery and Climate Experiment (GRACE) and the Global Positioning System (GPS). Before these geodetic data can be used to estimate present day mass changes, it is necessary to calculate the corresponding GIA signal and remove it from the observations. If the ice history is well-understood, calculating the effects of GIA is straightforward. However, in some previously glaciated regions, neither the ice history nor the Earth's response are sufficiently well-understood to permit a reliable reconstruction. In the absence of evidence constraining the ice history, changes in the gravity field observed by GRACE may be used to characterise the GIA signal. This reconstructed GIA signal can then be used to determine the corresponding vertical uplift due to GIA. These GIA effects can then be removed from the uplift observed at GPS sites to leave the signal due to modern processes. For such a technique to be practically useful, the relationship between the gravitational perturbation and vertical deformation should not be dependant on either the Earth's response function or the ice history.

We explored the validity of representing the effects of GIA using synthetically derived response parameters and developed a new technique for determining the ratio between changes in gravity and surface deformation. With this technique, one no longer needs to know accurately either the Earth's response or the ice load history. We can replace the ratio of the present-day response functions with a simple, linear expression that is independent of both Earth and ice histories, provided that the changes in the ice load have been static for at least 10,000 years. With this result, given an observed change in the Earth's gravity field we can derive the corresponding surface deformation with greater accuracy than has previously been possible.

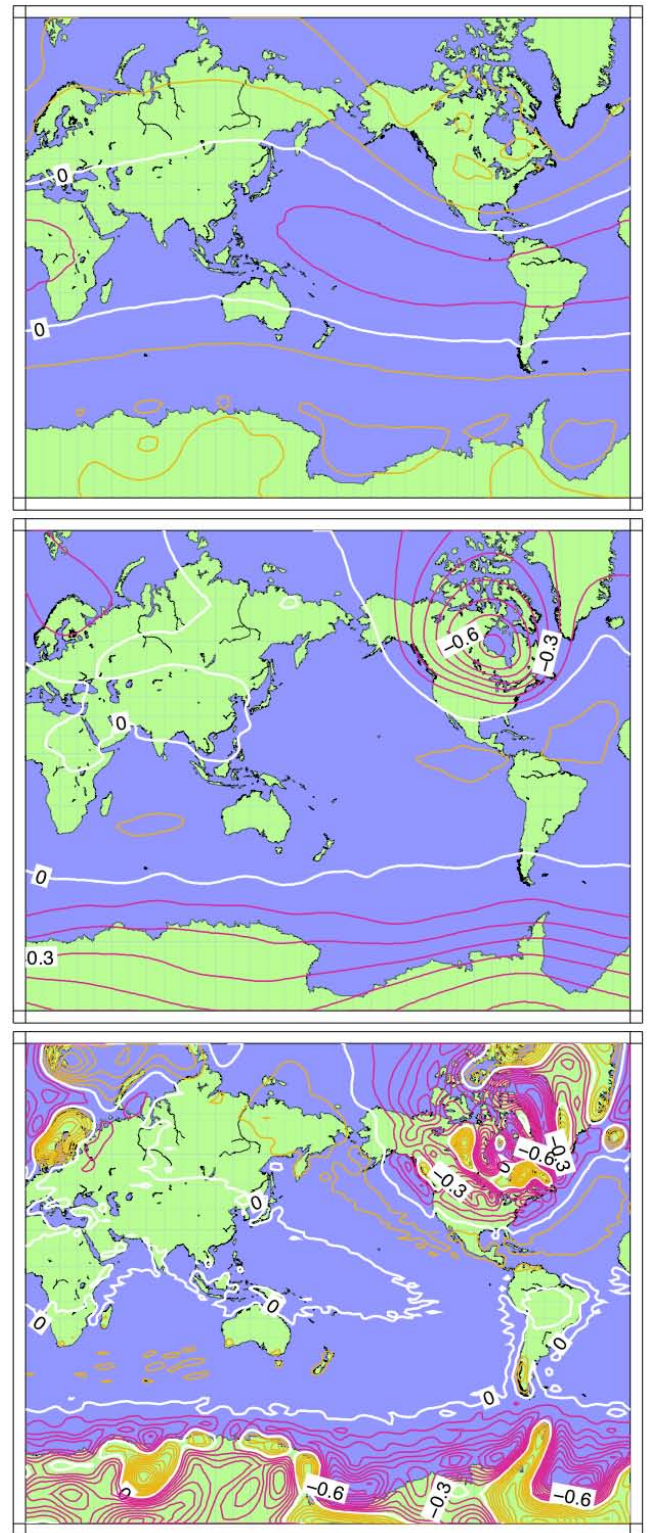


Figure 1. A comparison of synthetic response functions. Contours show the difference in uplift rate in mm/yr between a rigorous forward calculation performed using CALSEA and three separate synthetic response calculations. The bottom panel shows the standard results of Wahr et al 1995. The middle panel shows results obtained using a global average of the deformational and gravitational response functions. The top panel shows the results obtained using the refined linear approximation of the global average.

AuScope Geospatial Gravity Programme

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² *Geoscience Australia*

The gravity component of the AuScope project has purchased an FG5 absolute gravimeter, 3 gPhone portable earth tide gravimeters and completed the refurbishment of the Reynolds Dome at Mount Stromlo for use as a gravity instrument testing and intercomparison facility.

During 2010 absolute gravity observation were completed at existing gravity stations at Mount Stromlo CSO, Mount Stromlo Seismic vault and the Townsville AIMS facility. A standard maintenance service was completed on the FG5 gravimeter by the instrument manufacturer and a post maintenance test measurement at Mount Stromlo confirmed that the FG5 is performing to specification with an improvement in the operation of some sub-systems. This service took longer than anticipated with the instrument being unavailable for use for 3.5 months. Absolute gravity measurements using the FG5 gravimeter on the four new fundamental gravity piers in the refurbished Reynolds dome are planned to commence early in 2011.

The prime purpose of the FG5 absolute gravity measurements is to provide independent confirmation of the vertical deformation rates of the continent. Repeat absolute gravity measurements are being made at a network of existing and newly selected geometric measurement technique sites (e.g. SLR and GPS) across the Australian continent. Also, the FG5 is being used for calibrating and testing the relative gravimeters including the Mount Stromlo SG, and for other geodynamics projects requiring high precision absolute gravity.

Gravity measurements with the gPhone gravimeters has continued at Jabiru, Katherine and Tennant Creek during 2010. These gravimeters are performing well with interruptions to data acquisitions being due to failures of the controlling laptop computers. All three gPhone gravimeters are planned for deployment to new sites early in 2011.

The gPhone relative tidal gravimeter data are being used to model the actual ocean load tide around Australia. Sites in the north and north-west of Australia are being measured first to enable an assessment of the density of network sites required across the continent and to confirm the proposed analysis strategy for comparison of the gravity derived ocean load tides with models being used in GNSS data analysis.

AuScope gravity projects at RSES

<http://rses.anu.edu.au/geodynamics/gravity/index.php?p=projects>



Figure 1. FG5 gravimeter setup in Mount Stromlo seismic vault



Figure 2. Reynolds Dome after 2003 bushfire on left and after refurbishment on right

New High Resolution Seismic Imaging of the Core-Mantle Boundary with the WOMBAT Array

Pozgay, S.H., Tkalcic, H. and Rawlinson, N.

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

Southeastern Australia is favorably positioned relative to much of the Pacific Rim and SE Asian subduction systems for recording of PcP phases from subduction zone earthquakes.

PcP seismic phases bounce off the core-mantle boundary (CMB) and are valuable for investigating this complex region in the earth, especially when they are compared to P phases that travel nearly the same path except for close to the CMB. In this way, anomalous differences between PcP and P can be attributed to differences at the CMB. Differential $PcP-P$ phases are best recorded between approximately 25-75 deg, which is precisely the distance of SE Australia relative to the subduction zones of Indonesia, Papua New Guinea, Tonga/Kermadec, Philippine, Izu-Bonin-Mariana, and Japan. As such, any seismic stations deployed in this area have potential for accurate $PcP-P$ travel time studies.

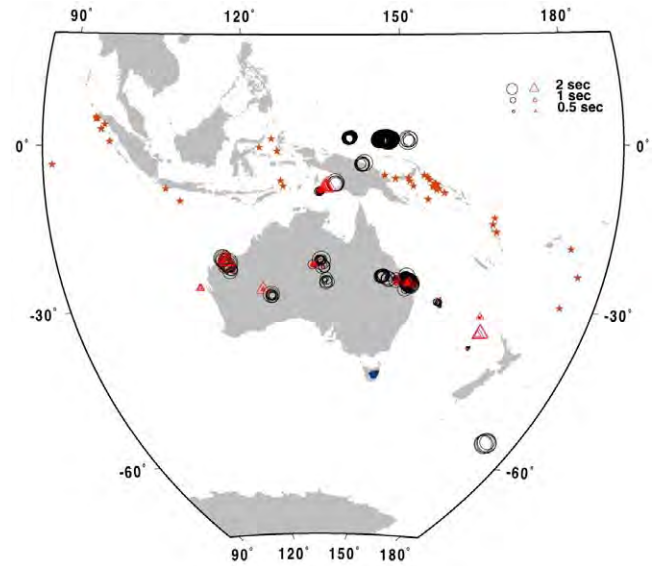


Figure 1. $PcP-P$ residuals for SETA array in Tasmania. Surface projection of $PcP-P$ bounce points. Points are scaled by $PcP-P$ residual: black circles are negative, red triangles are positive. Orange stars are earthquakes used in this study, and inverted blue triangles are stations used in the study.

New High-Resolution Seismic Attenuation Imaging of Australian Lithosphere with the WOMBAT Array

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Since 2001, Australia's WOMBAT array has been leap-frogging across the continent (see Fig. 2). Each subarray within WOMBAT consists of 30-72 short-period seismometers with solid-state recorders deployed for 6-12 months. Station spacing is 15-50 km, resulting in high-resolution coverage at the continent scale. To date, over 500 short-period stations have been deployed in SE Australia. Furthermore, the lack of anthropogenic noise for most stations, and the presence of low attenuation in parts of the upper mantle, enable good signal-to-noise ratio and make the dataset ripe for detailed seismic investigations beyond that of travel time tomography.

We extend prior travel time tomography studies to utilize amplitude data for analysis of the attenuation structure of the lithosphere and upper mantle (Fig. 1). We modify the adaptive stacking code of *Rawlinson & Kennett [2004]* to include frequency-dependent differential dt^* attenuation measurements. Initial analysis of teleseismic P waves recorded using only a preliminary dataset of 100 stations shows good structural coherency with travel time tomography. Further high-resolution studies will provide a comprehensive picture of the attenuation structure of the Australian lithosphere and will enable direct comparison and integrative interpretation between observed velocity and attenuation anomalies.

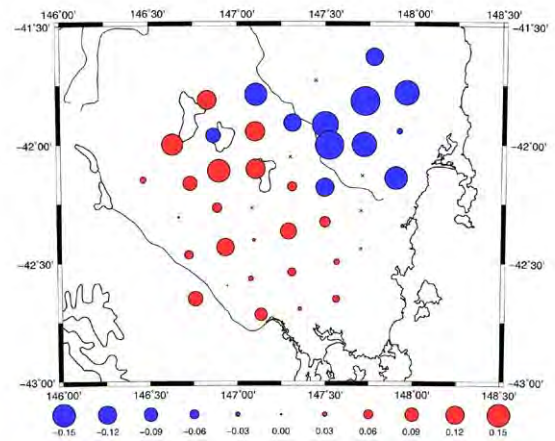


Figure 1. Seismic attenuation differential dt^* results from Jan 2007 Fiji earthquake as recorded at the SETA array in Tasmania. Note the distribution of positive and negative residuals forming a coherent pattern that is consistent with the boundary between the East and West Tasmanian Terranes.

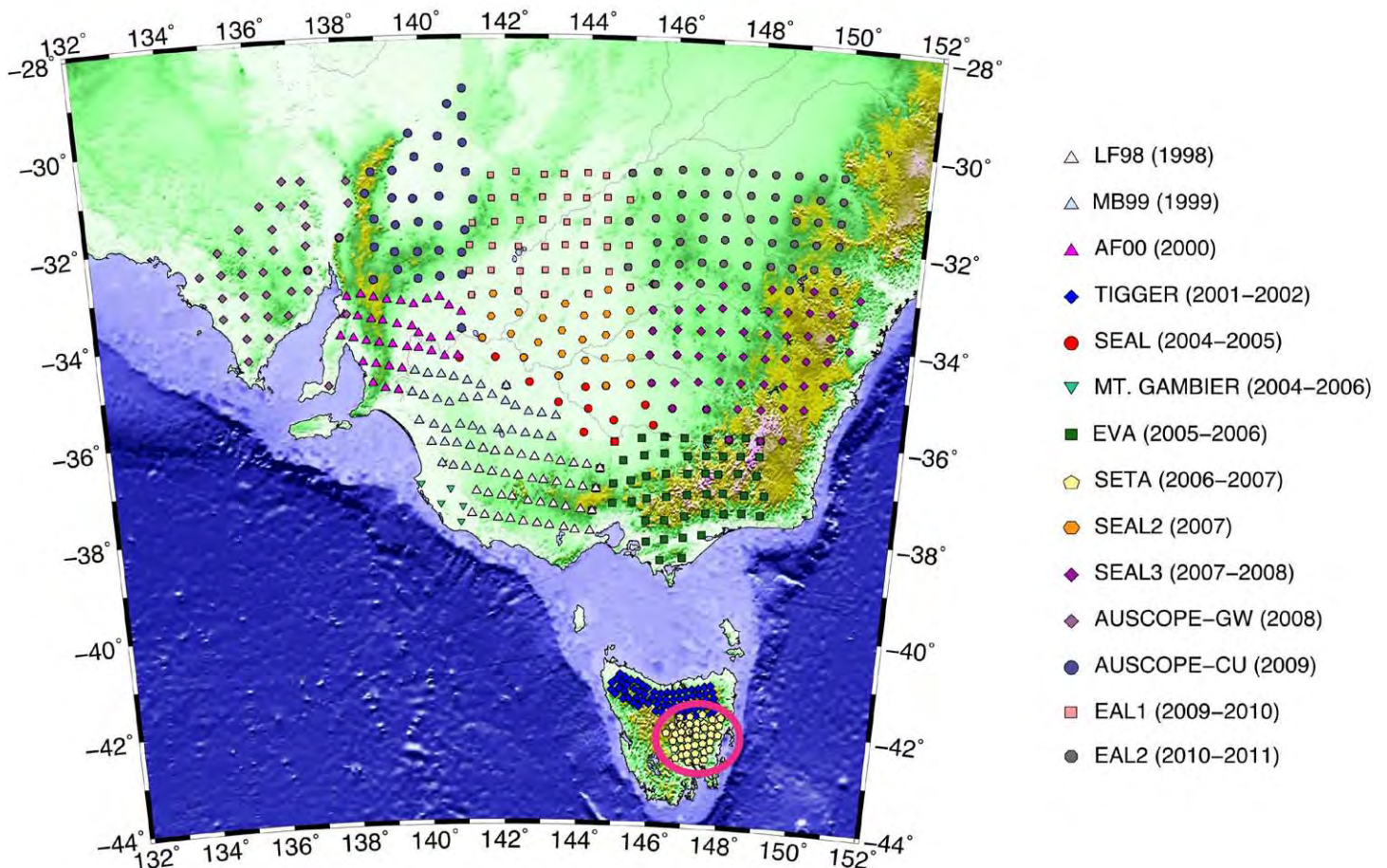


Figure 2. The WOMBAT array of short-period seismic stations marching across southeast Australia at 40-50 km spacing (15 km spacing in

Tasmania). The earliest deployment was LF98 in 1998 (light pink triangles) and the gray circles (EAL2) are currently recording. Data from the SETA deployment shown here are highlighted with the pink circle.

Hydrological deformation of the Earth

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Variations of water storage at different times of the hydrological cycle mean that the amount of water pressing down on the continents of the Earth varies. This causes changes in the deformation of the surface of the Earth that can reach up to 15 mm in the vertical. Such deformations can be detected in time series of site coordinates estimated by GPS, while the change in total water load can be estimated from the GRACE space gravity mission.

In this study, we used the hydrological loads derived from the French solutions of GRACE spherical harmonic monthly gravity fields to calculate the elastic deformation that would occur at the surface of the Earth. We then compared these deformations with those estimated from GPS coordinates on a global network. The agreement in height is at times spectacular, especially considering that these two space geodetic techniques are completely independent and are sampling different geophysical effects.

However, the variations in the horizontal coordinates is less convincing when the deformation signals are < 2 mm, suggesting that either the analysis of one of the two techniques is in error or that the broad-scale GRACE computations and the discrete GPS sites are not sampling the same hydrological loading effects.

Work is continuing to improve the GPS analysis, in particular to mitigate the presence of spurious harmonic signals in the site coordinates that are known to relate to orbital errors.

The research was published [Tregoning et al., 2009] in Geophysical Research Letters and is available at: <http://rses.anu.edu.au/geodynamics/tregoning/38.pdf>

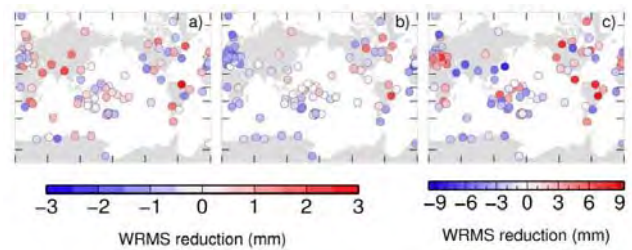


Figure 1. Reduction in RMS of GPS coordinate anomalies after removing a linear trend and elastic deformation derived from GRACE for a) no b) east and c) up components

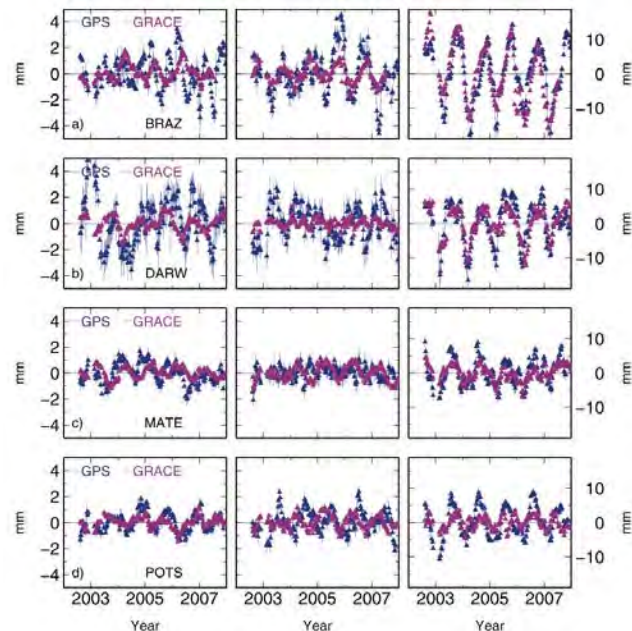


Figure 2. Time series of GPS coordinate anomalies (blue) with elastic deformation computations superimposed as derived from GRACE surface load estimates (pink) for (a) Brasilia, Brazil (b) Darwin, Australia (c) Matera, Italy and (d) Potsdam, Germany.

Improving GPS analysis strategies

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The Global Positioning System (GPS) can be used to detect earthquake deformation (including the buildup of strain prior to earthquakes), uplift and subsidence of continents, tectonic drift etc. Naturally, the higher the accuracy of the analysis, the greater the likelihood of detecting accurately these geophysical signals.

In this study, we focused on assessing the accuracy of different approaches to estimating the delay of the signals transmitted by the GPS satellites as they pass through the atmosphere, and the accuracy of different approaches to modelling atmospheric pressure loading deformation (the movement of the surface of the Earth as a result of changes in atmospheric pressure). We derived new estimates of atmospheric pressure loading that properly accounted for the weather-related loading (up to 15 mm deformation) and daily and semi-daily atmospheric tides (up to 1.5 mm amplitude).

We found that modelling the atmospheric tidal deformation reduced spurious periodic signals in site coordinate estimates and that modelling the atmospheric delays using information from global numerical weather models significantly improved the accuracy of the site coordinate estimates, in particular in the vertical component. However, our best analysis still contains periodic signals at harmonics of frequencies related to the satellite orbital dynamics. Research is continuing to understand and mitigate the causes of these errors.

The research was published [Tregoning and Watson, 2009] in the Journal of Geophysical Research (solid Earth) and can be found at the link below.

<http://rse.s.anu.edu.au/geodynamics/tregoning/37.pdf>

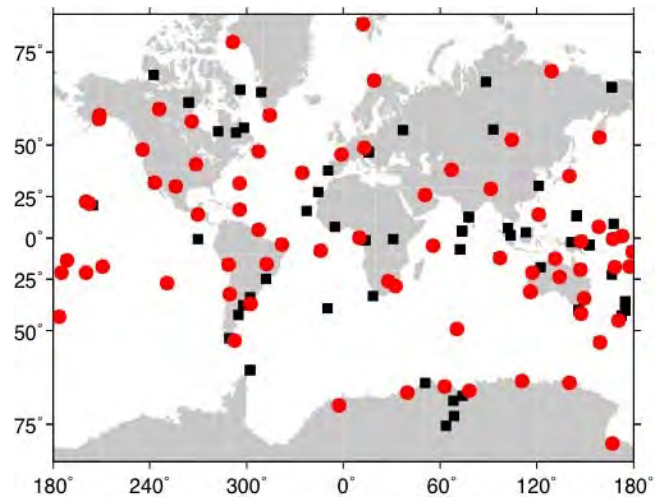


Figure 1. Global network of GPS sites analysed. Sites in red were used to study the noise characteristics of the GPS time series.

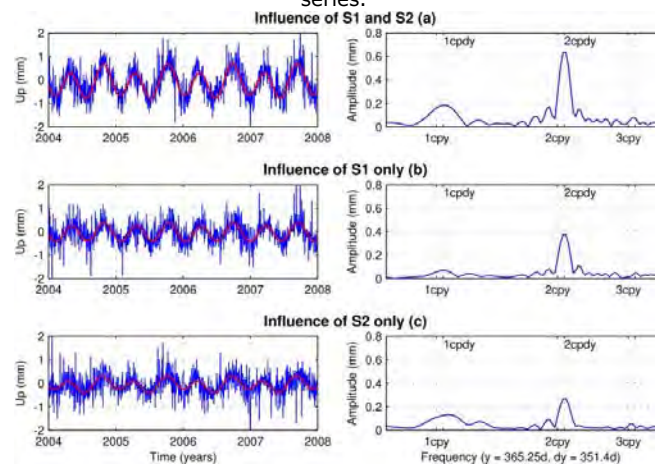


Figure 2. Effect of modeling of atmospheric tides on height estimates at Bahrain as demonstrated by calculating the difference in heights from solutions that treat the tidal atmospheric loading differently. (left) Time domain (red line is a best fitting polynomial at annual and semiannual periods related to the "GPS Year" of 351 days) and (right) amplitude spectra.

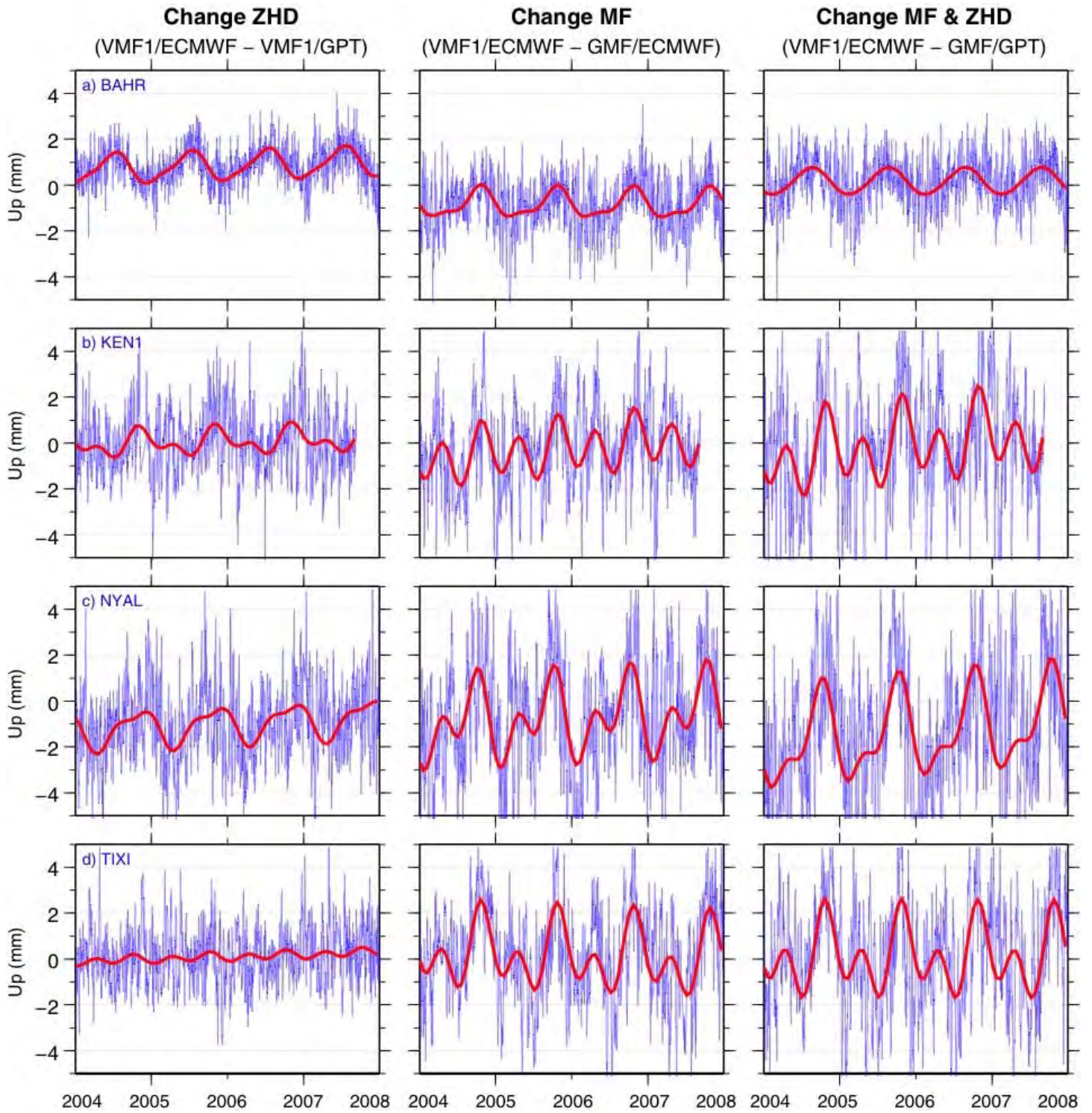


Figure 3. Time series showing differences in the up component between solutions using (left) different a priori tropospheric delays, (middle) different mathematical relations of tropospheric delay in the vertical to any elevation angle, and (right) the combined effect for (a) Bahrain, (b) Alaska, (c) NyAllesund, and (d) Northern Russia.

Monitoring groundwater variations in the Murray-Darling basin using space gravity measurements

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Data from the Gravity Recovery and Climate Experiment (GRACE) have been used in conjunction with borehole groundwater depth measurements, soil moisture models and surface water storage estimates to show that, of the 200 cubic kilometres of water lost in the in the Murray-Darling Basin since 2002 (equivalent to 400 Sydney Harbours), the majority has come from a loss of groundwater resources. The results were published in *Water Resources Research* (Leblanc et al., 2009), where monthly estimates of changes in the Earth's gravity field were used to calculate the change in total water resources in the basin.

The twin GRACE satellites were launched in 2002 and detect small changes in the Earth's gravity field. The satellites are in a tandem orbit (one following the other) 450 km above the Earth's surface and are separated by ~200 km. The distance between the satellites is measured with a K-band radar system and changes in the distance yield information on the time-varying nature of the gravity field.

Geophysical processes that can cause the Earth's gravity field to change include annual exchanges of water between oceans and continents, melting of polar ice sheets and mountain glaciers, droughts and floods, ongoing adjustment of the Earth's crust as a result of melting of ice sheets thousands of years ago, and even earthquakes.

The paper by Leblanc et al (2009) is available at the following link.

<http://rses.anu.edu.au/geodynamics/tregoning/34.pdf>

Information on the GRACE satellite mission can be found at

<http://podaac.jpl.nasa.gov/grace>

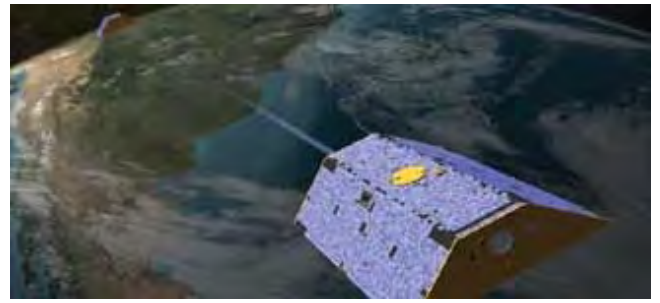


Figure 1. Artists impression of the GRACE satellites in orbit (source: <http://www.csr.utexas.edu/grace>)

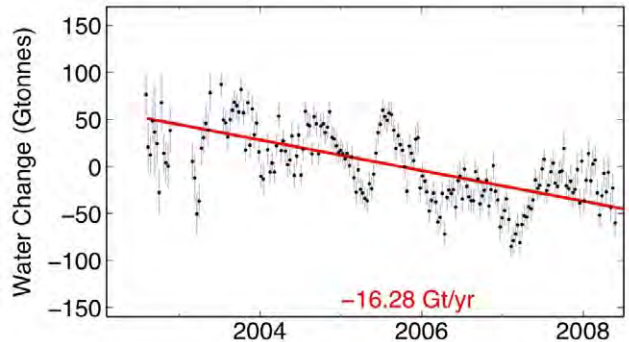


Figure 2. Time series of total water storage, integrated over the Murray-Darling Basin, as estimated from GRACE.

Slow slip subduction events in Mexico detected by GPS

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The world's largest observed Slow Slip Events (SSE) occurred in 2001–2002 and 2006 in the Guerrero subduction zone, Mexico. Using an improved GPS processing that accounts for time-varying atmospheric phenomena as well as oceanic, atmospheric and hydrologic loading corrections, the 11 year GPS position time series in Guerrero show a noise reduction of ~50% with respect to previous studies. Thanks to the improved position time series and, in particular, the simultaneous analysis of the three-dimensional GPS observations, we can provide new information about SSEs in the studied area. First, we detect seven nonperiodic anomalous displacements with subcentimeter amplitude, but no quasi-annual anomalies as proposed previously. The displacements seem to occur simultaneously with the observed peaks of non-volcanic tremor activity in the area. Second, we refine the characteristics of the two major SSEs in terms of timing, duration, and cumulative displacements, and highlight the complex surface spatiotemporal evolution of the displacements during these SSEs. In particular, we observe a clear initiation phase for the 2006 SSE as well as ending phases for both large SSEs. The ending phase shows a strong deceleration of the anomalous displacements with respect to the main displacement phase already observed, for the 2001–2002 and 2006 SSEs. The duration of the SSEs increases by 30–40% including the initiation and ending phases. For the 2006 SSE, the main displacement phase also shows spatiotemporal complexity. Our results demonstrate the need for improved three-dimensional GPS processing technique in order to undertake detailed studies of SSEs.

PDF

<http://rses.anu.edu.au/geodynamics/tregoning/41.pdf>

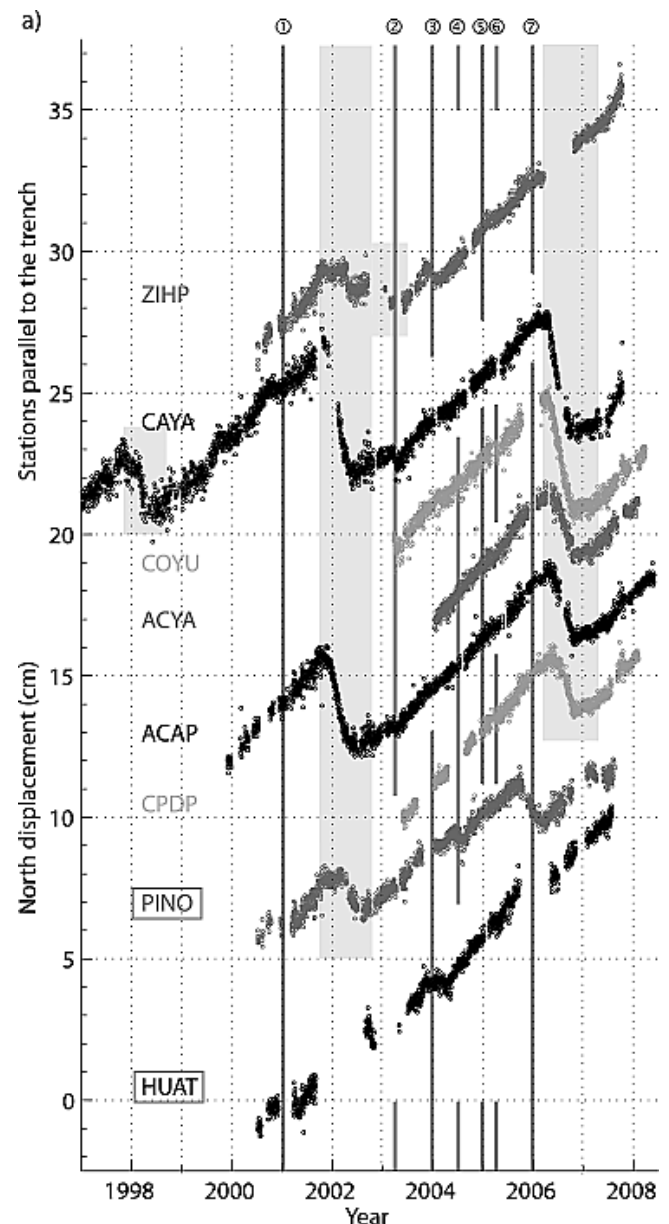


Figure 1. North position time series for the stations located on the parallel profile to the trench with respect to the North American plate reference frame. The large gray rectangles indicate the large 1998, 2001–2002 and 2006 SSEs. The width of these rectangles corresponds to the maximum duration of the SSEs over all the stations affected and all the GPS components. The vertical gray bars highlight the approximate median time of the detected small anomalous displacements

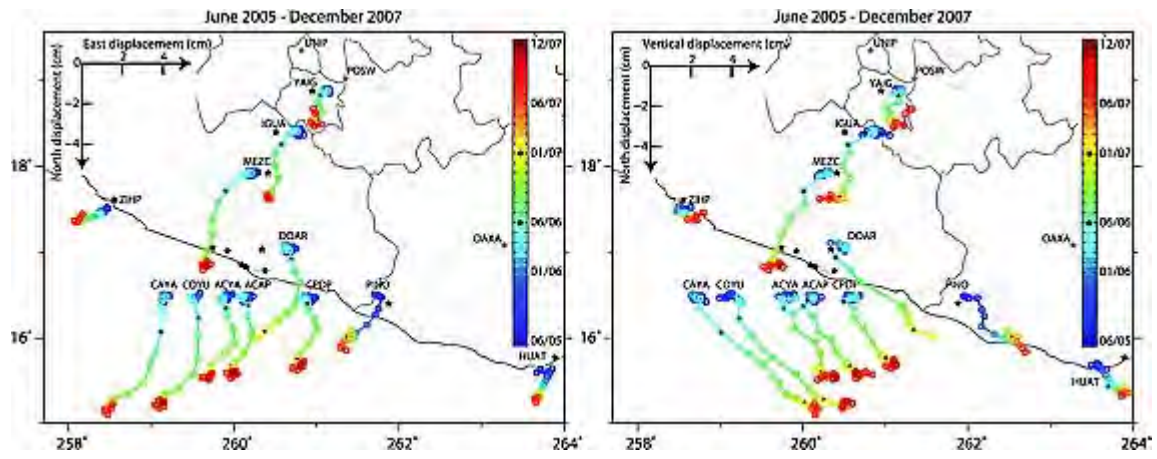
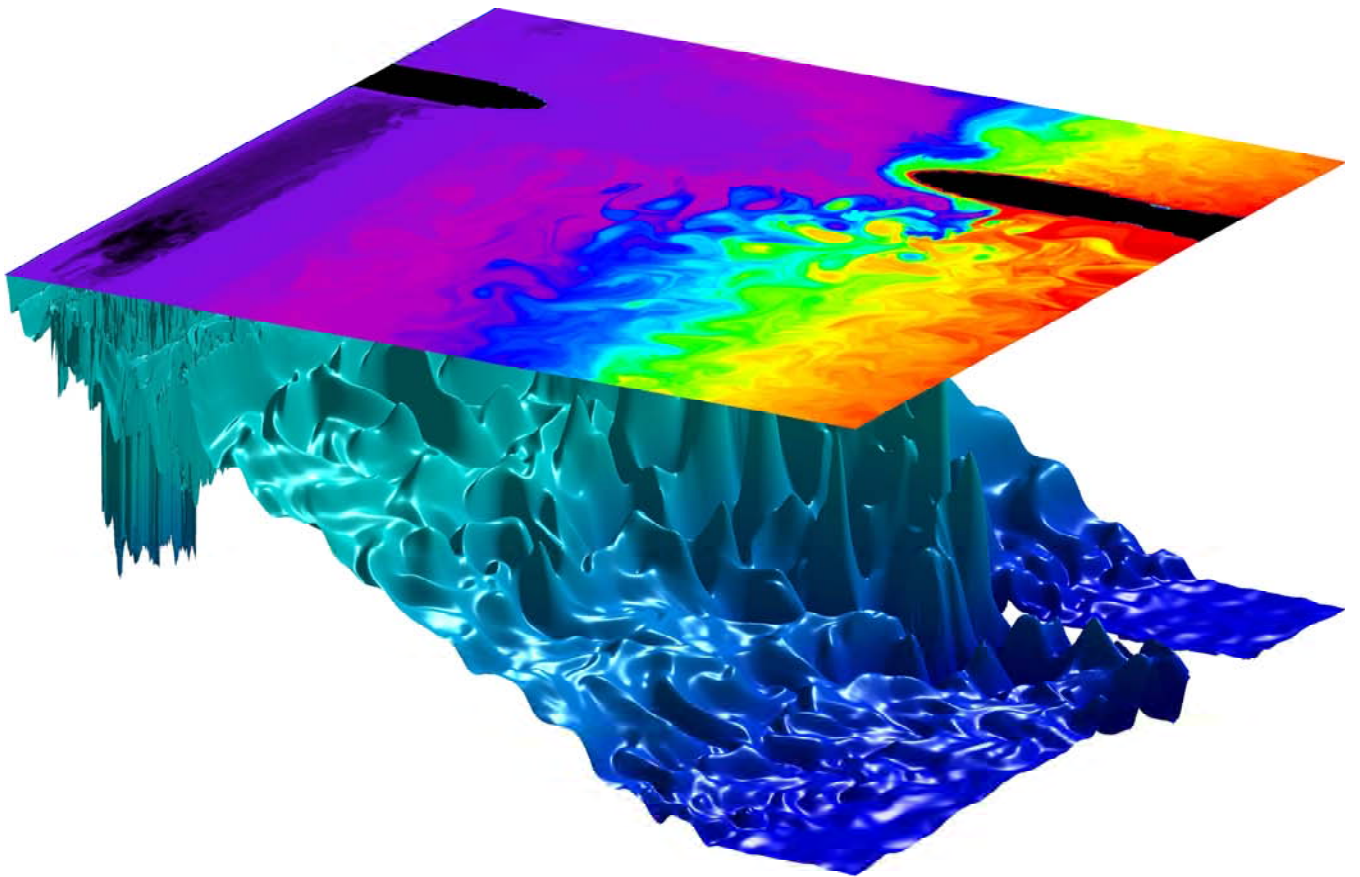


Figure 2. 3D time evolution of the displacement at each analyzed station from June 2005 to December 2007 representative of the 2006 SSE (see text for explanation, section 5.1). (left) Monthly cumulative displacement (in cm) with respect to the north and east components. (right) Monthly cumulative displacement (in cm) with respect to the north and vertical components.

Research School Of Earth Sciences (PRISE)

Research Activities 2010



Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.

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 archaeometry. PRISE scientists also conducted their own research projects as supported by successful grant applications and supervised activities of both RSES and international postgraduate students.

During 2010 Dr Greg Yaxley moved to the Earth Materials and Processes group in order to take up an ARC Future Fellowship and Dr Marc Norman was transferred to the Earth Environment group. A/Prof Mark Fanning was made a Fellow of the Geological Society of America and both he and Dr Richard Armstrong were recognised by colleagues at the VII South American Symposium on Isotope Geology for their long-standing scientific collaborations in Argentina, Brazil and Chile. Dr Richard Armstrong was part of a successful ARC Discovery grant led by Prof Rainer Grün (Earth Environment) and also received a grant from AusAid to attend the 23rd Colloquium of African Geology in South Africa as an invited speaker.

PRISE staff members were again 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 2010 PRISE hosted eighteen local and international visitors, most of whom were involved in ongoing collaborative projects using the SHRIMP, Laser ablation- and solution ICPMS and TIMS analytical facilities. PRISE staff also participated in field-orientated studies in Australia, Africa, SE Asia, Antarctica and North and South America.

Some areas of current research include:

- 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, including new protocols for the analysis of the minor isotopes ^{33}S and ^{36}S .
- Use of sulphur isotopes to aid in understanding the origin and conditions of formation of metal sulphides and sulphates. Developments and characterisation of new S sulphide and sulphate isotope standards.
- Chronology of the Archaean-Proterozoic transition and the rise of oxygen in the atmosphere
- Bioarchaeology in early Cambodian populations and in situ oxygen, carbon and strontium analysis of human teeth
- 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
- The growth, geochronology, evolution and mineralisation of cratons

Rapid Emplacement Of The One Of The World's Greatest Continental Magmatic Provinces

Precise Age Constraints On The Bushveld Complex

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The Bushveld Complex in southern Africa is one of the largest examples of continental magmatism on Earth. If the precursor felsic volcanic rocks of the Rooiberg Group are included, the volume of magma generated is estimated to be up to a staggering 1,000,000 km³. The timing and the origin of the various components of the complex are, however, poorly constrained with some work suggesting thermal activity could have continued for up to a billion years (McNaughton, et al., 1993). This research is aimed at determining a precise chronology of events covering the entire history of the Bushveld Complex, using combined zircon U-Pb dating, with the aim at establishing some constraints on the possible origin of this massive and economically important event.

In the broadest sense, the Bushveld Complex is generally considered to include the volcanic rocks of the Rooiberg Group, the basaltic layered rocks of the Rustenburg Layered Suite, the granitic intrusive rocks of the Lebowa Granite Suite, plus the enigmatic Rashoop Granophyres. Representatives of all these major components were sampled for dating. U-Pb zircon dating of felsites of the roofing Rooiberg Group show that these precursors to the main phase of the Bushveld Complex were emplaced 2059.9 ± 1 Ma ago. This is significantly prior to intrusion of the main phase of the complex – as shown by dates obtained on zircons from the famous PGE-bearing Merensky Reef, and from a late-stage basic pegmatoid. These gave statistically identical ages of 2055.3 ± 1.2 Ma and 2056.3 ± 0.7 Ma respectively. Dating of granites of the Lebowa Suite that demonstrably intrude and post-date the mafic rocks, shows they were intruded at 2054 ± 2 Ma (a mean of several dates obtained on a variety of granites from this suite). A date of 2054 ± 4 Ma recently published by Dorland et al., 2006 on a rhyolite within the overlying sedimentary sequence of the Waterberg Group shows that the Bushveld Complex had cooled and had undergone significant erosion short time after intrusion of the mafic phase.

This high-precision geochronological study established for the first time that the whole event occurred over a very short time interval of approximately 4 Ma. The emplacement of all the intrusive rocks took place over an even briefer period of just 1-2 Ma, a time interval similar to that measured for large igneous volcanic provinces such as the Karoo or Deccan. Extensive recent geochronological investigations of large parts of southern Africa have shown that Bushveld-aged igneous rocks occur over a vast region of the subcontinent. These are currently the focus of a larger study aimed at discovering the full areal extent of rocks of this age and to establishing a possible causal link between the Bushveld Complex and a larger regional event. It certainly seems probable that the Bushveld Complex, unique as it is, was a part of some larger "Bushveld event", rather than an isolated igneous event of unknown origin. Certainly some origins can now be discounted – it is unlikely that an extraterrestrial (impact) origin can be reconciled with the distinctly different ages now established for the Rooiberg and Bushveld events. The origin of this enormous and economically important complex is still uncertain, but the rapid emplacement and erosion does provide some clues. Even though the Bushveld was born in an instant – in geological terms – its impact on the geology and economy of region has been enormous.

References:

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- McNaughton, N.J., Pollard, P.J., Groves, D.I. and Taylor, R.G. (1993). A long-lived hydrothermal system in Bushveld Granites at the Zaaiploats Tin Mine: lead isotope evidence. *Economic Geology*, 88. 27-43.

Lu-Hf isotope evidence for the provenance of Permian detritus in accretionary complexes of Patagonia and the Antarctic Peninsula region

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Lu-Hf isotope data has been carried out for dated Permian zircon grains from six samples of the latest Palaeozoic to Jurassic low-grade metasedimentary rocks of western Patagonia and the Antarctic Peninsula, as well as from potential source rocks in the North Patagonian Massif. The results for the metasedimentary rocks yield e_{Hf} values mostly between -15 and +4 (130 analyses), with a dominant range (more than 85%) of -6 to +1, indicating provenance from Permian magmatic rocks that incorporated continental crust with a significant residence time. Other zircon grains record more negative e_{Hf} values indicating derivation from yet more mature crustal sources. Permian subvolcanic granites in the North Patagonian massif appear to be the closest large source area and dated zircon grains from eight samples of these granites yield initial e_{Hf} values of -12 to +4 (45 measurements), 84% of which fall between -6 and +1, the range shown by the metasediments. However, the North Patagonian massif also contains some more juvenile Permian-Carboniferous components not seen in the metasediments, so that this may not be the primary or unique source. These granites are considered to represent the southernmost extension of the Choiyoi province, which consists predominantly of Permian rhyolites that crop out on the eastern side of the Andes in central Argentina, for which unpublished Hf isotope data yield a very similar range to that of the metasediments. The widespread nature of the Choiyoi volcanic rocks and the predominance of Permian zircon could make this a more favoured source for the detrital grains.

Hf isotope data reinforce the uniformity of the provenance of the turbidite detrital zircons and confirm the Choiyoi siliceous large igneous province and the Permian granitic rocks of the North Patagonian Massif as feasible sources. They further confirm the dominantly crustal origin of the Permian magmas. A source region involving mixing of, for example, crustal materials of Panafrican/Brasiliano and Grenvillian ages, together with a minor but significant subduction-related magmatic input, is an isotopically feasible explanation and is broadly consistent with the provenance of pre-Permian crust in this region, but the proportions of such a mixture must have remained relatively constant. This supports the proposal that recently recognised but widespread Permian magmatism in Patagonia represents voluminous crustal melting in response to subducted slab break-off. The results are also consistent with the premise that the Antarctic Peninsula and southern Patagonia were closely located from Permian to Jurassic times, receiving detritus from the same source.



Figure 1. Reconstruction modified from Lawver et al. (1998), showing the position of the Antarctic Peninsula during the early Jurassic (200 Ma), with indication of the possible source areas for the detrital Permian zircons in TPG, MBF and DYC, as discussed. The location of potential sources such as the North Patagonian Massif (NPM) and the Choiyoi Group are shown.

Cosmic Time Machine

How Scientists are Able to Look Backon the early Solar System

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² *ANU ScienceWise*

³ *Curtin University*

If we were able to travel back in time about four and a half billion years, we'd be able to see the early planets of the solar system beginning to form around an infant sun. This was a time of massive and enormously violent impacts as forming planets swept debris and each other out of their orbital paths. It was around this time that scientists believe that a body about the size of mars smashed into the Earth which such force that enough matter was ejected to create the Moon.

As time passed things settled down, planets established their modern orbits and most of the collisions that were going to take place had done so. Then around four billion years ago, just about the time life was beginning on Earth, something odd happened. The orbits of Jupiter and Saturn shifted slightly which in turn perturbed Uranus and Neptune. The gravitational effects of this reshuffle extended out into the Oort Cloud – a halo of comets in the outer solar system. This gravitational wobble was enough to induce a shower of comets to enter the inner solar system, impacting asteroids and catapulting them like billiard balls across the orbits of the inner planets. The result was a second period of massive bombardment which undoubtedly had a profound effect on life on Earth.

But perhaps equally as interesting as these events are in themselves, is the way humans living four billion years later have been able to figure out just what did happen in the distant past. By working with tiny quantities of lunar soil gathered by the Apollo astronauts and using the most modern of analytical techniques we are starting to unravel the forensics of those distant times.

Using advanced mass spectrometry, we measured concentrations of elements like platinum and gold that are very rare on the Moon but abundant in asteroids and meteorites. This fingerprints what type of asteroid hit the Moon and where in the Solar System the impactor came from, that is, was it a comet or from the asteroid belt? This tells us about = large-scale dynamics of the Solar System that stirred up the impators and sent them careening toward the Sun, with us in the way.

Of course the really interesting question is not just where the impacts occurred but when? To work that out, we took advantage of radioactive decay. Over very long periods an isotope of potassium (40K) decays into argon (40Ar). When an asteroid or comet impacts the moon the enormous energy that's liberated tends to turn rock into a fine spray of molten glass. This cools into the form of tiny glass spherules a fraction of a millimetre across. These spherules contain small traces of potassium 40 but essentially no argon because the melting releases it. As the spherules age, the radioactive decay of potassium 40 begins to introduce argon again.

Although the samples were collected from the Moon almost 40 years ago, this is the first time it's been possible to perform advanced chemical analysis and isotope dating on the exact same spherule. Our aim is to build up a history of the frequency of impacts in our part of the solar system. One of the interesting and perhaps alarming things to arise from these studies is that the number of lunar impact has risen significantly over the last 400 million years. This raises interesting questions about recent shifts in orbital mechanics that might be tossing planet-size boulders towards the Earth, and possible effects that this cosmic billiard game might have had on our planet's climate and ecosystems.

ANU ScienceWise article with graphics

<http://sciencewise.anu.edu.au/articles/moon%20rock>

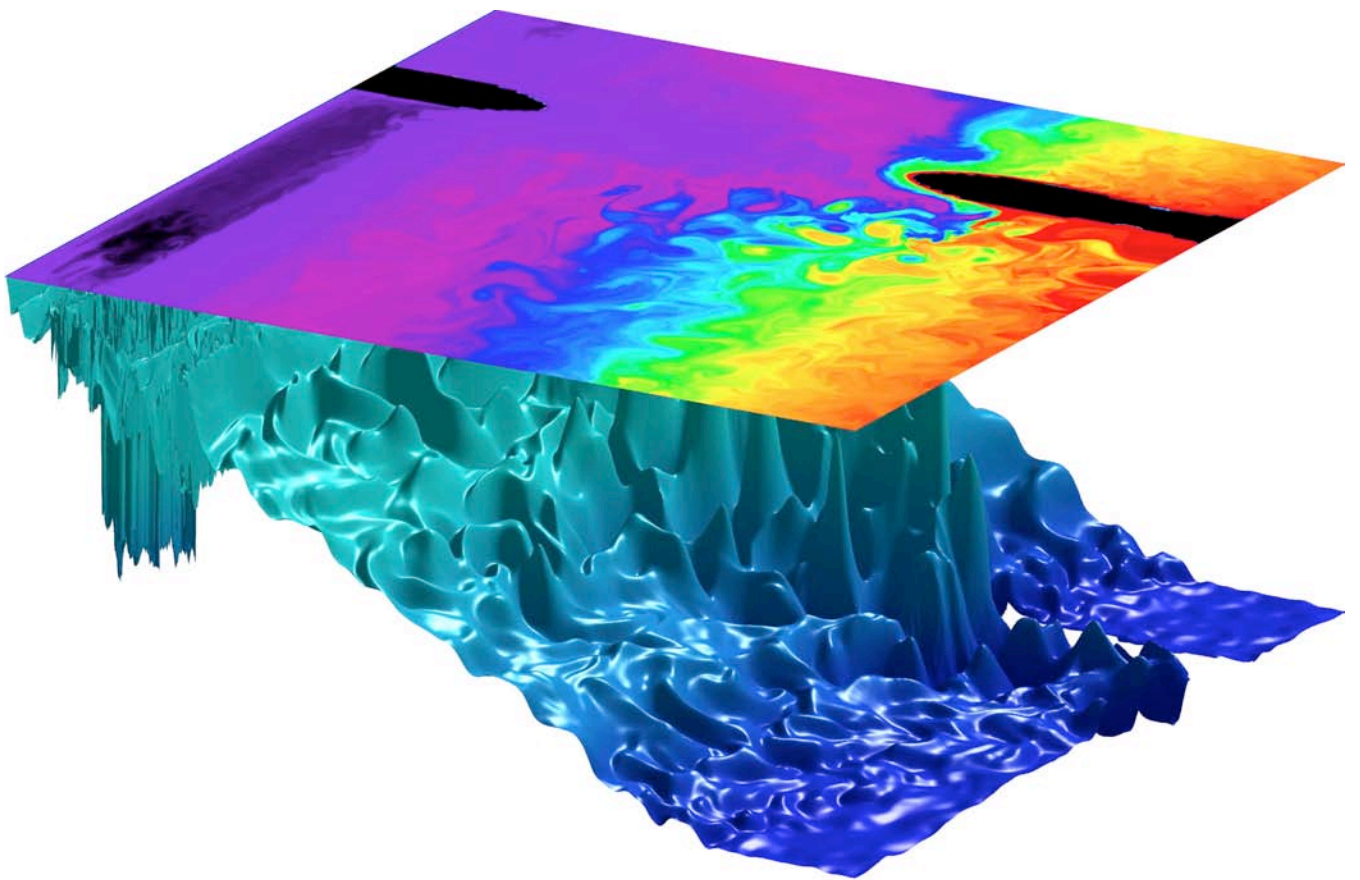
Article published in GCA on this topic (Norman et al. 2010, GCA 74, 15Jan2010, p. 763-783)

[http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V66-4XH5MNN-](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V66-4XH5MNN-4&_user=554534&_coverDate=01%2F15%2F2010&_alid=1387260939&_rdoc=1&_fmt=high&_orig=search&_cdi=5806&_sort=r&_docanchor=&view=c&_ct=44&_acct=C000028338&_version=1&_urlVersion=0&_userid=554534&md5=6d84652eb43ca1f4323f548df729779d)

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Research School Of Earth Sciences (Visiting Fellows)

Research Activities 2010



*Idealised numerical model of the Southern Ocean overturning,
at 1/16th degree resolution.*

New bradoriids (Arthropoda) from the early Middle Cambrian of the Georgina Basin, central Australia

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Bradoriids are an important group of marine Cambrian arthropods, characterised by a small (< 18 mm in length) bivalved head shield, that survived into the early Ordovician (Tremadocian). Their biological position within the Arthropoda has a long and controversial history, but increasing knowledge of their stratigraphic and global distribution is drawing attention to their biostratigraphic and biogeographic potential.

A low-diversity early Middle Cambrian (Ordian) bradoriid fauna has been found in core samples of the Thornton Limestone (from BMR Hay River 11 and BHD 9) and the Gum Ridge Formation (from NTGS 02/1) in the Georgina Basin, Northern Territory. The described taxa include a new hipponicharionid genus *Dictyocharion* (**type species** *D. euryis* sp. nov.), the comptalutids *Phasioa armini* sp. nov. and *Quetopsis kataracha* Hinz-Schallreuter, 1999. Other taxa are recorded as *Anabaroichilina*? sp., *Aristaluta*? sp., *Indota*? sp., *Monasterium oepiki* Fleming, 1973? and *Yaoyingella*? sp. Their ages are determined in terms of associated agnostines and other trilobites. Additionally, the comptalutid species *Zepaera rete* Fleming, 1973 is recognised in a core sample of the Wonarah Formation (NTGS00/1) of middle Middle Cambrian (late Templetonian to Floran) age. Palaeogeographically, the svealutid genus *Anabaroichilina* has a widespread distribution, whereas the comptalutid genera *Zepaera*, *Phasioa*, *Quetopsis*, *Aristaluta* and *Yaoyingella* show strong provincial relationships with genera from China. The new hipponicharionid genus *Dictyocharion* is presently endemic to Australia. An updated census of Australian Bradoriida and Phosphatocopida is provided as an appendix.

JONES, P.J. & KRUSE, P.D., 2009. New bradoriids (Arthropoda) from the early Middle Cambrian of the Georgina Basin, central Australia. *Memoirs of the Association of Australasian Palaeontologists* 37, 55-86.

Late Devonian benthic ostracod fauna from the Bonaparte Basin, NW Australia: their biostratigraphy, palaeoecology and palaeozoogeographic links

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The taxonomy and biostratigraphical distribution of the benthic ostracod fauna of the latest Devonian Buttons Formation has been revised to enhance its biozonal value for local and global correlation, and to evaluate its palaeoecologic and palaeobiogeographic significance. Twenty-seven species are reviewed and referred to 22 benthic genera: *Armenites*, *Bairdia*, *Baschkirina*, *Beyrichiopsis*, *Cavellina*, *Chamishaella*, *Coeloenellina*, *Cryptocyprois*, *Diphyochilina*, *Geisina*, *Indivisia*, *Katatona*, *Knoxites*, *Marginia*, *Notoscapha*, *Parabolbinella*, *Parabouchekius*, *Rhytiobeyrichia*, *Serenida*, *Shishaella*, *Sulcella* and *Urftella*?. Three biozones [*Sulcella* (*Postsulcella*) *altifrons* Zone, *Diphyochilina* *tryphera* Zone and *Bairdia* (*Bairdia*) *ordensis* Zone] are established and used for local correlation.

Palaeoecologically, the ostracods are interpreted as indigenous, low energy thanatocoenoses (life assemblages), and are indicative of a shallow, generally well-oxygenated lagoonal environment, below storm wave base. A gradual salinity increase is indicated by the appearance of stenohaline marine bairdoids in the upper part of the Buttons Formation. Long range correlation of this cosmopolitan ostracod fauna is with the late Famennian (Strunian, in particular). Strong zoogeographic links exist with the western margins of Palaeotethys (North Africa, Spain, France, Belgium, Poland), the East European Platform, and Kazakhstan. Weaker links are with south China, northeast Siberia (Omolon Massif) and the Cordilleran Province of North America. Benthic ostracods, lacking a pelagic larval stage, could have not crossed deep oceanic barriers. The observed zoogeographic links probably indicate that the shallow shelves of the western part of Gondwana and Laurentia-Baltica were close enough to permit genetic exchange, and migration during transgressive pulses, along juxtaposed shallow shelves of the adjacent blocks of Gondwana and Laurentia-Baltica. A similar connection probably existed between the South China Plate and northwestern Australia, via terranes within the eastern end of the palaeotethyan equatorial belt.

JONES, P.J., 2010. Latest Devonian (Strunian) Ostracoda from the Buttons Formation, Bonaparte Basin, NW Australia: their biostratigraphy, palaeoecology and palaeozoogeographic links. *Memoirs of the Association of Australasian Palaeontologists* 39, 261-322.

RESEARCH SUPPORT

Electronics Group

Andrew Latimore, Tristan Redman, Norm Schram, Derek Corrigan, Daniel Cummins,
David Cassar, Hideo Sasaki

Introduction

The Electronics Group provides electronic technical support to all areas of RSES academic research. The group maintains RSES electronic systems and offers a development facility able to engineer innovative electronic solutions. The Electronics Group endeavours to ensure the Research School of Earth Sciences' technology remains state of the art.

2010 has been a rewarding year for the Electronics Group with several projects completed and operating productively. Early 2010 all electronic systems of Earth Chemistry's latest development, the SHRIMP SI, were completed and successfully activated. This project combines a myriad of electronic devices developed by the Electronics Group.

This year the group has developed a new digital short period seismic recorder that provides superior resolution and performance than commercial products available. The Electronics Group has constructed a working prototype that has achieved the challenging specifications.

To comply with the ANU's Occupational Health & Safety Policy and Electrical Safety procedure, the school must record and maintain an equipment database containing risk assessments and safety test information of all in-service electrical items. During 2010 the Electronics group was given the task of updating the existing database and testing appropriate items in school. The group commenced a major testing and tagging campaign to achieve this goal, with exceptional effort by Cassar and Cummins who worked considerable overtime during the year.

We continually experience strong demand for electronic maintenance, our group endeavours to promptly attend to any problem and pride ourselves on maintaining legacy equipment. Table 1 displays the Electronics Group's resource distribution for 2010.

Electronic Engineering Highlights

SHRIMP SI (Electronics Group)

At the beginning of the year three final systems were required to complete SHRIMP SI. By April 2010 the Electronics Group finished construction and testing of the sample stage manipulator, rack motor system and primary beam monitor. The SHRIMP SI project has been a major employer of the Electronics Group's engineering and assembly time over the passed three years and we are excited and relieved to see our efforts come to fruition. The machine was successfully activated and is now an operating mass analyser. The Electronics Group has been closely involved with the fine-tuning of the SHRIMP SI this year. As expected with a project of this complexity, electrical and mechanical anomalies occur during implementation, we are committed to supporting the project now and in the future.

Table 1
RSES Electronics Group Resource Distribution 2010

Labour totals	hours	%
Administration total	1794	23
Maintenance total	1760	22
Research and Development	4202	54
Total	7756	
Administration		
Electronics Group overheads	746	9.6
Union, EBA	69	1
OHS Electrical Safety Testing	604	8
Study leave + other	375	5
Total	1794	
Maintenance		
Earth Chemistry	971	12
Earth Environment	171	3
Earth Materials & Processes	280	4
Earth Physics	73	1
External clients+ other	265	3
Total	1760	
Research and Development		
Earth Chemistry	2319	30
Earth Environment	102	1.3
Earth Materials & Processes	270	3.4
Earth Physics	1427	18.4
External clients + other	84	1.1
Total	4202	

The sample stage manipulator was a demanding task; the specification prescribed a motorised, three degrees of freedom stage system with repeatable position control of 0.3 micron. Our mechanical engineer Derek Corrigan upgraded an existing stage to meet the vibration and mechanical movement required. To achieve the resolution necessary we installed holographic linear encoders as feedback to direct current servo motors. In testing we recorded repeatable linear movements to 0.1 micron, a successful result that demonstrates electrical and mechanical precision.

IFLEX (Norm Schram)

The IFLEX project is an innovative fast responding electrometer developed by Norm Schram of the Electronics Group. During 2010 IFLEX was implemented onto Earth Chemistry's SHRIMP 2/SI and utilised to analyse Faraday cup electron flows. The project involves considerable research into electrometer design, bias current elimination and stabilisation. The IFLEX has enabled the SHRIMP SI users to capture data in charge capacitor mode that allows a 2 to 3 fold improvement in instrument precision. In order to implement the IFLEX, the group worked on improvements to the data acquisition systems of SHRIMP 2 and SI which involved a new electrometer controller circuit, temperature stabilisation circuit and microprocessor.

Short Period Seismic Recorder (Andrew Latimore, Tristan Redman, Derek Corrigan, Daniel Cummins)

This year the Electronics Group has worked for the Earth Environment department developing a new digital short period seismic recording system. The project specifications involved designing a rugged, high dynamic range, ultra low power, 24-bit digital acquisition system that recorded onto secure digital storage media. The Electronics Group researched several new technologies including low power electronics, battery management systems, low noise data acquisition, thin film displays, high density storage and global positioning systems. The project was built around the latest Xilinx field programmable gate array technology allowing us to create a powerful 32-bit microprocessor and peripherals functioning at extremely low operating power, below 0.2 watts. The project will activate 24-bit analogue to digital converters on a time-base systematically corrected by global positioning system data. A working prototype was completed by December of 2010. Initial results have been promising and the challenging power and resolution specifications have been achieved. In 2011 the group will continue development and testing with the units expected to be deployed in 2012.

Graphitization Furnace Automation (Hideo Sasaki, Andrew Latimore, David Cassar)

The Accelerating Mass Spectrometer facility incorporates a graphitization process for sample preparation. In previous years the Electronics Group has developed electronics to manually control the graphitization line. During 2010 we have focused on designing an automated 20 channel line to improve production and occupational safety of the procedure. Our research has covered methods of cryogenic trapping CO₂ with semiconductor Peltier devices and liquid nitrogen control. The project has allowed us to introduce new touch screen technology into the laboratory and deliver process control from the screen input eliminating need for keyboard or mouse. The automation component is currently under development expecting completion early 2011.

Other projects

OHS electrical testing and tagging	(Electronics Group)
MAT 261 upgrade	(Norm Schram)
Laser ablation cell drafting, design and assembly	(Derek Corrigan)
Piston cylinder electrical upgrade	(David Cassar)
Tesla Tamer assembly and testing	(Daniel Cummins)
J1PC tuning and implementation	(David Cassar)

Engineering Group

Andrew Wilson¹, David Thomson¹, Carl Were¹, Geoff Woodward¹, Brent Butler¹, Ben Tranter²
and Hayden Miller³

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

² *GFD Technical Officer part time in Workshop*

³ *Technical Officer 50/50 Earth Materials/Workshop*

The Engineering Workshop completed SHRIMP SI mechanical construction early in 2010 and continued to support the commissioning of the instrument throughout the year. Commitment to other internal, small to medium sized projects was unexpectedly high at times.

Due to the usual demand from the school, and the need to catch up on administration and workshop maintenance from a hectic 2009, only a small amount of external work was undertaken.

Workshop staff logged a total of 7055 hours to the month of December. 69% of total hours were devoted to RSES internal work. External clients accounted for 4% of our time.

29% of our charged/internal time was spent on jobs which took less than 50 hours to complete.

Major commitments for 2010:

As expected one of our major projects this year was the construction of a high temperature furnace for Dr Masahiko Honda. This was completed mid year with some development continuing until November.

SHRIMP- Completion and commissioning of SI, New Stainless Steel Optical Rails for SHRIMP 2, IFLEX Electrometers for SHRIMP 2 and SI, CDEM Shielding. (Geoff Woodward, David Thomson, Brent Butler, Carl Were, Ben Tranter, Hayden Miller and Andrew Wilson)

200T press refurbishment for Prof Hugh O'Neill (Carl Were, Brent Butler)

Laser ICPMS Sample Holders (Brent Butler, David Thomson)

Seismic Recorder Battery Enclosures (David Thomson)

AMS Graphite Line components (Carl Were, Brent Butler and Geoff Woodward)

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)



Water cooled electrical coupling used on Noble gas high temperature furnace

27% of our time (1917 hours) was uncharged and can be accounted for as follows:

17% Staff Training

35% Workshop Administration

35% Workshop Infrastructure. This includes the time taken for improvements and modifications to tooling, machines, workshop layout, workshop storage and assistance with workshop building maintenance.

8% Machine Maintenance

5% 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, Okuma MB-56, arrived early in 2010. The SHRIMP 2 Optical Rails and 200t piston cylinder ram housings were machined using this machine making use of the physically larger and more accurate CNC milling capacity.

During the year, Brent Butler will once more coach the Australian national team in the 'Worldskills' teams manufacturing category. He has also been selected as the deputy chief expert for this category, competition to be held in London in 2011.

Good progress has been made this year documenting our CNC machine procedures. Well refined written procedures are vital to enable staff to switch between machines easily and to lessen the training load on our regular CNC operators.

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Iizuka Tsuyoshi Dr, Deciphering the early Solar System chronology and planetary chemistry using isotope systematics of meteoritic zircon,

\$325,000 (2010-2013)

Fallon Stewart Dr - Dutton Andrea Dr, IODP drilling in the Great Barrier Reef: unlocking the causes rates and consequences of abrupt sea level and climate change (externally led by the University of Sydney),

\$163,358 (2010-2012)

Griffiths Ross Prof, Sensitivity and Change in the Global Ocean Overturning,

\$435,000 (2010-2012)

Campbell Ian Dr - O'Neill Hugh Prof, The high temperature geochemistry of the precious metals,

\$300,000 (2010-2012)

Senden Timothy Prof - Young Gavin Prof - Marshall Charles R - Zhu Min - Long John Albert - Trinajstić Katherine Mary - Burrow Carole Jan, Origin of jaws - the greatest unsolved mystery of early vertebrate evolution,

\$370,000 (2010-2013)

Amelin Yuri Dr - Metcalfe Ian, Understanding mass extinctions and deep-time climate change: International timescale calibration of the late Permian-Early Triassic of Australia (externally led by University of New England),

\$113,560 (2010-2012)

Pillans Brad Prof - Barrows Bradley, Understanding global warming using long-term glacier retreat records,

\$160,000 (2010-2011)

Williams Ian Dr, Global Climate Change CO₂ and the Evolution of Life in the Palaeozoic and Early Mesozoic (externally led by the University of Western Australia),

\$55,000 (2010-2012)

McPhail Derry Dr - Norman Marc Prof - Kyser Thomas K - Stirling Claudine H, Biogeochemical drivers of uranium isotope fractionation in regolith and groundwater,

\$380,000 (2010-2013)

Brocks Jochen Dr - George Simon - Volk H - Nelson P F - Jamie Joanne - Kannangara G S K - Tran Nguyen Hoang - Dennis Gary Ralph - Wilson Michael Amos - Snape I, Time-of-flight mass spectrometer for analysis of complex mixtures in oils ancient rocks recent sediments natural products and atmospheric aerosols (externally led by Macquarie University),

\$160,000 (2010)

Amelin Yuri Dr - Bennett Victoria Dr - Armstrong Richard Dr - Gagan Michael Dr - Norman Marc Prof - Ireland Trevor Prof - McPhail Derry Dr - Campbell Ian Dr - Kemp Anthony - Chivas A R - Roberts Richard - Murray-Wallace Colin V - Barley Mark - Hoskin Paul, A facility for Sensitive and Precise Isotopic Dating of Earth's and extraterrestrial Rocks,

\$450,000 (2010-2011)

Honda Masahiko Dr, Frontiers in integrated laser-sampled trace-element and isotopic geoanalysis (externally led by Macquarie University),

\$700,000 (2010-2011)

Christy Andrew Dr - Kennedy Brendan James - Gu Qinfen - De Marco Roland - McNaughton Donald - Brugger Joel - Stride John - Tobin Mark - Ling Chris David, Facilities for Spectroscopy and Diffraction at High Pressures (externally led by University of Sydney),

\$180,000 (2010)

Mavrogenes John Prof - Tomkins Andrew, Platinum deposit genesis: A new way of thinking (externally led by Monash University),

\$100,000 (2010-2013)

Other Grants

Australian Synchrotron Company Ltd. Grants

O'Neill Hugh Prof - Mavrogenes John Prof - Wykes Jeremy Mr, The oxidation state of Se in silicate glasses,

\$7,565 (2010)

O'Neill Hugh Prof, The oxidation state of Se in silicate glasses (2010)

O'Neill Hugh Prof, The oxidation state of vanadium in geological melts,

\$8,000 (2010)

Yaxley Gregory Dr, The oxidation state of Fe in mantle garnets: an indicator of diamond stability in the cratonic mantle and a potential new tool in diamond exploration,

\$1015 (2010)

Yaxley Gregory Dr - Berry Andrew Dr - Jones Jesse Mr, The oxidation state of Fe in mantle garnets: an indicator of diamond stability in the cratonic mantle and a potential new tool in diamond exploration (2010)

Commonwealth Department of the Environment and Water Resources Australian Antarctic Division

Ellwood Michael Dr - Hassler Christel - Maher Bill - Butler Edward - Bowie Andrew, Southern Ocean nutrients and their links to climate change,
\$28,050 (2010-2011)

Commonwealth Department of Climate Change

Tregoning Paul Dr, GRACE Analysis,
\$475,652 (2010-2013)

Geoscience Australia

Salmon Michelle Dr - Sambridge Malcolm Prof - Allen Trevor, Validation of event source parameters and ground-making records from Flinders Rangers temporary seismic deployment,
\$20,000 (2010)

Australian Agency for International Development (AusAID)

Cummins Phillip Dr, Earthquake Hazard Assessment in Indonesia,
\$1,656,062 (2010-2013)

NATIONAL AND INTERNATIONAL LINKS 2010

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 V.C. BENNETT with Dr A.P. Nutman (University of Wollongong) on determining the early history of the Earth through geochemical investigations of Eoarchean terranes.

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 thermal maturity of Archean organic matter.

Dr J.J. BROCKS with Prof P. De Deckker (RSES, ANU), Dr G. Allison and C. Munday (BamBi, ANU), Biomarkers in Australian Dust and Desert Crusts.

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,

Dr J. Sanderman (CSIRO, history of Coorong Delta); Dr L. Wallis (Flinders University, dating of Coorong settlement); Dr L. Reed (Flinders University, Vegetation history of Naracoorte Cave region).

Dr M.A. FORSTER has begun a collaboration with Dr F. Jourdan, Prof B. McInnes, S. Reddy and Z-X. Li, Curtin University of Technology; Dr G. Rosenbaum and P. Vasconcelos, The University of Queensland; Prof D. Cooke and Dr A. Harris, University of Tasmania; Prof D. Giles and Prof A. Collins, The University of Adelaide; Prof J. Aitchison, University of Hong Kong, Dr N. Daczko, Macquarie University; Prof W. Collins, James Cook University; Dr T. McCuaig and Dr J. Miller, The University of Western Australia; and Prof G. Lister, Prof B. Pillians and Prof R. Grun, The Australian National University; Dr H. Zwigmann, Dr N. Evans and Prof M. McWilliams, CSIRO – in association with the awarded LIEF Grant for an ANU Argon Facility.

Dr M.A. FORSTER has an ongoing collaboration with James Cook University, Qld working with Prof W. Collins on dating movement zones in far north Queensland.

Dr J. FOSTER with Australian Scientific Instruments, various SHRIMP Projects.

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.

Dr C.H. LINEWEAVER collaborates 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 is an Honorary Professor in the School of Earth Sciences, University of Queensland, where he is collaborating with Professor P. Vasconcelos, Dr B. Cohen and Dr D. Thiede on further isotopic dating by the $^{40}\text{Ar}/^{39}\text{Ar}$ technique of samples from the Turkana Basin in East Africa, especially in relation to evolution of the basin and the time scale for hominin evolution, as many important fossils have been found within the sedimentary sequences.

Dr D. RUBATTO collaborates with Dr G. Rosenbaum and Mr P. Li, University of Queensland, Brisbane, on chronology of magmatism in the New England Orocline.

Mr R. SCHINTEIE collaborated with Dr N. Sherwood (CSIRO, Sydney).

Dr I.S. WILLIAMS with Australian Scientific Instruments Pty. Ltd. (Canberra) – SHRIMP development and marketing. With Prof B.W. Chappell (University of Wollongong) – granite geochemistry.

Dr I.S. WILLIAMS with Dr J.A. Trotter (University of Western Australia, Perth) and Prof. I. Metcalfe (University of New England, Armidale) – Palaeoclimatology using marine bioapatite oxygen isotopes.

Earth Environment

Mr N. DARRENOUGUE collaborated with Dr. Daniel Ierodiaconou, Deakin University, Warrnambool (Vic) to organise a fieldtrip planned in Victoria for February 2010.

Ms A. DE LEON collaborates with Prof Bill Maher, University of Canberra; Prof Malcolm McCulloch (UWA); Mr Mark Rosenburg, CSIRO.

Dr M.J. ELLWOOD collaborates with Dr. Edward Butler (CISRO), Dr. Andrew Bowie (ACE CRC), Christel Hassler (University of Technology Sydney) on Trace metals in Tasman Sea waters, and Prof. William Maher (University of Canberra) on Germanium and silicon isotope fractionation in sponges and diatoms.

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

Dr M.K. GAGAN with Dr R. Drysdale (University of Newcastle) and Dr J. Hellstrom (University of Melbourne) on ARC Discovery grant DP1095673 (2010-2012): Multi-proxy fingerprinting, absolute dating, and large-scale modelling of Quaternary climate-volcano-environment impacts in southern Australasia.

Prof R. GRÜN obtained with Dr R. ARMSTRONG, Prof M SPRIGGS (Archaeology and Anthropology), Dr C. Falgueres (Département de Préhistoire du Muséum National d'Histoire Naturelle, Paris) and Dr. B. Maureille (Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1) an ARC grant Understanding the migrations of prehistoric populations through direct dating and isotopic tracking of their mobility patterns for 2011 to 2014, with a total value of \$ 460,000.

Prof R. GRÜN was also part of the consortium of the successful ARC LIEF application for a state of the art Ar/Ar dating facility (Prof G. LISTER being the lead CI).

Prof GRÜN collaborated with Prof A. 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 worked with Dr E. RHODES, Prof S Webb (Bond University) and Drs N Stern (La Trobe University) and A. Fairbairn (University of Queensland), on the ARC Linkage grant Environmental Evolution of the Willandra Lakes World Heritage Area.

MR S. HUI, with Dr. Fred Jourdan, Western Australia Argon Isotope Facility, Curtin University, Western Australia, on ^{39}Ar - ^{40}Ar dating of Lunar Impact Spherules.

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 Mr K. Mulvaney (Rio Tinto Iron Ore) on Aboriginal rock art, Burrup Peninsula, Western Australia.

Prof. A.P. ROBERTS collaborates with Prof. Z. Li (Curtin University), Dr P.W. Schmidt, Prof. M. McWilliams (CSIRO), Dr R. Musgrave (Geological Survey of NSW).

Miss C.M. THOMPSON collaborates with Dr C. Hassler (University of Technology, Sydney), Dr E. Butler (CSIRO), Dr A. Bowie (University of Tasmania) and Miss M. Sinoir (CSIRO, University of Tasmania).

Earth Materials & Processes

Prof R.J. ARCULUS with Prof D. Gust (QUT), Dr K. Knesel (University of Queensland), Prof S. Turner (Macquarie University), Dr L. Danyushevsky (University of Tasmania), Dr C. Yeats (CSIRO), Drs K.J.A. Wills and R. Langford (Flinders Mines).

Dr A.G. CHRISTY collaborates with Prof M.A. Knackstedt, Dr M. Madadi, Dr A.P. Sheppard and others in the Department of Applied Mathematics, RSPHSE, on characterisation of rock fabric and its relationship to acoustic anisotropy.

Prof S.F. COX and Dr A. Halfpenny are collaborating with 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 A. HALFPENNY collaborates with Rene Hoeg at Buehler technologies.

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.

Dr J. HERMANN collaborates with Dr M. Turner (Macquarie University, Sydney) on water incorporation into clinopyroxene.

Mr K.N. HORNER, Dr D.C. McPhail, Dr M.D. Norman, Dr W. McLean (Parsons Brinckerhoff, Sydney), Mr J.G. McDonald (ANU), ARC Linkage Project on the Groundwater Dynamics of the Lower Murrumbidgee Groundwater Management Area.

Prof I. JACKSON collaborated with Prof Z. Stachurski (Dept. of Engineering, CECS, ANU).

Ms K. KISEEVA with Prof V. Kamenetsky (CODES and School of Earth Sciences, University of Tasmania), Dr R. Maas (University of Melbourne) on investigations of early melting of eclogite xenoliths from kimberlite pipes.

Prof G. LISTER, in conjunction with the creation of an ANU-JdL joint argon facility, has begun collaboration with Dr F. Jourdan, Prof B. McInnes, S. Reddy and Z-X. Li, Curtin University of Technology; Dr G. Rosenbaum and P. Vasconcelos, The University of Queensland; Prof D. Cooke and Dr A. Harris, University of Tasmania; Prof D. Giles and Prof A. Collins, The University of Adelaide; Prof J. Aitchison, University of Hong Kong, Dr N. Daczko, Macquarie University; Prof W. Collins, James Cook University; Prof T.C. McCuaig and Prof J. Miller, The University of Western Australia; and Dr M.A. Forster, Prof B. Pillians and Prof R. Grun, The Australian National University; Dr H. Zwiggmann, Dr N. Evans and Prof M. McWilliams, CSIRO. The intended facility has attracted widespread national and international support, and it has been awarded an equipment grant by the Australian Research Council.

Prof G. LISTER has an ongoing collaboration with Prof W. Collins at James Cook University working with on dating movement zones in far north Queensland.

Prof G. LISTER has continued collaboration with the NCRIS NanoSIMS Facility at UWA and the AINSE SIMS at UWS for microprofiling enabling garnet-ilmenite geospeedometry.

Prof G. LISTER has continued collaboration with AngloGold Ashanti in Perth in support of the 4D South America project.

Dr L. MARTIN collaborates with Dr T. Rushmer and Dr S. Turner, on a lawsonite project, and with Dr M.-A. Kakzmarek (Curtin University) and Pr G. Clarke (University of Sydney), on the significance of texture and zoning in eclogitic garnet crystals.

Dr J. MAVROGENES collaborates with Steve Barnes (CSIRO E&M), Dr M. Fiorentini (UWA), Dr A. Tomkins (Monash).

Dr D.C. "Bear" McPHAIL, Dr J. Moreau (Melbourne University) on microbial impacts on U isotopes, Dr S. Lamontagne (CSIRO) on acid drainage and groundwater in salt disposal basins, Dr W. McLean (Parsons Brinckerhoff, Sydney) on groundwater dynamics in the Lower Murrumbidgee, Prof K. McQueen (University of Canberra) and Mr K. Scott (CSIRO) on regolith and ore deposits.

Dr O. Nebel with Dr T. Ivanic (WA Geologic Survey), Dr R. Langford (Flinders Inc) on an

ARC linkage project, Dr Woodhead (Melbourne).

Prof H. O'NEILL is collaborating with Dr C. Spandler of the School of Earth and Environmental Sciences, James Cook University, Townsville, on diffusion of trace elements in olivine and other minerals at high temperature.

Ms A. ROSENTHAL collaborates with Prof D. H. Green (CODES, University of Tasmania, Hobart, Tasmania, Australia) on the role of water and of melting in the upper mantle at pressures to 6 GPa.

Ms I. STENHOUSE, PhD candidate, with Assoc. Prof M. Kilburn of CMCA (University of Western Australia).

Miss D. TANNER with Dr J.A. Mavrogenes and Dr S.J. Barnes (CSIRO), The role of volatile metalloids and chalcogens in the evolution of sulfide melts.

Dr G.M. YAXLEY collaborates with Prof V. Kamenetsky (University of Tasmania) on petrological studies of garnet peridotite xenoliths from the Kaapvaal and Siberian cratons, with Prof V. Kamenetsky, Dr G.T. Nichols (Macquarie University) and Dr A. Rosenthal (ANU) on the petrogenesis of kimberlite-related rocks from Antarctica, with Dr A. Rosenthal (ANU) and Prof D.H. Green (University of Tasmania) on experimental studies of partial melting of heterogeneous mantle, and with Dr A. Rosenthal (ANU) on experimental studies of the stability of phlogopite in peridotite with excess water.

Mr L. T. WHITE collaborates with Dr P. Lennox (UNSW) on mapping the extent and nature of shear zones in the Wyangala Batholith.

Earth Physics

Dr G.O. HUGHES and Prof R.W. GRIFFITHS with Prof. K. Lovegrove and Dr J. Pye (Centre for Sustainable Energy Systems, ANU) on convective flows in solar thermal systems.

Dr G. IAFFALDANO collaborates with Prof. Dietmar Mueller and Dr. Christian Heine at the University of Sydney.

AuScope

Prof B.L.N. KENNETT acts as coordinator of the Earth Imaging component of AuScope, with particular responsibilities for the transect component.

In May 2010 a 640 km long reflection traverse was carried out jointly with the Geological Survey of Western Australia. A set of three reflection lines link from the Pilbara Craton across the Capricorn Orogen into the Northern Yilgarn Craton. Despite some offsets dictated by road access the continuity of structure is high and the quality of data very good.

Prof B.L.N. KENNETT has also been involved with the interpretation of the GOMA reflection line in southern central Australian, and the Delamarian transect in western Victoria and South Australia.

Prof K. LAMBECK was a member of the Antarctic Climate and Ecosystems CRC.

Dr S. POZGAY collaborates with Geoscience Australia and the University of New South

Wales.

Dr. N. RAWLINSON collaborates with Dr. Dick Glen and Dr. Dave Robson from the Geological Survey of New South Wales on seismic tomography in southeast Australia; with Dr. Anya Reading at the University of Tasmania on seismic imaging in Tasmania; and with Dr. Wouter Schellart from Monash University on subduction zone seismicity.

Dr M.L. RODERICK with Dr R. Donohue, Mr T. VanNeil, Dr T. McVicar of CSIRO, Hydrologic impacts of climate change.

Dr M.L. RODERICK with Prof G Farquhar (RSB, ANU), Prof Mark Adams (University of Sydney), Prof David Tissue (University of Western Sydney), Hydrologic impacts of bushfires.

Prof. M. SAMBRIDGE with Dr. A. Reading (Univ. of Tasmania) on inference methods applied to geological problems.

Dr H TKALČIĆ collaborates with Dr. A. Reading (University of Tasmania) on using CAPRA deployment data for studying lithospheric structure of Western Australia.

Dr P. TREGONING collaborates with Dr C. Watson (University of Tasmania), Dr M. Lebalnc (University of Queensland), Dr K. Fleming, Professor W. Featherstone (Curtin University of Technology), Dr. A. van Dijk (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 Adelaide, 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 2010 for broadband instruments in Central Australia and short-period experiments in NSW and Tasmania.

Integrated Ocean Drilling Program (IODP)

The Australian IODP Office (AIO) is at RSES. 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. Support has been provided to a petroleum geologist from Woodside Petroleum to enable him to get access to Triassic cores from the Exmouth Plateau held in the IODP core repository in Japan.

PRISE

Dr R.A. ARMSTRONG 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 Michael Fonti (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 and Dr M. Doyle (AngloGold-Ashanti) on geochronology of granite and gneiss.

Mr C.M. FANNING with Professor G. Clarke and Ms Kayla Maloney (Sydney University) on the timing and tectonic evolution of Cordillera Darwin, Tierra del Fuego; Dr Scott Bryan (University of Queensland) on oxygen isotope ratios and trace element compositions of quartz in felsic volcanic rocks from Mexico and Dr Pavlina Hasalova (Monash University) on the age of zircons in situ in pieces of Variscan age granitic rocks.

Visiting Fellows

Dr K. A. W. CROOK is working with Dr D. Fink of the Australian Nuclear Science and Technology Organisation, Dr E. A. FELTON, Earth and Marine Sciences, RSES, ANU & on cosmogenic age dating of rocky coastal geomorphic features.

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 P.J. JONES with Dr J. R. Laurie (Geoscience Australia), on palaeontological studies of Ostracoda (bivalved Crustacea) from the Early Carboniferous of the Bonaparte Basin, northwestern Australia.

Dr W. Mayer continued his collaboration 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 C. Klootwijk collaborates with Dr P.W. Schmidt (CSIRO) as guest editor for a special volume on paleomagnetism and rock magnetism for the Australian Journal of Earth Sciences.

KEITH SCOTT with CSIRO Earth Science & Resource Engineering and David Wallace, Ben Johnson and Vladimir David (MMG Ltd), carbonate geochemistry.

KEITH SCOTT with Robert Hough (CSIRO Earth Science & Resource Engineering) and Nigel Radford (Newmont Asia Pacific Ltd), rutile chemistry.

Dr GAVIN YOUNG has collaborated with Dr K. Trinajstić and Dr K. Grice (Curtin University), Dr T. Holland (Museum Victoria), Dr T. Wright (Univ. of Wollongong), Drs I. Percival, J. Pickett and L. Sherwin (NSW Geological Survey), Dr C. Burrow (Queensland Museum), and Dr Yong-Yi Zhen and Mr R. Jones (Australian Museum).

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 Professor 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.

Dr Y. AMELIN with Dr Q. Yin, University of California Davis, USA, on the origin of chondrites and their parent asteroids.

Dr V.C. BENNETT with Dr A. D. Brandon (University of Houston) on development and application of high precision isotopic methods to reconstruct the early histories of the Earth and Moon.

Dr V.C. BENNETT with Dr J. Baker and Dr M. Handler (Victoria University of Wellington) on the development of analytical techniques for measurement of Pt stable isotopic compositions applied to understanding terrestrial core formation.

Dr V.C. BENNETT with Dr Q. Yin (University of California, Davis) and Dr V. Debaille (University Libre de Bruxelles) on determining high precision Nd isotopic compositions of meteorites.

Dr J.J. BROCKS with Prof J. Banfield, C. 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, M. Pawlowska (University of Cambridge) and R. Schinteie (RSES, ANU), The Paleontology and organic geochemistry of Mesoproterozoic successions from Russia, and Molecular Taphonomic Models of the Proterozoic.

Ms T.A. EWING collaborates 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 collaborates with Dr B. Roark (Texas A&M), 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 M.A. FORSTER has started a collaboration with Prof J. Burg, ETH Zurich, Switzerland, on the dating of movement zones in Rhodope, Northern Greece.

Dr M.A. FORSTER is collaborating with Dr Lozios, The National University of Athens, Greece, dating movement zones associated with exhumation of HP/LT rocks, Evia, Greece.

Dr M.A. FORSTER with SE Asia Research Group – Royal Holloway University of London, UK, Prof R. Hall and Dr M. Cottam, dating the granitic exhumation on Borneo, Malaysia, and extension on Sulawesi, Indonesia.

Dr M.A. FORSTER with Prof T. Ahmad, The National University of Delhi, India, an Australia-India Strategic Research Fund (AISRF) Grant has been submitted to date extension in northern India (Title: 'Himalayan Mantled Gneiss Domes').

Dr M. HONDA with Dr J. Harris (The University of Glasgow, UK) and Dr T. Matsumoto (International Atomic Energy Agency, Austria), Continuation of collaboration on noble gas studies in diamonds.

Mrs A. JARRETT with Simon Poulton, Newcastle University, Newcastle upon Tyne, on the speciation of iron in Neoproterozoic oceans of Australia.

Dr C.H. LINEWEAVER with Prof P.C.W. Davies, Director of Beyond: Center for Fundamental Concepts in Science, Arizona State University on efforts to find alternative or "shadow" life on Earth and on taking an astrobiological approach to understanding cancer.

Dr C.H. LINEWEAVER 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 and life on billion year timescales.

Dr C.H. LINEWEAVER is developing collaborations with Prof N. Sleep, Stanford University, Prof P. Nicholson, Cornell University, Prof L. Krauss, Director of the Origins Initiative, Arizona State University and Dr C. Maley, Center for Evolution and Cancer, University of California, San Francisco.

Emeritus Professor I. McDOUGALL is working closely with Professor F.H. Brown of the University of Utah, Salt Lake City, Utah, USA in relation to the Turkana Basin in East Africa. Professor Brown and his collaborators have been responsible for much of the stratigraphy and stratigraphic assignments of fossils in the basin.

Mr S. McKIBBIN with R. Mishra of the Centre de Recherches Petrographique et Geochimie (CRPG -CNRS), Nancy, on Fe-Ni systematics in olivine from meteorites.

Dr D. RUBATTO with Prof M. Engi, Mr D. Regis and Miss P. Manzotti University of Bern, Switzerland, on the chronology of Alpine subduction and Permian extension in the Western Alps.

Dr D. RUBATTO with Prof R. Carosi, University of Pisa, Italy and Dr D. Visona', University of Padova, Italy on the chronology of granite formation and deformation in the Himalaya.

Dr D. RUBATTO with Prof S. Chakraborty, Ruhr Universität Bochum, Germany, Dr R. Anczkiewicz, Polish Academy of Sciences, Krakow, Poland, Prof S. Dasgupta,

University of Allahabad, India and Prof D. K. Mukhopadhyay, Indian Institute of Technology Roorkee, India on the chronology of metamorphism in the Sikkim region of the Himalayas.

Dr D. RUBATTO with Prof R. Compagnoni, Dr B. Lombardo and Dr S. Ferrando, University of Torino, Italy, on the age and composition of zircon in high-pressure granulites from the Argentera Massif, Western Alps.

Dr D. RUBATTO with Dr M. Beltrando University of Turin, Italy and Dr G. Manatchal, University of Strasburg, France, on the chronology of major detachments within the Alpine orogeny.

Dr D. RUBATTO with Dr M. Beltrando and Mr A. Vitale-Brovarone University of Turin, Italy on the timing of subduction of the Corsican ophiolites.

Dr D. RUBATTO with Dr B. Cenko-Tok, University of Montpellier, France on the behaviour of allanite during deformation.

Dr D. RUBATTO with Dr P. Vonlanthen, University of Lausanne, Switzerland on the deformation and recrystallization of zircon.

Dr D. RUBATTO with Prof K. Stüwe and Miss D. Gasser, University of Graz, Austria on the chronology of metamorphism in the Chugach Metamorphic Complex, Alaska.

Mr R. Schinteie with Ms M. Pawlowska (Cambridge University, UK), Dr D. Fike (Washington University at St Louis) and Dr M. van Zuilen (Bergen University, Norway).

Mr A. STEPANOV with Dr A. Korsakov, Institute of Geology and Mineralogy, Novosibirsk, on the geochemistry of UHP rocks from the Kokchetav metamorphic complex.

Mr A. STEPANOV with C.Y. Wang, Guangzhou Institute of Geochemistry, China, on the interpretation of detrital zircons from Russia.

Dr I.S. WILLIAMS and Prof R.W.R. RUTLAND with Dr J. Kousa (Geological Survey of Finland) on the evolution of the Svecofennian orogen.

Dr I.S. WILLIAMS with Dr J. Wiszniewska and Dr E. Krzeminska (Polish Geological Institute, Warsaw) on the evolution of the basement beneath the East European Platform in Poland.

Dr I.S. WILLIAMS with Dr K. Sajeew (Indian Institute of Science, Bangalore) on the thermal history of ultra-high temperature granulites, Sri Lanka.

Dr I.S. WILLIAMS with Dr E.V.S.S.K. Babu (National Geophysical Research Institute, Hyderabad). Dating of Indian kimberlite.

Dr I.S. WILLIAMS with Dr P. Ghosh and Mr R. Rangarajan (Indian Institute of Science, Bangalore). Oxygen isotope proxies for sources of Indian rainfall.

Dr I.S. WILLIAMS with Dr K. Terada (Hiroshima University). Oxygen isotopes in meteoritic apatite.

Dr I.S. WILLIAMS helped host short visits to RSES by scientific delegations from the Chinese Ministry of Land and Resources (April) and the Korea Basic Science Institute (November).

Earth Environment

Mr N. DARRENOUGUE, with Dr. C. Payri (member of the PhD supervisory panel) and Dr. G. Cabioch from the IRD (Institut de Recherche pour le Développement), Nouméa (New Caledonia).

Prof P. DE DECKKER collaborates with Ms A. DE LEON collaborates with Dr Helen Bostock, National Institute for Water and Atmospheric Research (NIWA), New Zealand; Dr Michelle Kelly, NIWA, Dr Martin Wille (University of Tübingen).

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 M.K. GAGAN with Dr W. Hantoro and Dr D. Natawidjaja (Indonesian Institute of Sciences), Prof. Z. Liu (University of Wisconsin – Madison), and Prof. K. Sieh (Earth Observatory of Singapore) on ARC Discovery Grant DP0663227 (2006-2010): The Indian Ocean Dipole, Australasian drought, and the great-earthquake cycle: Long-term perspectives for improved prediction.

Dr M.K. GAGAN with Dr W. Hantoro (Indonesian Institute of Sciences), Prof. L. Edwards and Dr H. Cheng (University of Minnesota), and Dr G. Schmidt (NASA Goddard Institute for Space Studies) on ARC Discovery grant DP1095673 (2010-2012): Multi-proxy fingerprinting, absolute dating, and large-scale modelling of Quaternary climate-volcano-environment impacts in southern Australasia.

Dr M.K. GAGAN with Co-Chief Investigators Dr Jody Webster (University of Sydney), Assoc. Prof. Y. Yokoyama (University of Tokyo) and the Expedition Scientists of Integrated Ocean Drilling Program (IODP) Expedition 325: Great Barrier Reef Environmental Changes.

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'Histoire Naturelle, Paris, and Dr. M Duval (Centro Nacional de Investigación sobre la Evolución Humana, Burgos) on the further development of dating techniques. He collaborates with Drs D. Grimaud-Hervé and M.H. Moncel on the application of new isotopic systems on Neanderthal remains.

Prof R. GRÜN collaborates on similar application 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 Rescoududou where Mr. I. MOFFAT will carry out aspects of his PhD studies.

Prof R. GRÜN collaborates with many international scholars on the timing of modern human evolution. He has collected hominid samples 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). He 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) on 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.

Prof R. GRÜN continues collaboration with Dr A. Pike, Department of Archaeology, University of Bristol, on uranium uptake of bones and Prof T. de Torres, Escuela Técnica Superior de Ingenieros de Minas de Madrid, on the calibration of amino acid racemisation in bones, cave bear evolution.

MR S. HUI, with Prof. Ralph P. Harvey, Department of Geological Sciences, Case Western Reserve University, Cleveland, Ohio, USA, on analysis of cosmic spherules from the Lewis Cliff, Antarctica.

Ms S.C. LEWIS, with Dr A. LeGrande, Dr M. Kelley and Dr G. Schmidt at NASA Goddard Institute for Space Studies, New York, on modelling water isotopes in precipitation.

Prof B.J. PILLANS, with Prof J. Ogg (Purdue University, USA), Prof. F. Gradstein (University of Oslo, Norway) and Prof P. Gibbard (Cambridge University) on the status of the Quaternary in the International Geological Time Scale.

Prof B.J. PILLANS, with Dr T. Barrows (Exeter University) on Southern Hemisphere Late Pleistocene glacial chronologies.

Prof B.J. PILLANS, co-editing a new book on Australian geomorphology with Prof P. Bishop (Glasgow University).

Prof. A.P. ROBERTS collaborates with Prof. E.J. Rohling, Prof. P.A. Wilson, Dr L. Chang, Dr I. Harding, Dr I. Bailey, Dr J. Stanford, Dr L. Jovane, Dr H. Pälike (National Oceanography Centre, University of Southampton, UK), Dr Fabio Florindo (Istituto Nazionale di Geofisica, Rome, Italy), Prof. Wyn Williams, Dr Chris Rowan (University of Edinburgh, UK), Dr Adrian Muxworthy (Imperial College, London), Dr Chorng-Shern Horng (Academia Sinica, Taiwan), Dr J.C. Larrasoña (Spanish Geological Survey, Zaragoza, Spain), Prof. Q. Liu, Dr G. Paterson (Chinese Academy of Sciences, Beijing), Dr C. MacNiocaill (Oxford University), Prof. R.D. Norris (Scripps Institution of Oceanography, USA), Prof. J.C. Zachos (University of California, Santa Cruz, USA), Dr Kais Mohamed (Woods Hole Oceanographic Institution, USA), Prof. K. Kodama, Dr. Y. Yamamoto (Kochi Core Center, Japan), Dr Yusuke Suganuma (National Institute of Polar Research, Tokyo, Japan).

Miss C.M. THOMPSON collaborated with Dr P. Rafter (Princeton, US) and Miss A. Robinson (University of Lincoln, New Zealand).

Earth Materials & Processes

Prof R. ARCULUS collaborates with Prof T. Plank (Lamont Doherty Earth Observatory), Prof K. Kelley (University of Rhode Island), Profs J. Blundy and M. Kendall (University of Bristol), Prof J. Davidson and Dr C. MacPherson (University of Durham), Drs J.

Lupton and E. Baker (NOAA) on the Lesser Antilles Island Arc and submarine arc-backarc volcanism of the western Pacific.

Mr C. AUGENSTEIN collaborates with Prof J-P. Burg at ETH in Zurich on the tectonic evolution of the European Central Alps.

Dr A.G. CHRISTY collaborated with Drs D. Atencio and M.B. Andrade (Universidade de São Paulo, Brazil), Dr R. Gieré (Institut für Geowissenschaften, Freiburg, Germany) and Dr P.M. Kartashov (IGEM, Moscow, Russia) on the report of the Pyrochlore Group subcommittee of the Commission on New Minerals, Nomenclature and Classification of the IMA.

Dr A.G. CHRISTY collaborates with Drs J. Chen, Y. Zhou and others (Peking University, Beijing, China).

Dr A.G. CHRISTY collaborates with Dr S.J. Mills and others (University of British Columbia, Vancouver, Canada).

Dr A.G. CHRISTY collaborates with Sr S.M. Clark and others (Advanced Light Source, Berkeley, USA).

Dr A.G. CHRISTY collaborates with Dr M.D. Welch (Natural History Museum, London, UK).

Prof S.F. COX and Mr P. Stenhouse are collaborating with Prof J. 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.

Prof D. ELLIS collaborates with Dr Kei Sato, University of Kyoto and Dr G. Zhang, Beijing University.

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.

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 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 Prof L. Baumgartner and Prof O. Müntener (University of Lausanne, Switzerland), on the formation and subduction of altered oceanic crust in the Alps.

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 with 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 with Dr M. Beltrando (University of Torino, Italy), on formation and evolution of blueschist and eclogite facies rocks in the Western Alps and Corsica.

Mr K.N. HORNER and Dr D. Allen (Department of Earth Sciences, Simon Fraser University, Vancouver, Canada) collaborated on the development of a numerical mass transport model of the Lower Murrumbidgee Groundwater Management Area.

Prof I. JACKSON collaborated with Dr D.R. Schmitt and Ms H. Schijns (University of Alberta, Canada), Dr U.H. Faul (Boston University, Profs D.L. Kohlstedt and M. Zimmermann (University of Minnesota, Minneapolis), Dr A. Barnhoorn (Utrecht University), Dr J. Kung (National Cheng-Kung University, Taiwan), Prof R.C. Liebermann (Stony Brook University), Prof Y. Kono (Ehime University, Japan), and Drs S.J.S. Morris and L.C. Lee (University of California, Berkeley) in the laboratory measurement and modelling of seismic properties.

Ms K. KISEEVA collaborated with Dr D. Petrov, Prof Yu. Marin, Saint-Petersburg State Mining Institute, Russia on investigations of Rare Earth Elements patterns of zircons from Salmi Granite Pluton, Russia.

Ms K. KISEEVA collaborated with Dr K. Litasov, Tohoku University, Sendai, Japan on high pressure (up to 20 GPa) experimental studies of carbonate eclogite.

Prof G. LISTER has continued collaboration with Prof Jean-Pierre Burg, ETH Zurich, Switzerland, on the evolution of the Lepontine culmination in the Swiss Alps.

Prof G. LISTER has continued collaboration with Prof Sumit Chakraborty, Ruhr University Bochum, Germany, on garnet-ilmenite geospeedometry.

Prof G. LISTER has continued collaboration with Prof Talat Ahmad, The National University of Delhi, India, investigating the evolution of the Ladakh Batholith and environs.

Dr L. MARTIN collaborates with Pr S. Duchene (LMTG, Toulouse, France), Dr E. Deloule (CRPG, Nancy, France) and Pr O. Vanderhaeghe (G2R, Nancy, France) on the metamorphic evolution of Ikaria Island (Greece). Dr L. Martin collaborates with Dr M.

Ballevre and Dr P. Boulvais (University of Rennes, France) on the significance of texture and zoning in eclogitic garnet crystals.

Dr J. MAVROGENES collaborates with Dr S.J. Barnes (Quebec), Dr B. Berger (USGS), Dr A. Reyes (GNS New Zealand), Dr J. Mungall (Toronto), Dr C. McFarlane (UNB), Dr F. Jenner (Misasa).

Dr D.C. "Bear" McPHAIL, Prof K. Kyser (Queen's University, Canada), Dr C. Stirling (Otago University, New Zealand) and Dr S. Wakelin (AgResearch, New Zealand) on uranium isotope fractionation.

Dr O. NEBEL collaborates with Dr van Westrenen and Dr Vroon, Vrije Universiteit Amsterdam, The Netherlands; Dr Scherer, Universität Münster, Germany; Dr Mezger, Universität Bern, Switzerland; Dr Raith, Universität Bonn, Germany.

Prof H. O'NEILL is collaborating with Dr A. Berry, Imperial College, University of London, UK, on using XANES spectroscopy to quantify oxidation states in silicate melts. He is working with Prof. Herbert Palme of the Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt, Germany on refining estimates of the chemical composition of the Earth.

Dr R. RAPP is collaborating with Prof T. Irifune (Director), of the Geodynamics Research Center, Ehime University, Matsuyama, Japan, Prof N. Shimizu of Woods Hole Oceanographic Institution, USA, and Prof D.J. Weidner, of the Mineral Physics Institute, Department of Geosciences, Stony Brook University, USA, on experimental characterization of the physical and chemical properties of subducted crustal rocks (MORB, continental sediment) in the mantle transition zone.

Dr R. RAPP is collaborating with Prof Herve Martin and Dr D. Laporte of the Laboratoire Magmas et Volcans, Universite de Blaise Pascal in Clermont-Ferrand, France, and Dr G. Yaxley and Dr M. Norman of the Research School of Earth Sciences, ANU, on experimental studies on the origin of "primitive" granitoids in the Neo-Archean, and their genetic relationship to the chemical evolution of the subcratonic lithospheric mantle (SCLM).

Ms A. ROSENTHAL collaborates with Dr I. Kovács, Eötvös Lorand Geophysical Institute of Hungary, Budapest, Hungary, on studies of minor amounts of H₂O in melts of residual eclogite, and H₂O in nominally anhydrous minerals.

Ms A. ROSENTHAL collaborates with Prof S.F. Foley, Mainz University, Germany on a) the establishment of near-solidus melts of peridotite in the presence of CO₂ and H₂O at 4-6 GPa, using piston-cylinder apparatus; and b) studies regarding the petrogenesis of East African Rift volcanics.

Ms I. STENHOUSE, PhD Candidate, collaborates with Prof Sumit Chakraborty & Dr Ralf Dohmen of Ruhr-universität Bochum, Germany on experiments designed to investigate exchange kinetics between garnet and ilmenite.

Mr P. STENHOUSE and Prof S. F. Cox collaborate with Prof J. Urai, M. Arndt and S. Virgo, RWTH-Aachen, Germany, on the fracture-controlled fluid flow in the Jabal Akhdar dome of Oman.

Mr L.T. WHITE collaborates with Prof T. Ahmad (Delhi University) on geochronology in

the Indian Himalaya and Shillong Plateau; as well as with Prof J. Aitchison (Hong Kong University) on deformable reconstructions of the Indian and Eurasian plates.

Mr J. L. WYKES commenced his Fulbright Postgraduate Scholarship in Science and Engineering sponsored by BHP Billiton at the University of California Los Angeles, in collaboration with Prof C. E. Manning investigating the solubility of mantle minerals in aqueous fluids.

Dr G.M. YAXLEY collaborates with Dr A. Berry (Imperial College) and Prof A. Woodland (University of Frankfurt) on use of Mössbauer Spectroscopy and XANES to determine Fe³⁺ contents of mantle garnet, with Prof S. Foley (University of Mainz) and Dr A. Rosenthal (ANU) on high pressure melting of peridotite+CO₂+H₂O, and with Prof G.P. Brey and Dr Qiao Shu (University of Frankfurt) on Sm-Nd-Lu-Hf isotope systematics of garnet peridotites from the Diavik diamond mine, Canada.

Earth Physics

Mr T. BODIN collaborated with Kerry Gallagher, Universite de Rennes, France, on various aspect of transdimensional inverse methods. Thomas visited Kerry in Rennes in May 2010.

Prof. P. CUMMINS with Herve Damlamian and Arthur Web of the Sotuh Pacific Applied Geosciences Commission (SOPAC) in Fiji on tsunami modeling for the 2006 Tonga and 2007 Solomon Islands earthquakes; and Ms. Natalie Balfour of U. Victoria, Canada on stress inversion of earthquake data in the Flinders Ranges.

Prof. P. CUMMINS with Dr. Wayan Sengara and Prof. Sri Widiyantoro of Bandung Institute of Technology, Dr Danny Natawidjaja and Dr. Eko Yulianto of the Indonesian Insitute of Sciences, and Dr. Fauzi of the Indonesian Agency for Meteorology, Climatology and Geophysics on problems related to earthquake hazard in Indonesia.

Dr A.McC. HOGG, Prof R.W. Griffiths and Dr M.L. Ward with Dr P. Berloff, Imperial College London, UK, and Prof W.K. Dewar, Florida State University, USA on the ocean energy cascade.

Dr A.McC. HOGG and Dr M.L. Ward with Dr R. Morrow, LEGOS/CNRS, Toulouse, France on eddies in the Southern Ocean.

Dr A.McC. HOGG with Dr M. Meredith, British Antarctic Survey, UK, Dr A.C. Naveira Garabato, National Oceanography Centre, UK and Dr R. Farneti, International Centre for Theoretical Physics, Trieste, Italy on the Southern Ocean overturning circulation.

Dr G. IAFFALDANO collaborates with Dr. Laurent Husson at Geosciences Rennes – France.

Dr G. IAFFALDANO collaborates with Prof. Claudio Faccenna, Dr. Francesca Funiciello, and Fabio Corbi at University of Rome 3 – Italy.

Dr G. IAFFALDANO collaborates with Dr. Erika Di Giuseppe at Universite Paris Sud – France.

Dr G. IAFFALDANO collaborates with Prof. Hans-Peter Bunge at LMU Munich – Germany.

Prof B.L.N. KENNETT continues to collaborate with Dr S Fishwick, University of Leicester, UK, and Dr A. Fichtner, University of Utrecht, the Netherlands on surface wave tomography.

Prof B.L.N. KENNETT has collaborated with Dr T. Furumura at the Earthquake Research Institute, University of Tokyo, Japan on a variety of issues in seismic wave propagation, particularly the propagation of seismic waves in complex subduction zones and long range propagation in the oceanic lithosphere. A study testing conclusions from tomographic images of the subduction zones at the Hokkaido bend through the properties of guided waves was published this year.

Dr R.C. KERR with Prof. J. Lister and Mr A. Crosby, University of Cambridge, UK, and Dr. C. Meriaux, University of Lisbon, Portugal, on mantle plumes.

Prof K. LAMBECK has been a member of the Executive Committee of the InterAcademy Panel on International Issues and a Board Member of the InterAcademy Council. He continues as President of the Federation of Asian Scientific Academies and Societies. He continues his research collaboration with researchers at the University of Lund (Sweden), with ENEA: Italian National Agency for New Technologies, Energy and Sustainable Economic Development, and Instituto Nazionale di Geofisica e Vulcanologia, Rome (Italy), and with the UK Environmental Factors in the Chronology of Human Evolution & Dispersal (EFCHED) programme focussing on the Africa-Arabia connection. He was a Senior Visitor at University College London during June-July 2010.

Prof K. LAMBECK is a lead author for the fifth IPCC assessment (Working Group 1) and a member of the steering committee of PALSEA (PALeo-constraints on SEA-level rise - a PAGES/IMAGES working group).

Dr H. MCQUEEN and Prof K. LAMBECK with Dr Y. Tamura (National Astronomical Observatory of Japan, Mizusawa) on operation of a Superconducting Gravimeter at Mt Stromlo.

Dr H. MCQUEEN with S. Bonaimé and Dr E. Stutzmann of Programme Geoscope 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 collaborates with Dr. Stewart Fishwick from the University of Leicester on seismic tomography, and Prof. Greg Houseman from the University of Leeds on teleseismic tomography.

Dr S. POZGAY collaborates with Dr C Haberland (GFZ, Germany), M Barklege (ExxonMobil, USA), D Wiens (Washington University in St Louis, USA).

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.

Dr M. SALMON with Prof. T. Stern and Prof. M. Savage at Victoria University of Wellington, New Zealand, Continental Moho depth and its geodynamic consequences in the Northwest North Island, New Zealand.

Prof. M. SAMBRIDGE with Prof. K. Gallagher (Univ. of Rennes) on Bayesian methods of data inference, Prof. R. Snieder (Colorado School of Mines), Coda wave interferometry, Drs. E. Debayle and C. Zaroli (Univ. of Strasbourg) on mantle imaging with body waves, Prof. A. Jackson (ETH, Zurich) on statistical approaches to signal detection.

Dr E. SAYGIN collaborates with Prof. Tuncay Taymaz (Istanbul Technical University-Turkey) and Dr. Stewart Fishwick (University of Leicester-UK).

Dr. H TKALČIĆ collaborates with Prof. V Cormier, University of Connecticut, and Dr. S Tanaka, JAMSTEC, Japan, on structure of the inner core and core-mantle boundary, with Profs. M Herak, D Herak, S Markusic and PhD student J. Stipcevic, University of Zagreb, on lithospheric structure of Croatia and the Adriatic Sea, with Dr. A Fichtner, Utrecht University on earthquake 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, with Prof. J Rhee, Seoul University on the Earth's core, and with Dr B-S Huan and PhD student T-C Chi, Academia Sinica on lithospheric structure of Taiwan.

Dr P. TREGONING collaborates with Dr R. King and Prof. T.A. Herring (Massachusetts Institute of Technology) and Dr G. Ramillien (CNRS, Toulouse, France).

Dr. E VANACORE collaborates with Dr. T. Taymaz and Y. Çubuk (Department of Geophysical Engineering, Istanbul Technical University, Istanbul, Turkey) on characterization of the Anatolian crust.

Dr. E VANACORE collaborates with Dr F. Niu (Rice University) on seismic structure of the lowermost mantle.

Dr M.L. WARD with Prof. W.K. Dewar, Florida State University, on gravity wave dynamics.

Integrated Ocean Drilling Program (IODP)

Collaboration occurs with many scientists in America, Japan, Europe, New Zealand and Korea in the IODP context. We are part of ANZIC (Australian and New Zealand IODP Consortium) and send Australian scientists to join IODP drilling expeditions each year. We also 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) 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; C. Sanchez-Garrido and Prof Gary Stevens (University of Stellenbosch) on the U-Pb age and oxygen isotope composition of pebbles in the Moodies Group, Barberton Mountain Land, South Africa; J. Taylor and Prof Gary Stevens (University of Stellenbosch) on the monazite geochronology of the granulites from the Ancient

Gneiss Complex, Swaziland; Dr H. Mouri (University of Johannesburg) on the geochronology of komatiites from the Limpopo Mobile Belt, South Africa; Dr M. Rigby (University of Pretoria) on the timing of granulite metamorphism in titanites from the Limpopo Mobile Belt, South Africa; Dr P. Poprawa (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; Professor S. McCourt (University of KwaZulu-Natal) on the geochronology and O and Hf isotope characterisation of volcanic rocks of the Tugela Valley, South Africa.

Mr C.M. FANNING continued collaborations with Prof Paul K. Link, Ms Elizabeth Balgord and Mr Joshua Keeley (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) on the 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) 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) 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 Dr Rory McFadden (University of Minnesota) on the tectonic evolution of the Fosdick Mountains, Mary Byrd Land, Antarctica.

Visiting Fellows

Dr K. A. W. CROOK is working with A/Prof. A. SWITZER, Nanyang Technological University, Singapore, on cosmogenic age dating of rocky coastal geomorphic features.

DR K. A. W. Crook served as an Assessor for Auburn University, Auburn AL, USA, at the request of Prof C E SAVDRA, Chairman of the Dept of Geology & Geography, to evaluate Dr Ashraf Uddin's suitability for promotion to the rank of Professor, and to assess his achievements in teaching, outreach & research.

Dr E. A. FELTON collaborates with A/Prof. A. Switzer, Nanyang Technological University, Singapore, on cosmogenic age dating of rock coastal geomorphic features.

Dr C. Klootwijk collaborates with Prof. D Ravat (University of Kentucky) on interpretation of Australian lithospheric magnetic anomalies.

Dr GAVIN YOUNG's collaborations include Dr John Long, LA County Museum, Los Angeles, Prof. C. Marshall at University of California, Prof. M. Coates at the University of Chicago, Prof B. Fritzsch at Creighton University, Nebraska, Dr G. Retallack at the University of Oregon, Dr J. Maisey at the American Museum of Natural History, New York, Prof Zhu Min, Prof Chang Meemann and Dr Zhao Wen-Jin at the Institute of Vertebrate Palaeontology & Palaeoanthropology, Academia Sinica, Beijing, Profs D. Goujet, P. Janvier and H. Lelievre at the Museum nationale d'Histoire naturelle, Paris, Dr B. Meyer-Berthaud at Montpellier University, Prof. P. Ahlberg at the University of Uppsala, Dr Peter Bartsch at Museum fur Naturkunde, Berlin, Dr Z. Johanson and Dr G.

Edgecombe at the Natural History Museum, London, Dr Oleg Lebedev and Dr N. Krupina (Palaeontological Institute Russian Academy of Sciences, Moscow).

COOPERATION WITH GOVERNMENT AND INDUSTRY

Earth Chemistry

Dr V.C. BENNETT and Dr M. Honda with Dr M.J. van Kranendonk (Geological Survey of Western Australia); Determining early atmosphere compositions through noble gas investigations of the Archean Pilbara sediments.

Dr J.J. BROCKS with Dr A. Wygralak (Northern Territory Geological Survey), Organic matter in copper deposits in Northern Territory.

Dr. S.J. FALLON with Dr. A. McDougall (Dept. Natural Resources & Water, aging of Queensland Lungfish).

Dr M.A. FORSTER with Dr G. Fraser (Geoscience Australia) undertaking $40\text{Ar}/39\text{Ar}$ geochronology on major shear zone movement in Australia.

Dr M.A. FORSTER with Geological Survey of Queensland (Withnall, I.W. and Blenkinsop T.G., Donchak, P.J., Fergusson, C.L.) via Williams Collins ARC Linkage Grant, LP0884011, Crustal Growth in the Northern Tasmanides.

Mr R. SCHINTEIE with Dr E. Grosjean and Dr J. Chen (both at Geoscience Australia).

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. As part of his work with ASI, Dr Williams provided SHRIMP technical and scientific advice to the Geological Survey of Canada (Ottawa, Canada), Hiroshima University (Hiroshima, Japan), The National Institute of Polar Research (Tachikawa, 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), the University of São Paulo (São Paulo, Brazil), the University of Granada (Granada, Spain) 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, or are considering purchasing, SHRIMP ion microprobes. From March to August, 2010, he hosted a visit to RSES by Prof F. Bea and Dr. P. Montero (University of Granada, Spain) during which he provided training in SHRIMP operation and maintenance. He continues to provide more advanced training to Dr C. Talavera (University of Granada, Spain) who arrived in April, 2010 for a stay of ~18 months. In January he assisted with SHRIMP marketing at a meeting of Indian geoscientists in Bangalore, in August he assisted with SHRIMP marketing at a meeting of Polish geoscientists in Warsaw, in September he spent about two weeks in Brazil assisting with the installation of the SHRIMP IIe/MC at the University of São Paulo and in October he spent three days in Tokyo assisting with the retuning of the NIPR SHRIMP II.

Dr I.S. WILLIAMS and Ms H. Jeon are collaborating with Dr P. Blevin (Geological Survey of New South Wales) in an isotopic study of the Late Palaeozoic granites of southeastern Australia.

Dr I.S. WILLIAMS with Dr R.S. Nicoll (Geoscience Australia, Canberra) on palaeoclimatology using marine bioapatite oxygen isotopes.

Dr I.S. WILLIAMS with Dr K. Sircombe (Geoscience Australia) and the Australian Federal Police exploring potential forensic applications of the SHRIMP II.

Earth Environment

Prof R. GRÜN, with the Department of Environment and Conservation, NSW, and the Three Traditional Tribal Groups in the ARC Linkage grant Environmental Evolution of the Willandra Lakes World Heritage Area.

Prof B.J. PILLANS, with Mr J. Wilford (Geoscience Australia) on landscape evolution in the Harden-Young region, N.S.W.

Earth Materials & Processes

Prof R.J. ARCULUS cooperates with Dr T. Ivanic (Geological Survey of Western Australia) and Dr K. Wills through an ARC Linkage Grant on the Windimurra-Narndee layered intrusions.

Prof S.F. COX is collaborating with Gold Fields Australia Limited in a PhD project "Deformational Controls on Dynamics of Fluid Flow, Hydrothermal Alteration and Ore Genesis, Argo Gold Deposit, WA", and also collaborating with Gold Fields on an Honours project on the structural evolution of the Athena gold deposit.

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.

Prof S.F. COX and Dr J. Mavrogenes collaborated with Anchor Resources in supervision of an honours project on the Wild Cattle Creek antimony-gold project.

Prof D. ELLIS collaborates with Dr C. Hepplewhite ACTEW Corporation.

Dr A. HALFPENNY and Prof S.F. Cox collaborate with Messrs 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 Messrs B. Scott and J. Pinder, Rio Tinto on structural controls on the North Parkes copper/gold mine, NSW, AUS.

Mr K.N. HORNER (ANU), collaborated with Ms W. McLean and Ms L. Webb (Parsons Brinckerhoff, Sydney) and Mr P. Kumar (New South Wales Office of Water) during research conducted in the Lower Murrumbidgee Groundwater Management Area.

Mr K.N. HORNER (ANU), collaborated with Mr P. Kumar, Mr D. Mampitiya and Mr D. O'Neill (New South Wales Office of Water) during development of a mass-transport model of the Lower Murrumbidgee Groundwater Management Area.

Prof G. LISTER is collaborating with the Geological Survey of Queensland in connection with ARC Linkage Grant, LP0884011, Crustal Growth in the Northern Tasmanides.

Dr J MAVROGENES collaborates with Mr K. Wills (Flinders Mines).

Dr D.C. "Bear" McPHAIL, Mr P. Kumar (New South Wales Office of Water) and Dr W. McLean (Parsons Brinckerhoff, Sydney) on groundwater dynamics in the Lower Murrumbidgee.

Dr G.M. YAXLEY was awarded 4 days beamtime on the XFM beam-line at the Australian Synchrotron in Melbourne in May.

Earth Physics

Prof P. CUMMINS has worked with the Australia-Indonesia Facility for Disaster Reduction to scope a project for earthquake hazard assessment in Indonesia.

Prof P.CUMMINS has worked with the Joint Australian Tsunami Warning System to improve methods for source characterization of tsunamigenic earthquakes.

Prof K. LAMBECK was President of the Australian Academy of Science until May 2010. In this capacity he served on a number of Government Committees and Councils including the Prime Minister's Science Engineering and Innovation Council. He was co-chair of the PMSEIC Expert Working Group 'Challenges at Energy-Water-Carbon Intersections' whose report was released on 1 December 2010.

Dr H. MCQUEEN with R. Tracey and N. Dando (Geoscience Australia) operation of absolute and relative gravimeters for monitoring 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. N. RAWLINSON cooperates with Kuth Energy Ltd via a linkage project. New cooperation with FROG tech, Mineral Resources Tasmania and GeoScience Victoria is set to commence in the new year via a new Linkage Project.

Dr M.L. RODERICK with J. Alexandra (Murray-Darling Basin Authority), Workshop/Journal Special Issue on Water Availability in the Murray-Darling Basin.

Dr E. SAYGIN collaborates with Geoscience Australia.

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.

Dr H TKALČIĆ cooperates with Dr A Gorbatov and E Leask of Geoscience Australia on the determination of seismic sources in Australia and surroundings in real time using Geoscience Australia stations.

Dr P. TREGONING collaborates with Dr J. Dawson (Geoscience Australia).

Dr E. VANACORE with D. Glen (Geologic Survey of NSW) on the seismic characterization of the South Australian Lithosphere from multiple datasets.

PRISE

Dr R.A. ARMSTRONG with Dr Hielke Jelsma and Dr Samantha Perritt (De Beers) on the geochronology of Angola and the DRC.

Dr R.A. ARMSTRONG and Calum Macaulay of Shell International Exploration and Production Inc., USA, on sulphur isotope studies of sulphide- and sulphate-bearing veins in shales, including the characterization of new sulphate standards for in situ SIMS analyses.

Dr R.A. ARMSTRONG with J. Hollis, E. Beyer, J. Whelan and L. Glass 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 R.A. ARMSTRONG with Reinaldo Brito and colleagues from CPRM, Brazil, on the geochronology of selected areas in Brazil.

Dr R.A. ARMSTRONG with scientists from the Polish Geological Institute on the geochronology of the Carpathians in Poland and Slovakia.

Dr R.A. ARMSTRONG with Dr David Broughton of African Minerals (Barbados) Ltd., on the U-Pb geochronology of mafic rocks and sediments associated with the Neoproterozoic glacial sequences of Zambia and the DRC.

Dr R.A. ARMSTRONG with Dr Peter Vikre of the Western Mineral and Environmental Resources Science Center, U.S. Geological Survey, USA, on the sulphur isotope composition of pyrrhotite and other sulphides occurring as inclusions in silicate minerals.

Dr R.A. ARMSTRONG with Dr Mike Wingate of the Western Australian Geological Survey on the Sm-Nd compositions of rocks from Western Australia.

Visiting Fellows

Dr K. A. W. CROOK is a Fellow of the Australian Institute of Geoscientists. He is a BA(ANU) in Political Science, and is a Life Member of the Australian Labor Party. He provides professional advice to Ministers of the Commonwealth & NSW Governments on topics within his competence.

Dr K. A. W. CROOK is a collaborator with First Investigator Prof Bradley Pillans, RSES and others, in an ARC Linkage Project "Enigmatic Lake George - Changing environments, sustainable sand", which was submitted to the ARC on 17 November 2010.

Dr C. Klootwijk collaborates with Dr B. Musgrave (NSWGS) as guest editor for a special volume on paleomagnetism and rock magnetism for the Australian Journal of Earth Sciences.

Dr C. Klootwijk collaborates with Dr P. Milligan (Geoscience Australia) on interpretation of Australian lithospheric magnetic anomalies.

Dr GAVIN YOUNG has worked with the Heritage division of the Dept. of the Environment, Water, Heritage and the Arts regarding site protection of significant Australian fossil localities.

CONFERENCES AND OUTSIDE STUDIES

Earth Chemistry

Dr Y. AMELIN, 41st Lunar and Planetary Science Conference, The Woodlands, TX, USA, March 1-5, 2010. Oral presentation. Followed by 5 day stay at Q-Z. Yin's lab at the University of California Davis, Cr isotope analysis of chondrites.

Dr Y. AMELIN, 2010 Australian Earth Sciences Convention, Canberra, Australia, July 4-8, 2010. Oral presentation.

Dr Y. AMELIN, V.M. Goldschmidt Conference, Knoxville, TN, USA, June 13-18, 2010. Oral presentation.

Dr Y. AMELIN, 10th Australian Space Science Conference, Brisbane, Queensland, Australia, September 27 - 30, 2010. Oral presentation.

Dr Y. AMELIN, 2010 Annual Meeting of the Geological Society of America, Denver, Colorado, USA, October 31 - November 3, 2010. Oral presentation. Followed by visits to geochronological labs at the University of Toronto, Boise State University, and Geological Survey of Canada, to explore new developments in high-precision U-Pb geochronology.

Dr V.C. BENNETT, Goldschmidt Conference, Knoxville, USA, 13-18 June presented a talk entitled, "Hadean isotopic signatures in Mesoarchean Pillow Basalts".

Dr V.C. BENNETT, Australian Earth Sciences Convention, Canberra, 4-8 July, presented a talk on: "4.5 billion years of crust -mantle evolution from a modern isotopic perspective".

Dr V.C. BENNETT, Fifth International Archean Symposium, Perth, Western Australia, 5-9 Sept, presented a talk entitled: "The Hadean Earth as viewed from the Eoarchean rock isotopic record The Hadean Earth as viewed from the Eoarchean rock isotopic record".

Dr J.J. BROCKS – Session Chair and Speaker 'The origin of biomarkers (molecular fossils) of eukaryotes and oxygenic cyanobacteria in Archean and Proterozoic rocks', 20th Australian Earth Sciences Convention, 4-8 July 2010, Canberra, Australian Capital Territory.

Dr J.J. BROCKS – Session Chair and Invited Speaker 'Molecular Fossils and the late rise of eukaryotes and oxygenic photosynthesis', 13th International Symposium on Microbial Ecology (ISME), Seattle, USE, August 21 - 27, 2010.

Dr J.J. BROCKS – Chair and organizer, The 16th Biannual Australian Organic Geochemistry Conference (AOGC 2010), National Museum of Australia, Canberra, 7 - 10 December 2010.

Mr A. CHOPRA, Seminar at the School of Biomedical and Chemical Sciences of the University of Western Australia in Perth, 22 September, presented a talk entitled "What do the elements tell us about life in the universe?".

Mr A. CHOPRA, Seminar at the International Centre for Radio Astronomy Research of

the University of Western Australia in Perth, 24 September, presented a talk entitled "What do the elements tell us about planets and life in the universe?".

Mr A. CHOPRA, Student Seminars of the Research School of Earth Sciences, 20 July, presented a talk entitled "Astrobiology: One step ahead of the bible".

Mr A. CHOPRA, Earth Chemistry Seminars at RSES, 2 July, presented a talk entitled "Sun → Earth → Crust → Biosphere → Life: What do the elemental abundances tell us?"

Mr A. CHOPRA, 2010 Planetary Science and Astrobiology Workshop, 10 June, presented a lightening talk entitled "Sun → Earth → Crust → Biosphere → Life: What do the elemental abundances tell us?"

Mr A. CHOPRA, 2010 ANU ResearchFest, 6 April, presented a poster entitled "What is Life made of?" (awarded 2nd prize).

Mr A. CHOPRA, Research School of Earth Sciences Student Conference, 7 October, presented a talk entitled "How did we get here? From the Big Bang to the Big Ben."

Mr A. CHOPRA, Australian Space Sciences Conference in Brisbane, Australia, 28 September, presented a talk entitled "Stars to Planets to Life: An Elemental Scheme.

Mr A. CHOPRA, Australian Earth Sciences Convention in Canberra, Australia, 5 July, presented a talk entitled "Sun → Earth → Crust → Biosphere → Life: What do the elemental abundances tell us?"

Mr A. CHOPRA, Australian Earth Sciences Convention in Canberra, Australia, 5 July, presented a poster entitled "Evolution of the stoichiometry of the essential elements of life."

Mr A. CHOPRA, Astrobiology Graduate Conference in Tällberg, Sweden, 14 June, presented a talk entitled "From stars to planets to life: What do the elemental abundances tell us?"

Mr A. CHOPRA, Astrobiology Science Conference in League City, Texas, USA, 27 April, presented a talk and a poster entitled "Sun → Earth → Crust → Biosphere → Life: Quantifying the elemental fractionations that led to life on Earth."

Mr A. CHOPRA, Gordon Research Conference and Seminars on Origin of Life, Galveston, Texas, USA, 10 January, presented a poster entitled "Evolution of the stoichiometry of the essential elements of life."

Ms T.A. EWING, Australian Earth Sciences Convention 2010, Canberra, Australia, 4-8 July, presented a paper entitled "Testing the behaviour of Hf isotopes in rutile in a high-temperature metamorphic environment".

Ms T.A. EWING attended the EURISPET intensive short course on "High-temperature metamorphism and crustal melting", Padova, Italy, 1-10 June.

Dr S. FALLON, Australian Organic Geochemistry Conference, Canberra, Australia, 8-9 December, presented a paper entitled "Using radiocarbon to monitor atmospheric CO₂ storage".

Dr M.A. FORSTER participated in workshop sessions at The National University of Athens with a small group of four academics and students on the geology of Evia, Greece.

Dr J. FOSTER, 5th SHRIMP Workshop, Beijing, China, 10-11 October, Presented paper entitled "Construction and development of SHRIMP SI, International Workshops on Zircon Geochronology, Beijing, 12-20 October.

Ms B. FRASL, Australian Earth Sciences Convention 2010, Canberra, Australia, 4-8 July, presented a poster entitled "Solar Wind Exposure Effects on Lunar Metal Grains".

Ms B. FRASL, Planetary Science and Astrobiology Workshop, Canberra, Australia, 09-10 June.

Ms B. FRASL, Science Communication Workshop, Canberra, Australia, 2-30 September.

Dr M. HONDA attended the Goldschmidt Conference in Knoxville and the Australian Earth Sciences Convention in Canberra, and presented a paper entitled "Distinct neon isotope compositions found in polycrystalline diamonds and framesites from the Jwaneng kimberlite pipe, Botswana".

Dr. T. IIZUKA, Australian Earth Science Convention 2010, Canberra, Australia, 4-8 July, presented a paper entitled "In situ U-Pb and Sm-Nd isotopic systematics of monazites from metasediments in Mt. Narryer, Western Australia: Constraints on the tectonothermal history and provenance".

Dr. T. IIZUKA, 5th International Archean Symposium, Perth, Australia, 5-9 September, presented a paper entitled "U-Pb age, trace elements and Nd isotopes of monazites from metasediments in Mt. Narryer, Western Australia".

Mrs A. JARRETT, Abgradcon- Astrobiology Graduate Conference, Tallberg, Sweden, 14-18 June, presented a paper entitled "Sterane Biomarkers in the Proterozoic: Implications for Eukaryote Evolution".

Mrs A. JARRETT, Australian Earth Sciences Convention, Canberra, Australia, 4-8 July, presented a paper entitled "The Syngeneity of Sterane Biomarkers in the Proterozoic".

Mrs A. JARRETT, Australian Organic Geochemistry Convention, Canberra, Australia, 7-10 December, presented a poster entitled "Molecular Fossils and Iron Speciation of the Wallara-1 drillcore, Central Australia".

Ms H. JEON, Australian Earth Science Convention, Canberra, ACT, Australia, 4-8 July, presented a paper entitled "Implications of contrasting patterns of inherited zircon in the Late Palaeozoic granites of the Lachlan and New England fold belts".

Ms H. JEON, 5TH SHRIMP Workshop (Workshop on Advances in High-Resolution Secondary Ion Mass-Spectrometry (HR-SIMS) and LA-ICP-MS Geochronology, and Application to Geological Processes), Beijing, China, 10-16 October, presented a paper entitled "Probing the petrogenesis of I-type granites using inherited zircon: the case of the Carboniferous granites of the Lachlan Fold Belt, southeastern Australia".

Ms H. JEON, New England Orogen 2010 Conference, Armidale, NSW, Australia, 16-19

November, presented a paper entitled "Zircon U-Pb and O isotopic evidence for the age and source of the S-type Bundarra Supersuite granites, southern NEO."

Dr C.H. LINEWEAVER attended and presented 9 papers at the Astrobiology Science Conference (AbSciCon, largest astrobiology conference in the world) April 25 to April 30, 2010, League City, Houston, Texas organized by NASA's National Astrobiology Institute:

Dr C.H. LINEWEAVER attended and presented "Cancer's Place in Evolution: insights from astrobiology" at Cancer Forum Workshop at Arizona State University, organized by Paul Davies, Center for the Convergence of Physical Science and Cancer Biology, Director, Beyond: Center for Fundamental Concepts in Science, June 2-4, 2010.

Dr C.H. LINEWEAVER attended and presented a paper "Earliest Divergences in the Tree of Life and Constraints on the Earliest Terrestrial Environments" (with Chopra) at the Australian Space Science Conference, Univ. Queensland, September 27-30, 2010.

Dr C.H. LINEWEAVER attended and presented a paper "A Simple Treatment of Complexity: Cosmological Entropic Boundary Conditions on the Evolution of Complexity" at the Templeton Conference "Is there a general principle of Increasing Complexity?", Arizona State University, Organized by Paul Davies, Director of Beyond: Center for Fundamental Concepts in Science, December 10-12, 2010.

Emeritus Professor I. McDOUGALL attended the Australian Earth Sciences Convention, held in Canberra in July, 2010. As an Invited Speaker he presented a paper related to dating the level at which Homo sapiens fossils have been found at Kibish, southern Ethiopia. At ~195 ka, these are the oldest presently known, well-dated fossils of our own species.

Mr S. McKIBBIN, Australian Society Exploration Geophysicists – Petroleum Exploration Society of Australia Conference (23rd to 26th August, Sydney).

Mr S. McKIBBIN, ATP Innovations workshop – Successfully commercializing your PhD (8th and 9th September, Sydney).

Mr S. McKIBBIN, Australian Earth Sciences Conference (4th to 8th July 2010, Canberra).

Mr S. McKIBBIN, Australian Space Science Conference (27th to 30th September, University of Queensland, Brisbane).

Mr S. McKIBBIN, Paneth Kolloquium (27th to 30th October, Noerdlingen Germany).

Mr S. McKIBBIN, UK Young Planetary Scientists Forum (4th November, London England).

Mr S. McKIBBIN, Geoengineering: Taking control of our planet's climate (8th and 9th November, London, England).

Mr S. McKIBBIN, Eurispet: Experimental Petrology and Rock Deformation (20th to 27th November, Zürich, Switzerland).

Dr D. RUBATTO, 2010 Australian Geoscience Convention, Canberra, July 4-8 presented

a paper on "Inheritance and polymetamorphism in monazite: examples from Central Australia and the Alps".

Dr D. RUBATTO, 2010 Meeting of the Italian Society of Mineralogy and Petrology, Ferrara, Italy, 13-15 September 2010, presented a plenary lecture on "Microanalysis and internal structure of U-Pb minerals: from melting to sub-solidus recrystallization".

Dr D. RUBATTO, presented an invited talk at the University Joseph Fourier, Grenoble, France, at the Universities of Lausanne, Bern and Geneva, Switzerland.

Dr D. RUBATTO conducted field work in Sikkiim, India from 6-19 April.

Dr D. RUBATTO visited the University of Lausanne from August to December 2010.

Mr R. SCHINTEIE, 16th Australian Organic Geochemistry Conference, Canberra, Australia, 7-10 December, presented a talk entitled "Compound-specific carbon isotopic signatures of biomarkers from Precambrian evaporites: pitfalls, solutions and insights into ancient biogeochemistry".

Mr R. SCHINTEIE, Australian Earth Science Convention, Canberra, Australia, 4-8 July, presented a talk entitled "Assessing microbial diversity during the deposition of a Neoproterozoic (c.800 Ma) saline giant: evaporites as an archive for Precambrian halophiles".

Mr A. STEPANOV, AESC, Canberra, 4-8 July, presented a poster entitled "Experimental Study Of Monazite/Melt Trace Element Partitioning".

Mr A. STEPANOV attended EURISPET school in Padova, Italy and presented a poster entitled "Experimental Study Of Monazite/Melt Trace Element Partitioning".

Ms J. THORNE, Australian Earth Sciences Convention 2010, Canberra, Australia, 4-8 July.

Ms J. THORNE conducted fieldwork with T.R Ireland and P. Holden at Mt Narryer, Western Australia from 17th-23rd October 2010.

Dr I.S. WILLIAMS attended the Australian Earth Sciences Convention 2010, Canberra, where he presented a talk entitled The Svecofennian of Fennoscandia and Eastern Europe: a Lachlan Fold Belt analogue, 4-8 July.

Dr I.S. WILLIAMS attended the New England Orogen 2010 Conference at the University of Armidale, 12-20 November.

Mrs I. ZHUKOVA, RSES Student Conference 2010, Canberra, Australia, 7 October, presented a paper entitled "The experimental study of Al diffusion in synthetic forsterite at different silica activities: preliminary results".

Mrs I. ZHUKOVA, European Intensive Seminars of Petrology (EURISPET), Zurich, Switzerland, 20-27 November, presented a paper entitled "The experimental determination of PGE solubilities in forsterite using diffusion to avoid the micronugget problem".

Earth Environment

Mr. N. DARRENOUGUE, AESC (Australian Earth Sciences Convention) July 2010, Canberra, presented parts of his PhD research through an oral presentation entitled "Rhodoliths: new biogenic archives of environmental change?".

Prof P. DE DECKKER attended the AMOS Conference and lead the associated fieldtrip to Lake George.

Prof P. DE DECKKER attended Lakes Advisory Committee meetings for the Corangmite Shire, Victoria on several occasions.

Prof P. DE DECKKER attended the Eden Marine Forum, 19-21 March.

Prof P. DE DECKKER attended the Dust Workshop, Lamont USA, 25-28 June.

Prof P. DE DECKKER attended the Peter Kershaw Symposium at Monash University, Melbourne, 1 November.

Ms A. DE LEON, Australian Earth Sciences Convention, Canberra 4-9 July, presented a paper entitled "The boron geochemistry of siliceous sponges from the Southern Ocean".

Ms A. DE LEON attended ARC Centre of Excellence for Coral Reef Studies symposium, "Coral Reefs in a Changing Environment" 7-8 October.

Dr M.J. ELLWOOD attended the Australian Marine Science Association Conference and presented a talk entitled "Characterising the macro and micro-nutrient status of the North Tasman Sea", Wollongong, 4-8 July 2010.

Dr M.J. ELLWOOD and Ms J.N. SUTTON attended the American Geophysical Union Fall Meeting and presented the paper "Silicon isotopic fractionation in marine sponges: A new model for understanding silicon isotopic variations in sponges", Portland, Oregon, USA, 22-26 February 2010.

Dr M.K. GAGAN, 1st Australasian 2k (Aus2K) PAGES Regional Workshop: Towards Data Synthesis, Melbourne, 31 May to 2 June, presented a paper entitled "The last 2,000 years in tropical Australasia: Towards a comprehensive climate analysis based on speleothems and corals".

Dr M.K. GAGAN, Onshore Science Party for Integrated Ocean Drilling Program (IODP) Expedition 325 (Great Barrier Reef Environmental Changes), Bremen, Germany, 2-16 July.

Dr M.K. GAGAN, Integrated Ocean Drilling Program (IODP) Expedition 325 (Great Barrier Reef Environmental Changes) Post-cruise Meeting, College Station, Texas, USA, 7-11 December.

Prof R. Grün gave a ten-hour lecture series on Quaternary Geochronology at the Institute of Geology, China Earthquake Administration, Beijing and was invited to give a seminar at the Dept of Geography, Peking University and the Centro Nacional de Investigación sobre la Evolución Humana, Burgos. He gave seminars at the Research school of Biological Studies, ANU, and the John Curtin School of Medical Research,

ANU.

Mr S. HUI attended the Planetary Science and Astrobiology Workshop, 9th-10th June 2010 and presented a lightning talk entitled "Lunar Spherule Age Distributions: Gardening or Young Spike?".

Mr S. HUI's presentation at the Goldschmidt 2010 conference, Knoxville, Tennessee 13th -18th June – "Lunar Spherule Age Distributions: Gardening or Young Spike?" was given by Dr. F. Jourdan.

Mr S. HUI attended the Australian Earth Sciences Convention 2010, 4th-8th July and presented a Poster entitled "Records of Bombardment History: Provenance and Age Distribution of Lunar Impact Spherules from Apollo 16" and an Oral Presentation "Provenance and Age Distribution of Lunar Impact Spherules from Apollo 16: Integration of Major and Trace Element Chemistry and $^{40}\text{Ar}/^{39}\text{Ar}$ Ages".

Ms T.E. KELLY participated in the Terrestrial Archives of Past Climate and Biodiversity Change Workshop, Archaeology and Natural History, ANU. 2 – 6 February, 2010.

Ms T.E. KELLY attended The Association for Environmental Archaeology (AEA) Annual Conference, International Research Centre for Japanese Studies, Kyoto, Japan, 1 - 3 December, 2010, and presented a paper entitled "Interactions between humans and the environment in semi-arid Australia: from Australia's earliest occupants to European pastoralists".

Ms S.C. LEWIS, AMOS 17th Annual Conference, Canberra, Australia, 27-29 January, presented a paper entitled "Water vapour source impacts on tropical $\delta^{18}\text{O}$ during Heinrich events."

Dr J. MALLELA presented a talk entitled "Long-term records of fertiliser use in the Tully catchment captured in near-shore coral cores." Marine and Tropical Research Facility, 18-20 May 2010.

Dr J. MALLELA presented a talk entitled "Tobago brain coral provides a long-term archive of South American river runoff, tropical climate variability and shifts in coral growth." At the 85th Annual Australian Coral Reef Society Conference, Coffs Harbour, September 2010.

Dr J. MALLELA presented a talk entitled "From catchment to reef: deciphering terrestrial runoff signals in coral cores and assessing the implications on reef health" at the 85th Annual Australian Coral Reef Society Conference, Coffs Harbour, September 2010.

Ms J. MAZERAT, AMOS National conference, Canberra, 27-29 January 2010, presented a paper entitled "Coral and Speleothem Reconstruction of Ocean-Atmosphere Dynamics in Southern Indonesia during the 8.2ka event".

Ms J. MAZERAT, Australian Earth Sciences Convention, Canberra, 4-8 July 2010, presented a paper entitled "Coral and Speleothem Reconstruction of Ocean-Atmosphere Dynamics in Southern Indonesia during the 8.2ka event".

Ms J. MAZERAT, 10th International conference on paleoceanography, San Diego, USA, 31 August-3 September 2010, presented a paper entitled "The 8.2ka response of the

ocean-atmosphere system in southern Australasia".

Prof. A.P. ROBERTS, Invited speaker, American Geophysical Union Fall Meeting, San Francisco, USA.

Prof. A.P. ROBERTS, Invited speaker, 2nd International Symposium, Earth's & Planetary Interiors: Observations & Numerical Models of Paleomagnetism and Planetary Magnetism, Beijing, China.

Prof. A.P. ROBERTS, Invited speaker, Australian Earth Sciences Convention, Canberra.

Prof. A.P. ROBERTS, Invited speaker, Santa Fe Rock Magnetism Workshop, New Mexico, USA.

Prof. A.P. ROBERTS, Invited speaker, Cosmic Magnetism from Stellar to Intergalactic Scales Conference, Kiama.

Miss C.M. THOMPSON attended the Eden Marine Science Forum, 20/21 March 2010.

Miss C.M. THOMPSON attended the RSES Sea-level change workshop, 28 May 2010.

Miss C.M. THOMPSON presented a poster at the Australian Marine Science Association annual conference, 4 – 8 July 2010, entitled "Copper cycling in the oligotrophic north Tasman Sea".

Miss C.M. THOMPSON presented a talk at the RSES marine science forum, 1 October 2010, titled "Refining the role of nutrient copper in marine systems".

Miss C.M. THOMPSON presented a talk at the RSES student conference, 7 October 2010, titled "Refining the role of nutrient copper in marine systems".

Miss C.M. THOMPSON conducted fieldwork in the Tasman Sea during the 'primary productivity induced by nitrogen and iron in the Tasman Sea' voyage, 23 January 2010 – 15 February 2010.

Miss C.M. THOMPSON is conducting weekly water sampling in Lake Burley Griffin, 25 November 2010 – ongoing.

Earth Materials & Processes

Dr C. ALLEN attended and gave a talk at the Goldschmidt meeting in June 2010 in Knoxville TN, USA entitled: Changes of detrital zircon composition through time: deductions from a large database.

Dr C. ALLEN attended a Linkage Proposal Sponsors meeting and field trip in Leinster, WA in Nov 2010 and presented a talk entitled: "U-Pb dating of zircon using LA-Q-ICP-MS for provenance studies of Archean sandstones." The linkage grant is to Squire, Cas and Campbell.

Mr A. ARAD attended the meeting of the Society of Petrophysicists and Well Log Analysts in Perth, June 19th-23rd, where he gave an invited talk as the recipient of the 2009 Hugh Crocker Scholarship on "Understanding elastic properties and acoustic anisotropy at the pore/grain scale".

Prof R.J. ARCULUS attended the Australian Earth Science Convention, Canberra, 4–8 July 2010 and presented a paper entitled "New backarc magma types, active boninite magmatism, fresh peridotites: reports of some recent Marine National Facility voyages to the Southwest Pacific", and was a co-author of several other papers. He also attended the 5th State of the Arc Meeting held on Syros and Santorini in September, 2010.

Prof R.J. ARCULUS was a shipboard scientist (RV Kilo Moana) on two research voyages in the northern Lau Basin in April and December, 2010, and conducted field work in the Bushveld Complex, South Africa in April 2010.

Mr C. AUGENSTEIN visited the Structural Geology and Tectonics working group at ETH Zurich and conducted field work in the Central European Alps from the 29th June to the 27th July.

Dr A.G. CHRISTY attended the Australian Earth Sciences Convention, Canberra, 4th–8th July 2010, where he gave talks "Are Archaean microfossils really biotites?" and "What really controls coordination number in mineral crystal structures?", a poster "Pressure-dependent Zr-in-rutile thermometry of western Chinese eclogites from varied tectonic settings" (with Drs D.J. Ellis and G. Zhang) and co-authored a poster with Drs K.J.D. Adena and M.D. Norman "The geochemistry of volcanic and impact glasses from the Taurus-Littrow Valley on the Moon." He chaired half of the Special Session in memory of Ernie Nickel. He also attended the Conference Field Trip to the unconformity underneath Parliament House.

Dr A.G. CHRISTY attended the 21st Australian Conference on Microscopy and Microanalysis, Brisbane, 11th–15th July, 2010.

Dr A.G. CHRISTY attended the 20th meeting of the International Mineralogical Association, Budapest, Hungary, 20th–27th August, 2010, where he presented a talk "What really determines coordination numbers in mineral structures – can a two-radius model for atoms help?", co-authored a talk by Stuart Mills "Maximal-degree-of-order structures based on hydromagnesite layers" and a poster by Jing Chen "Spinel and orthopyroxene exsolution in clinopyroxene from gabbro, southwest Tianshan Mountains: an indicator of fO₂ decrease during cooling in post-collision environment", and attended business meetings of the Commission on New Minerals Nomenclature and Classification.

Dr A.G. CHRISTY attended the IMA field trips to Slovenia, 17th–20th August 2010, and the Czech Republic, 28th August – 1st September, 2010.

Dr A.G. CHRISTY conducted fieldwork in southwest England, 2nd–4th September 2010.

Dr A.G. CHRISTY visited the Institut für Mineralogie at the University of Münster (Germany) for discussions with Prof A. Putnis and others, 7th–8th September 2010.

Dr A.G. CHRISTY visited the University of Bristol (UK) and gave a talk "Are Archaean microfossils really biotites?", 10th September 2010.

Dr A.G. CHRISTY attended the Digicore Consortium Meeting, Canberra, 16th–17th November, 2010, where he gave a talk on "Analysis of acoustic anisotropy: the role of grain contact orientation", co-authored by Messrs A. Arad and M. Madadi.

Prof S. COX, , presented a paper entitled "Stress-driven growth versus fluid-driven growth of fracture permeability: Experimental approaches and implications for coupled fluid flow and deformation in hydrothermal ore systems" at the Australian Earth Science Convention, Canberra, July 5-8. He also presented an invited paper at a conference at Tohoku University, Japan, and presented another paper at the EM Anderson Conference at the University of Glasgow, 6-8 September.

Prof D. ELLIS attended the Australian Earth Science Convention (Canberra) July 2010 with a poster presentation on Zr-in-rutile thermometry.

Dr J.D. FITZ GERALD presented a paper "Three dimensional analysis of the hard structures in a sea urchin spine" at the 21st Australian Conference on Microscopy and Microanalysis held at Brisbane in July.

Dr A. HALFPENNY attended the Specialist Group in Tectonics and Structural Geology (SGTSG), Port Macquarie, Australia, 1st-5th February 2010 and presented a talk entitled "Evolution of Fracture-Controlled Flow Regimes: Implications for Gold Mineralisation."

Dr A. HALFPENNY attended the Australian Earth Science Convention (AESC), Canberra, Australia, 4th-8th July 2010 and presented a talk entitled "Controls on Mineralisation at the Porgera Gold Deposit, PNG" and presented a poster entitled "Comparison of Dynamically recrystallised Quartz Rich Microstructures utilising Electron Backscatter Diffraction."

Dr A. HALFPENNY attended the ARC Centre of Excellence for Ore Deposits Science Planning Meeting, Hobart, Australia, 10th June 2010 and presented a talk entitled "Macro- to Microstructures from the Porgera Gold Deposit, PNG."

Dr A. HALFPENNY attended the HKL users group meeting, Sydney, Australia, 23rd-24th September 2010 and presented a talk entitled "Mineralisation characteristics at the Porgera Gold Deposit, PNG."

Mr B.J. HANGER attended the Australian Earth Science Convention in Canberra, July 2010.

Mr B.J. HANGER organized the RSES Student Conference in October with K. Stewart and C. Thompson.

Dr J. HERMANN conducted field work in the Central Alps from 19-28 June; in the Western Alps from 18-23 July 2005 and in New Caledonia from 22-29 November.

Dr J. HERMANN, Australian Earth Science convention, Canberra, Australia, 4-8 July, presented a paper "Carbonate melts released from subducted sediments at sub-arc depth" and was co-author on 6 other contributions.

Dr J. HERMANN, State of the Arc meeting, Santorini, Greece, 19-26 September, presented a paper "Experimental constraints on mantle wedge metasomatism" and was coordinating one day of the meeting.

Dr J. HERMANN, Swiss Geoscience Meeting, Fribourg, Switzerland, 20 November, presented a paper "Pre-Alpine metamorphism in the classical Alpine staurolite-garnet

schist of Campolungo".

Dr J. HERMANN was on sabbatical at University of Lausanne, Switzerland from the 8 August to 23 December.

Dr J. HERMANN presented invited seminars at the Macquarie University, Sydney; Universities of Lyon (France); Lausanne, Geneva, Bern (Switzerland); Bochum and Frankfurt (Germany)

Mr K.N. HORNER, Australian Earth Sciences Convention 2010, Canberra, Australia 4-8 July, presented a poster titled "Development of a Geochemical Toolbox for the Lower Murrumbidgee GMA".

Mr K.N. HORNER, International Association of Hydrogeologists 2010 Annual Congress, Krakow, Poland, 12-17 September, presented a paper titled "Quantifying groundwater dynamics in a semi-arid silicate aquifer, Murray Basin, Australia".

Mr K.N. HORNER, Groundwater 2010, Canberra, Australia, 31 October to 4 November, presented a paper titled "A Conceptual Model of Groundwater Salinity in the Lower Murrumbidgee GMA".

Mr K.N. HORNER conducted field work in the Eastern Murray Basin, NSW, from 23-30 January, 13-18 May, and 12-16 July.

Mr K.N. HORNER conducted a cross-institutional study with Dr D. Allen and Dr D. Kirste at the Department of Earth Sciences, Simon Fraser University, Burnaby, Canada from 27 September to 17 December.

Prof I. JACKSON attended a meeting of the Bureau of the International Association for Seismology and Physics of the Earth's Interior (Shanghai, March), attended and presented papers at the Western Pacific Geophysics Meeting (Taipei, June) and at the Meeting of the Americas (Iguassu Falls, Brazil, August), presented a paper at the Australian Earth Sciences Convention (Canberra, July), and visited and lectured at the Deep Earth Mineralogy Centre of Excellence (Ehime University, Matsuyama, Japan, March), the University of Alberta (Edmonton, Canada, July), and the University of Minnesota (Minneapolis, July).

Ms K. KISEEVA attended the 20th general meeting of the International Mineralogical Association, 21-27 August, Budapest, Hungary.

Ms K. KISEEVA attended the New England Orogen Conference, November 16th-19th, 2010 with pre-conference field trip

Ms K. KISEEVA gave a seminar in the Saint-Petersburg State Mining Institute on the 14th of September, 2010

Huijuan Li, Australian Earth Sciences convention 2010, Canberra, Australia, 4-8 July, presented a paper entitled "Experimental constraints on Chlorine behavior in subducted sediments".

Dr D.C. "Bear" McPHAIL, convened a session on Water Resources and presented a paper entitled "Groundwater Interactions in the Lower Murrumbidgee Catchment, New South Wales" at the Australian Earth Sciences Convention, Canberra, July 2010;

Dr D.C. "Bear" McPHAIL, presented a paper entitled "River Water and Groundwater Interaction in the Lower Murrumbidgee Catchment, NSW, Australia" at Groundwater November 2010, Canberra;

Dr D.C. "Bear" McPHAIL, had 4 field trips (3-5 days each) to the Lower Murrumbidgee for groundwater and river water studies;

Dr D.C. "Bear" McPHAIL, had a 7-day field trip to the Namoi catchment, northern New South Wales.

Dr O. NEBEL, 5th International Archaean Conference Perth, presented a paper.

Dr O. NEBEL, bi-annual Australian Earth Science Convention AESC, Canberra

Dr O. NEBEL attended the post-conference field trip (5th IAS, Perth) to the Murchison Domain in Western Australia

Mr T.P. O'KANE attended the "SGTSG Biennial Conference" in Port Macquarie, Australia, from 1-5 February 2010, presenting a paper entitled " Evolution of the subducting Solomon Sea Plate ". Attended the "Australian Earth Sciences Convention" in Canberra, Australia, from 4-8 July 2010, presenting a poster entitled "Trench dynamics of the Northern Melanesian Arc". Attended "The Meeting of the Americas" in Foz do Iguassu, Brazil, from 8-13 August 2010, presenting a paper entitled "The evolution of the Bolivian orocline: application of the Pplates deformable plate tectonic reconstruction software to the question of straightening the Andes".

Prof H. O'NEILL gave a plenary lecture at the Deutsche Mineralogische Gesellschaft conference in Münster, Germany in Sept., and also attended the State-of-the-Arc meeting in Sanotorini, Greece.

Prof H. O'NEILL conducted experiments using synchrotron X-rays at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, and the Australian National Beamline Facility (ANBF) at the Photon Factory, Tsukuba, Japan in April, and the Diamond Light Source, UK, in August.

Mr J. PARK, 11th International Platinum Symposium, Sudbury, Canada, 21-24 June, presented an abstract entitled "The role of chromite crystallization on the PGE geochemistry of mafic magmas".

Ms I. STENHOUSE, PhD Candidate, SGTSG 2010 conference, presented a paper entitled "Diffusional rims and moats around ilmenite inclusions in garnet and their significance for garnet geospeedometry" and European Geosciences union general assembly 2010, presented a paper entitled 'Diffusion in Natural Ilmenite".

Ms I. STENHOUSE conducted field work in NE Scotland from 30th May – 17th June 2010.

Mr P. STENHOUSE attended the FRACS group field meeting from 28 February to 5 March.

Mr P. STENHOUSE attended the ArcGIS Desktop 2: Tools and functionality workshop from 25-27 May.

Mr P. STENHOUSE attended the Structural Analysis of crystalline rocks EGU summer school from the 22-28 August.

Mr P. STENHOUSE attended the CPAS Science communication workshop from 28-30 September.

Mr P. STENHOUSE conducted fieldwork from 11 January to 27 February in Oman.

Mr P. STENHOUSE conducted fieldwork from 11-20 August in Switzerland.

Miss D. TANNER conducted fieldwork on the Bushveld Complex in South Africa from 18-26 May.

Miss D. TANNER, Australian Earth Science Convention 2010, Canberra, 4-8 July presented a paper called "Re-equilibration of plagioclase under magmatic conditions".

Mr J. WYKES 11th International Platinum Symposium, Sudbury, Canada, 18-29 June 2010 presented a paper entitled: "The effect of FeO on the sulfur content at sulfide saturation (SCSS): A comparison between sulfur and selenium"

Earth Physics

Mr C.C. CHAPMAN, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, January; the Australian-New Zealand Climate Forum, Hobart, October, presented a paper entitled "Immersed boundary methods for the representation of coastlines in high-resolution numerical models of the Southern Ocean"; CAWCR Annual Workshop, Hobart, November.

Prof P. CUMMINS, co-convened a subtheme 'New Science for a Changing Natural Hazard Landscape' in the 'Geoscience for Society' theme of the Australian Earth Sciences Convention in Canberra, 4-8 July, and also gave a presentation at this session.

Prof P. CUMMINS gave a seminar at Geoscience Australia.

Dr. G.F. DAVIES attended the American Geophysical Union Fall Annual Meeting, at San Francisco in December, giving a paper entitled "Noble Gases in a Heterogeneous, Dynamic Mantle".

Dr R.W. GRIFFITHS, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, February, presented a paper entitled "Effects of topography on mixing efficiency in exchange flows"; American Geophysical Union Ocean Sciences, Portland, February, presented a paper entitled "Mixing efficiency in exchange flows over topographic sills"; 63rd American Physical Society – Division of Fluid Dynamics, Longbeach California, November, presented a Plenary Lecture on "Ocean overturning circulation and surface buoyancy fluxes: dynamics and energetics"; 17th Australasian Fluid Mechanics Conference, Auckland, December, presented a paper entitled "Mixing efficiency in exchange flows over topography".

Dr A.McC. HOGG, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, February, presented a paper entitled "Buoyancy and wind forcing of an eddy-resolving Antarctic Circumpolar Current"; American

Geophysical Union Ocean Sciences, Portland, February, presented a poster entitled "Buoyancy & wind forcing of the Antarctic Circumpolar Current"; 6th meeting of the CLIVAR/CliC/SCAR Southern Ocean Region Implementation Panel, Southampton, June, presented a paper entitled "Buoyancy forcing of an eddy-saturated ACC"; Australian Academy of Science/Royal Society UK Frontiers of Science meeting, Perth, October, presented a paper entitled "How & why do small things matter?"; CAWCR Annual Workshop, Hobart, November, presented a keynote address entitled "Eddies and Climate".

Dr G.O. HUGHES, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, February, presented a paper entitled "Consequences of the parameterisation in ocean models of deep and bottom water formation"; American Geophysical Union Ocean Sciences, Portland, February, presented a paper entitled "The role of available potential energy in the ocean overturning circulation"; 17th Australasian Fluid Mechanics Conference, Auckland, December, presented a paper entitled "Shallow wake flows and the shallow-water approximation".

Dr G. IAFFALDANO attended the EGU General Assembly 2-7 May 2010. Contribution title: "Monsoon speeds up Indian plate motion".

Dr G. IAFFALDANO attended Australian Earth Science Convention 4-8 July 2010.

Prof B.L.N. KENNETT attended the European Geosciences Union Meeting in Vienna in May where he gave a presentation on nested regional tomography and an invited talk on "Reconciling Seismology and Mineral Physics in the Mantle. He combined this meeting with a visit to ENS Lyon where he gave two seminars and a short visit to Munich. He gave an invited

presentation on Seismic Arrays at the IRIS Workshop in Snowbird, Utah in June. In July he presented on the Earth Imaging component of AuScope at the AESC in Canberra. In August he delivered a Keynote Address on Australian structure at the international SEISMIX2010 conference in Cairns.

Professor K. LAMBECK attended the Quaternary Research Association meeting 'Sea-Level Changes: the Science of a Changing World' in Durham (UK) in January where he gave keynote lecture 'From sea level to ice sheets: New results for the Eurasian ice sheets from Saalian to Holocene'; the Arctic Frontiers meeting in Tromsø, Norway, with the lecture 'The ice sheets of northern Eurasia from MIS 6 to the Holocene: solutions from glacial rebound analyses'; the International Space Science Institute (in March in Bern) workshop on the Earth's cryosphere and sea level change with the invited lecture 'Evolution of ice sheets during glacier cycles: lessons from the past'; the Australian Academy of Science Symposium 'Following in the Footsteps of Darwin', Galapagos in May; the Albert Tarantola memorial workshop at the Institut de Physique du Globe (in Paris in June); The Lindau Nobel Meeting (Lindau, Germany in June-July); the PALSEA workshop on palaeo-constraints on sea level change (in Bristol in September); and, as lecturer, the Karthaus 2010 Summer School on Ice Sheets and Glaciers in the Climate System.

Ms A.K. MORRISON, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, January; the Australian-New Zealand Climate Forum, Hobart, October, presented a paper entitled "The Response of the Southern Ocean Overturning to Past and Future Climate Change"; CAWCR Annual Workshop, Hobart, November.

Dr. N. RAWLINSON attended the Seismix 2010 meeting held in Cairns between August 29 - September 3, and presented a paper titled "Seismic imaging results from a decade of rolling array deployments in southeast Australia".

Mr J.C. ROBERTSON attended the Australian Geological Convention, Canberra, July, where he presented a paper entitled "Cooling and solidification of channelized viscoplastic lava flows". He also attended the 17th Australasian Fluid Mechanics Conference, Auckland, December, where he presented a paper entitled "Rheological controls on the dynamics of channeled lava flows".

Dr S POZGAY presented a paper at the Australian Earth Sciences Convention entitled "High Resolution Imaging of the Core-Mantle Boundary with PcP-P Seismic Traveltime Data" with colleagues H Tkalcic and N Rawlinson.

Dr S POZGAY presented a paper at the Australian Earth Sciences Convention entitled "A New Master of Natural Hazards Program at The Australian National University" with colleague D Zoleta-Nantes.

Dr S POZGAY presented a paper at the Australian Earth Sciences Convention entitled "Rayleigh and Love Wave Ambient Noise Tomography of Australian Continent" with colleagues E Saygin and B Kennett.

Dr S POZGAY presented a paper at SEISMIX convention entitled "Crustal Structure of Australia from Ambient Noise Tomography" with colleagues E Saygin and B Kennett.

Dr S POZGAY presented a paper at the SEISMIX convention entitled "New High-Resolution Seismic Imaging of Australian Lithosphere and the CMB with the WOMBAT Array" with colleagues H Tkalcic and N Rawlinson.

Dr. N. RAWLINSON conducted fieldwork in New South Wales to deploy, service and retrieve WOMBAT array stations on four separate occasions

Dr M.L. RODERICK, American Geophysical Union Conference, San Francisco, USA, 13-17 December, convened a session titled "Evaporation and Water Transport Dynamics in the ABL".

Dr M.L. RODERICK, presented an invited talk at the GRACE: Science Outcomes and Future Prospects" workshop, Canberra, 26 May.

Dr M.L. RODERICK, presented the keynote address titled "Water, Forests and Fire" at the Canopy Processes in a Changing Climate International Conference, Tarraleah (Tasmania), 7-15 October.

Dr. M. SALMON, SEISMIX 2010, The 14th International Symposium on "Deep Seismic Profiling of the Continents and their Margins, Cairns, Australia, 29 August – 3rd September, presented a paper entitled "AusMoho: The Moho Map of the Australian Continent.

Dr M. SALMON, AESC 2010, Canberra, Australia, 5-8th July, presented two papers entitled "New Results from the South Australian Seismic Arrays" and "AusMoho: The Moho Map of the Australian Continent"

Dr M. SALMON, EGU General Assembly 2010, Vienna, Austria, co-author of paper entitled "Slab break off –or loss of mantle instability – beneath Western North Island, New Zealand?"

Prof. M. SAMBRIDGE, attended and gave presentations at the Australian Earth Sciences Convention in Canberra, 4–8 July, and at the Australian Society for Exploration geophysics meeting in Sydney, 22–26 August.

Prof. M. SAMBRIDGE visited and gave seminars at Univ. of Rennes and Univ. of Lyon.

Dr E. SAYGIN presented two posters at EGU 2010 entitled Australian Crust and Upper-Mantle Structure from Ambient Noise Tomography with colleagues B.L.N. Kennett and Sara Pozgay, The Ambient Noise Tomography of Turkey: Crust to Upper Mantle with colleagues T. Taymaz and B.L.N. Kennett.

Dr E. SAYGIN presented a poster at the Australian Earth Sciences Convention entitled "Rayleigh and Love Wave Ambient Noise Tomography of Australian Continent" with colleagues B.L.N. Kennett and Sara Pozgay.

Dr E. SAYGIN presented a poster at the Australian Earth Sciences Convention entitled AusMoho: the Moho map of the Australian continent with colleagues M. Salmon and AusMoho working group.

Dr E. SAYGIN presented a poster at SEISMIX convention entitled "Crustal Structure of Australia from Ambient Noise Tomography" with colleagues B.L.N. Kennett and Sara Pozgay.

Dr E. SAYGIN presented a poster at SEISMIX convention entitled "Crustal Structure of Australia from Ambient Noise Tomography" with colleagues B.L.N. Kennett and Sara Pozgay.

Dr E. SAYGIN presented a poster at SEISMIX convention entitled "AusMoho: The Moho Map of the Australian Continent." with colleagues M. Salmon, B.L.N. Kennett and AusMoho group.

Dr E. SAYGIN presented a poster at SEISMIX convention entitled "Imaging Turkey's Crust with receiver functions and ambient noise" with colleagues E. Vanacore, Y. Cubuk, and T. Taymaz. Mallory Young, SEISMIX 2010: 14th International Symposium on "Deep Seismic Profiling of the Continents and their Margins", Cairns, Australia, 29 August – 3 September 2010, presented a poster entitled "Ambient Noise Tomography of Tasmania."

Mr K.D. STEWART, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, January, presented a paper entitled "Effects of Marginal Seas on Global Ocean Density Structure"; American Geophysical Union Ocean Sciences, Portland, February, presented a paper entitled "Effects of Marginal Seas on Global Ocean Density Structure"; University of Rhode Island, USA, March, presented a paper entitled "Diapycnal Mixing and the Rate of the Global Overturning Circulation of the Oceans: Insights from a Laboratory Experiment"; Fundamental Processes in Geophysical Fluid Dynamics and the Climate System, Alpine Summer School XVIII, Valsavarenche, Italy, June; CAWCR Annual Workshop, Hobart, November.

Dr H TKALČIĆ chaired a special session entitled "Structure and Dynamics of the Earth's

Core" at the AGU Fall Meeting in San Francisco, December 2010.

Dr H TKALČIĆ coauthored 7 presentations and gave a talk entitled "Earth's Core as a Conglomerate of Anisotropic Domains" in the special session on the Earth's core at the AGU Fall Meeting in San Francisco, December 2010.

Dr H TKALČIĆ gave a talk on the Earth's inner core in the geodynamics session of the AESC in Canberra, June 2010.

Dr H TKALČIĆ spent 2 weeks at Academia Sinica in Taiwan collaborating with Dr B-S Huang and his students.

Dr P. TREGONING attended the European Geophysical Union meeting in Vienna in May and was a co-author three papers: "Origin of the ITRF: finding consistency between GPS and GIA models", "Uplift in the Prince Charles Mountain: A perspective from GPS, GRACE and GIA models" and "Spurious draconitic harmonic errors in GPS analyses".

Dr P. TREGONING attended the American Geophysical Union meeting in San Francisco in December and was a co-author on three papers: "An Australian contribution to CryoSat-II cal/val in East Antarctica including the Totten glacier region", "Environmental effects and the validation of GPS time series" (invited) and "Great Earthquakes and the stability of the Australian Plate" (invited).

Dr. E. VANACORE, AESC Conference, July 2010, presented the paper Multiple Seismic Analyses of the SEAL3 Dataset to Determine Crust and Lithosphere Structure in Central New South Wales

Dr. E. VANACORE, Seismix Conference, 29 Aug – 3 Sept, presented the paper, Imaging Turkey's Crust with Receiver Functions and Ambient Noise Tomography

Dr. E. VANACORE, AGU Conference, Dec 12-17, presented the papers: 1. Imaging Turkey's Crust with Receiver Functions and Ambient Noise Tomography; 2. Simultaneous Absolute and Relative Traveltime Inversion Technique to Combine Independent Arrays in southeastern Australia.

Dr M.L. WARD, the 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, January, presented a paper entitled "The Force Balance of Wind-Driven Channel Flows"; American Geophysical Union Ocean Sciences, Portland, February, presented a poster entitled "The Force Balance of Wind-Driven Channels"; Geophysical Fluid Dynamics Laboratory, Princeton, March, presented a paper entitled "The Force Balance of Wind-Driven Channel Flows"; Florida State University, Tallahassee, March, presented a paper entitled "The Force Balance of Wind-Driven Channels"; Australian-New Zealand Climate Forum, Hobart, October, presented a paper entitled "The Arrested Development of Wind-Driven Southern Ocean Models"; 17th Australasian Fluid Mechanics Conference, Auckland, December, presented a paper entitled "Scattering of Gravity Waves by Potential Vorticity in a Shallow Water Fluid".

Miss M. YOUNG, Fall American Geophysical Union Conference, San Francisco, USA, 13-17 December, presented a poster entitled "A Synthesis of Local, Teleseismic, and Ambient Noise Data for High-Resolution Models of Seismic Structure in Western and Southeast Australia".

Miss M. YOUNG conducted field work in New South Wales from the 10th to 18th of May.

Integrated Ocean Drilling Program (IODP)

Neville Exon helped organize and chair an IODP session at the Australian Earth Sciences Convention in Canberra, and presented a paper there. He also gave a public lecture in Wellington, on IODP and what it means for New Zealand. Sarah Howgego organised an information booth at this conference. There was a range of questions regarding applications for shipboard positions, the science, life on board and general information about the membership and organisation of IODP. A number of IODP brochures, expedition fact sheets and media presentations were displayed and distributed.

PRISE

Dr R.A. ARMSTRONG attended Goldschmidt 2010, Knoxville, USA, 13-18 June.

Dr R.A. ARMSTRONG, Australian Earth Sciences Convention 2010, Canberra, 4-8 July, presented a paper "Rapid emplacement of one of the world's greatest continental magmatic provinces – precise age constraints on the Bushveld Complex".

Dr R.A. ARMSTRONG, VII South American Symposium on Isotope Geology, Brasilia, Brazil, 25-28 July, presented a paper "High spatial resolution analyses of sulphur isotopes using the SHRIMP II: Developments and new potential".

Mr C.M. FANNING co-convened a session in honour of Dr Kenneth R Ludwig at Goldschmidt 2010, Knoxville, Tennessee, USA, 13-18 June and presented two papers entitled "U-Pb and Trace Elements in Xenotime from Sediment-Hosted Co-Cu-Au and Cu-Ag Deposits" and "Zircon Oxygen and Hf Isotopic Constraints on 150 My of subduction magmatism, South Patagonian Batholith, South America".

Mr C.M. FANNING, Australian Earth Sciences Convention 2010, Canberra, 4-8 July, presented a paper entitled "Oxygen and Hf isotopic constraints on 150 My of subduction-generated magmatism in the South Patagonian Batholith, South America: implications for tracking plate configurations and movements".

Mr C.M. FANNING, VII South American Symposium on Isotope Geology, Brasilia, Brazil, 25-28 July, presented a paper entitled "Multi-dimensional zircon tracking: a case study using the 150my evolution of the South Patagonian Batholith". He also attended a post conference field trip to examine Neoproterozoic sequences.

Mr C.M. FANNING attended the SCAR Open Science Conference, Buenos Aires, Argentina, 3-7 August.

Mr C.M. FANNING conducted fieldwork in central Chile, 8-20 October.

Mr C.M. FANNING conducted fieldwork in southern Victoria Land and the Transantarctic Mountains, Antarctica, 17 November 2010 - 12 January 2011.

Visiting Fellows

Dr K. A. W. Crook attended the Sapphire Coast Marine Discovery Centre's Marine Science Forum 'Living on the Edge' at Eden on 21-22 March, 2010.

Dr K. A. W. Crook co-authored "The age of the coastal cliff-top platform and boulders at Little Beecroft Head, southeast Australia", presented at the European Geological Union General Assembly (D. M. Fink, A. D. Switzer, E. A. Felton and K. A. W. Crook).

Dr K. A. W. CROOK attended the Australian Earth Sciences Convention and associated field-trips in Canberra on 4-9 July 2010. The paper "Overturned cliff-top mega-boulders at Little Beecroft Head, Jervis Bay, NSW, Australia: A mega-tsunami or above-ground bolide impact about 20 ka BP?" was presented by Dr. E. A. Felton at the Australian Earth Science Convention, Canberra, ACT, co-authored by A. D. Switzer, D. M. Fink and K. A. W. Crook.

Dr K. A. W. CROOK attended the New England Orogen Symposium and associated Field-trips in Armidale, NSW on 13-17 November 2010.

Dr E. A. FELTON attended the Sapphire Coast Marine Discovery Centre's Marine Science Forum 'Living on the Edge' at Eden on 21-22 March, 2010.

Dr E. A. FELTON co-authored "The age of the coastal cliff-top platform and boulders at Little Beecroft Head, southeast Australia", presented at the European Geological Union General Assembly (D. M. Fink, A. D. Switzer, E. A. Felton and K. A. W. Crook).

Dr E. A. FELTON presented "Overturned cliff-top mega-boulders at Little Beecroft Head, Jervis Bay, NSW, Australia: A mega-tsunami or aboveground bolide impact about 20 ka BP?" at the Australian Earth Science Convention, Canberra, ACT 3-8 July, 2010 (E. A. Felton, A. D. Switzer, D. M. Fink and K. A. W. Crook).

Dr C. Klootwijk, 19th Australian Geoscience Convention, Canberra, 4-8 July, presented a paper "A heretic view of the Alice Springs Orogeny: Australia-Asia collision and tectonic extrusion

Dr W. Mayer, The discovery and exploitation of iron ores in colonial Australia, with emphasis on deposits in the Tamar Valley district of northern Tasmania. International Commission for the History of Geology, Annual Conference, Madrid-Almadén-Iberian Pyritic Belt, Spain, July 2010.

Dr W. Mayer, Experiments carried out by François Péron and Louis Depuch to determine the temperature and salinity of seawater at various depths in the ocean. François Péron and the figure of the scientific traveller, Symposium held at Kingscote, Kangaroo Island, November 2010

KEITH SCOTT, 17th National Conference of the Australian Meteorological and Oceanographic Society, ANU, 27-29 January 2010, contributed a paper entitled "Source area characteristics of aeolian materials across northwest Australia".

KEITH SCOTT, First Australian Regolith Geoscientists Association Conference, Arkaroola, South Australia, 21-27 February 2010, presented a paper entitled "Characteristics of soils at the Hera Au-Zn-Pb-Cu-Ag deposit, Nymagee region, NSW".

KEITH SCOTT, Australian Earth Sciences Convention 2010, Canberra, 4-8 July 2010, contributed a paper entitled "Shaping a continent – building a nation: a geology of Australia".

KEITH SCOTT, 7th International Conference on Aeolian Research, Santa Rosa, Argentina, 5-9 July 2010, contributed paper entitled "Transport of aeolian dust west of the Lake Eyre Basin, Australia".

Dr GAVIN YOUNG presented two papers at the Australian Earth Science Convention (Canberra 4-8 July 2010) entitled 'Terrestrialization of the biota and atmospheric fluctuations during the Middle Palaeozoic' and 'Marine-terrestrial transitions associated with the world's oldest coral reef fish assemblage (Early Devonian, Wee Jasper, New South Wales)'. He produced a 48 pp. field guide and led a one day post-convention excursion to the Wee Jasper area on Saturday 10 July 2010.

EDITORIAL RESPONSIBILITIES

Earth Chemistry

Dr Y. AMELIN, Associate Editor, *Geochimica et Cosmochimica Acta*.

Dr Y. AMELIN, Member of the Editorial Board, *Chemical Geology*.

Dr J.J. BROCKS, Associate Editor, *PALAIOS*, a Journal of the Society of Sedimentary Geology.

Mr A. CHOPRA, Editor, *ANU Undergraduate Research Journal*.

Dr M. HONDA, Associate Editor, *Geochemical Journal*.

Dr C.H. LINEWEAVER, Newest Member of the Editorial Board, *Astrobiology Journal*.

Dr D. RUBATTO, Associate Editor, *Lithos*.

Dr D. RUBATTO, Editorial Board, *Chemical Geology*.

Dr D. RUBATTO, Editorial Review Board, *Journal of Metamorphic Geology*.

Earth Environment

Prof R. GRÜN collaborates with the Department of Environment and Conservation, NSW, and the Three Traditional Tribal Groups in the ARC Linkage grant *Environmental Evolution of the Willandra Lakes World Heritage Area*.

Dr B.J. PILLANS, Editorial Board, *Quaternary Science Reviews*.

Prof. A.P. ROBERTS, Associate Editor, *Geochemistry, Geophysics, Geosystems*.

Prof. A.P. ROBERTS, Editorial Board, *Frontiers of Earth Science in China*.

Earth Materials & Processes

Dr A.G. CHRISTY, Editorial Board, *Mineralogical Magazine (UK)*.

Dr A.G. CHRISTY, Editorial Board, *Central European Journal of Geosciences*.

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 is an Associate Editor for the *Journal of Geophysical Research*, *Solid Earth* and routinely reviews for several professional journals. Dr J. MAVROGENES is a member of the Editorial Board of *Ore Geology Reviews*. Prof H. O'NEILL is a member of the Editorial Board, *Chemical Geology*.

Earth Physics

Prof R.W. GRIFFITHS, Associate Editor, Journal of Fluid Mechanics, Cambridge University Press.

Dr G. IAFFALDANO, Associate editor of Annals of Geophysics

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).

Visiting Fellows

Dr K. A. W. CROOK is a Foundation Member of the Editorial Board, and an Editor-in-Chief Emeritus of the journal Sedimentary Geology, who continues to serve as a reviewer on request. Recently he reviewed the paper "Palaeo-tsunami in the Pacific Islands" by James Goff and 13 other authors.

Dr E. A. FELTON reviewed papers on aspects of tsunami deposit sedimentology for the journals Geology and Earth Science Reviews.

Dr C. Klootwijk, Guest Editor Special Volume on Paleomagnetism and Rock Magnetism for the Australian Journal of Earth Sciences.

KEITH SCOTT, Editorial Board for book "Shaping a continent, Building a nation: A geology of Australia" for 34th International Geological Congress 2012.

Dr GAVIN YOUNG, Editorial Board, Alcheringa; Guest editor, Palaeoworld (IGCP 491 special issue).

OUTREACH AND WORKSHOPS

Earth Chemistry

Dr J.J. BROCKS was interviewed by the NRC Handelsblad, about 3.2 billion year old microfossils and biomarker evidence for early life.

Dr J.J. BROCKS was interviewed by freelance science writer Amy Maxman about the evolution of early life and oceans.

Dr J.J. BROCKS and Prof J. Rullkötter (U. Oldenburg) gave a two week workshop 'Echoes of Life' on molecular fossils for students of the German Scholarship Foundation (Studienstiftung des Deutschen Volkes) in September in Guidel, Brittany, France.

Mr A. CHOPRA was interviewed live on radio about the significance of the discovery of bacteria using arsenic instead of phosphorus. Approximately 9 minute interview with Sonya Feldhoff, 891 ABC Radio Adelaide's Drive Program at 5:15pm on 4 December.

Mr A. CHOPRA was interviewed on radio about the significance of the discovery of bacteria using arsenic instead of phosphorus. Approximately 4 minute interview with Ashley Hall, ABC Radio National's The World Today Program at 12:15pm on 4 December.

Mr A. CHOPRA provided written commentary for the Australian Science Media Centre's Expert's Response on the discovery of bacteria using arsenic instead of phosphorus on 4 December.

Mr A. CHOPRA was an invited guest on the Fuzzy Logic Science Show. Approximately 60 minute interview with Rod Taylor, Canberra's Community Radio 2XX at 11pm on 23 May.

Mr A. CHOPRA was featured in a newspaper science article on his PhD research titled 'A recipe for evolution' published in the Sunday Canberra times 23 May by writer Nyssa Skilton.

Mr A. CHOPRA presented a public lecture discussing planetary processes that shaped the Earth and the future of life on the Earth, leading up to the annual Earth Hour event entitled 'The Earth in an Hour' at UniLodge ANU on 27 March.

Mr A. CHOPRA assisted with other RSES staff and students in organising hands-on astronomy and planetary science based activities at the 2010 National Science Week event hosted at CSIRO Discovery Centre on 20-22 August.

Mr A. CHOPRA was invited to represent ANU at the Post-graduate and MBA Expo in Perth, WA on 23 September.

Mr A. CHOPRA participated in the 8th Annual Stromlo Student Christmas Seminars in Canberra, Australia on 26 November.

Mr A. CHOPRA participated in a 3-day online NASA Astrobiology Institute "Workshop Without Walls on Molecular Paleontology and Resurrection" on 8-10 November.

Mr A. CHOPRA participated in a series of workshops during the ResearchFest week on scientific poster design and abstract writing organised by Research Student Development Centre, ANU on 6-9 April.

Mr A. CHOPRA participated in a series of 6 workshops introducing teaching and tutoring organised by Research Student Development Centre, ANU (through August and September). Topics: student learning, small group facilitation, building confidence for teaching, marking and giving feedback and effective presentations for learning.

Mr A. CHOPRA completed a Tutor Induction Workshop at ANU on 5 March 2010.

Mr A. CHOPRA's comment was featured in a newspaper science article on the discovery of bacteria using arsenic instead of phosphorus titled 'Planet Arsenic' published in the Daily Telegraph by reporter Malcolm Holland on 4 December.

Mrs A. JARRETT was interviewed in the Swedish magazine Popular Astronomy about organic geochemistry and its use in the field of Astrobiology.

Dr C.H. LINEWEAVER appeared in the ABC Compass UNSW production of the retrial of Galileo. Interview about Galileo's contribution to science. Lineweaver played the Vatican astronomer Christopher Clavius. Broadcast May 9, 2010 on ABC television at 10 pm.

Dr C.H. LINEWEAVER appeared on the ABC "Catalyst" science show, interviewed by Graham Philips about Entropy and the Universe, filmed on May 21, 2010, broadcast "Is the end of the universe nearer than we thought?" 8 pm, Thursday, July 15, 2010.

Dr C.H. LINEWEAVER appeared on the ABC "Catalyst" science show, interviewed by Graham Philips about the Big Questions in Astronomy over the past decade, with L. Krauss, B. Schmidt, R. Norris, filmed at Mt Stromlo July 23, 2010, broadcast "Cosmology" 8 pm, September 16, 2010.

Dr C.H. LINEWEAVER participated in a public debate with Mary Rodwell at the Australian Academy of Science's Shine Dome "We should tell the public we are not alone" August 26, 2010. The debate was filmed as part of an SBS documentary "My Mum Talks to Aliens" Broadcast Nov 30, 2010, 8:30 pm on SBS One. ~5 minutes of the documentary is the debate.

Dr C.H. LINEWEAVER was interviewed by Al Jazeera television, about Stephen Hawking's new book "The Grand Design" Recorded 11 – 11:08 am.

Dr C.H. LINEWEAVER was interviewed by David Oldfield, Drive Programme, Radio 2GB Sydney, 5:50 – 5:56 pm January 5, 2010.

Dr C.H. LINEWEAVER was interviewed by Denis Rose for Australian Press about the entropy of the universe. 11 am January 25, 2010.

Dr C.H. LINEWEAVER was interviewed live by Kelly Devine and Pauline Turnbull of Queensland Brisbane Radio ABC 612, 3:45 – 3:56 pm, January 25, 2010.

Dr C.H. LINEWEAVER was interviewed by Annie Guest of ABC World Today, 1 pm, January 27, 2010.

Dr C.H. LINEWEAVER was interviewed by Rod Quinn, ABC Radio 10:15 – 10:30 pm, broadcast at 7am on Friday, January 29th, 2010.

Dr C.H. LINEWEAVER was interviewed on Community Radio, 2XX, 98.3 FM in Canberra by Nyssa Skilton and Rod Taylor on Fuzzy Logic, 10am – 11am Sunday, January 31, 2010. <http://fuzzylogicon2xx.podbean.com/?s=Lineweaver>

Dr C.H. LINEWEAVER was interviewed live about his research on dwarf planets and Pluto, on ABC 666 Canberra, Drive Show with Louise Maher, 3:20 – 3:27pm, April 8, 2010.

Dr C.H. LINEWEAVER was interviewed live about his research on dwarf planets and Pluto, on ABC 702 Sydney, Breakfast Show with Adam Spencer, 6:37am – 6:39am, April 12, 2010.

Dr C.H. LINEWEAVER was interviewed live about his research on dwarf planets and Pluto on ABC Central Australia by Alice Brennan, 10:46am – 10:53am, April 12, 2010.

Dr C.H. LINEWEAVER was interviewed live about his research on dwarf planets and Pluto on ABC Illawara (Wollongong) by Nick Rheinberger, 10:51 – 10:58 am April 12, 2010.

Dr C.H. LINEWEAVER was interviewed on Thursday, April 8, 2010 3:45 to 4pm about his research on dwarf planets and Pluto by Stuart Garry for ABC's Science Starstuff Program, which broadcast on Thursday April 15th on various ABC stations.

Dr C.H. LINEWEAVER was interviewed by Marc West of 2SER Sydney community radio, 107.3 fm from 12–12:30 pm April 12, broadcast on April 19th, 6:30 pm.

Dr C.H. Lineweaver was interviewed live on ABC Perth radio by Geoff Hutchinson on Mornings Program, 11:35–11:45, producer Leonie Harris, April 12, 2010.

Dr C.H. LINEWEAVER was interviewed live about his research on dwarf planets and Pluto on ABC 936 Hobart by Michael Veitch, 3:40 – 3:57 pm April 12, 2010.

Dr C.H. LINEWEAVER was interviewed by Pia of "The Wire" (thewire.org) distributed on the CAAMA network of community radio stations in Adelaide, Melbourne and Sydney. 12:45–1:15 pm, April 14, 2010.

Dr C.H. LINEWEAVER was interviewed by Lindy Burns, ABC Melbourne, 3:10 – 3:22 pm, produced by Tim Wright, April 14, 2010 about Spudis and Reiss articles.

Dr C.H. LINEWEAVER was interviewed by John Barron ABC Radio National, ~5:30 pm April 15, 2010 about Obama's plans for NASA.

Dr C.H. LINEWEAVER was interviewed live on ABC 774 Melbourne, Drive Show by Lindy Burns about Stephen Hawking and time travel, 3:36 – 3:45pm, on May 6, 2010.

Dr C.H. LINEWEAVER was interviewed about his research on uninhabited water on Earth, live on ABC Southern Queensland (Toowoomba) Mornings Show by Robert Blackmore 9:53 – 9:59am, on June 9, 2010.

Dr C.H. LINEWEAVER was interviewed by Paula Kruger on ABC World Today, Tomorrow, Canberra 666, about new Kepler mission planet discoveries. ~ 3 – 3:10 pm, June 17, 2010.

Dr C.H. LINEWEAVER was interviewed by Ilona Fraser 9:40 am for Capital Radio about the June 26th, 2010 partial lunar eclipse, 9:40 am, June 26, 2010.

Dr C.H. LINEWEAVER was interviewed by Genevieve Jacobs ABC 666 Canberra about "ANU for a day" lecture series at Hyatt Hotel, Canberra, July 23, 2010.

Dr C.H. LINEWEAVER was interviewed live about coronal mass ejections from the Sun and their effects, on ABC 774 Melbourne Drive Show by Lindy Burns 4:25 – 4:31pm, on August 4, 2010.

Dr C.H. LINEWEAVER was interviewed at the ABC Canberra Northbourne studios by Anthony Funnell for Future Tense, ABC Radio National, Brisbane, 10:30– 11:30 am August 5, 2010.

Dr C.H. LINEWEAVER participated in a public panel discussion "Are We Still Alone?" organized by ABC Café Scientifique, ABC1 radio MC'ed by Bernie Hobbs and Paul Willis, with Fred Watson and Carol Oliver.

www.abc.net.au/tv/bigideas/stories/2010/08/17/2984127.htm

Dr C.H. LINEWEAVER was interviewed live about a new report on the red rain of Kerala, India on ABC 774 Melbourne Drive Show by Lindy Burns 4:18 – 4:23pm, on September 10, 2010.

Dr C.H. LINEWEAVER was interviewed live about potentially habitable planets orbiting Gliese 581 on 2CC Canberra 12:01 – 12:02 pm, on October 1, 2010.

Dr C.H. LINEWEAVER interview by Eleni Psaltis about potentially habitable planets orbiting Gliese 581 rebroadcast on 2CC Canberra 1206 AM 3:02 – 3:03pm, on October 1, 2010.

Dr C.H. LINEWEAVER had a recorded interview with Stuart Garry for RadioNational StarStuff Program, about habitable planets and Gliese 581, 4 pm October 1, 2010.

Dr C.H. LINEWEAVER interviewed live on ABC South East NSW by Tim Holt, about solar flares and coronal mass ejections. 9:05 –9:15 am November 19, 2010.

Dr C.H. LINEWEAVER's research on the entropy of the universe was reported on January 25th, 2010 in:

AAP Newswire

on January 26th, 2010 in:

The Bendigo Advertiser p 11, "Scientists hot on energy trail"

The Age, p 3, "End to end all ends is closer than you think"

Canberra Times, p 3, "End of the world is nigh but still 5b years away"

Ballarat Courier, p 10, "The is not nigh just yet"

Newcastle Herald, p 3 "Universe running out of gas, scientists say"

Daily Liberal, p 8 "Universe is low on fuel: experts"

and on January 27th in:

The Age, p 13, "Harness those black holes for good not evil"

Dr C.H. LINEWEAVER's research on the lower size limit for dwarf planets was reported on April 8, 2010 in

AAP Newswire "Pluto's place in solar system under question again"

on April 9, 2010 in

Herald Sun, p 15, "Pluto will be dwarfed by change"

Canberra Times, p 3, "Potato plan could dwarf Pluto further"

Border Mail, p 16, "New blow to Pluto"

on April 10, 2010 in

Newcastle Herald, p 34, "Tiny Pluto dogged by size want"

on April 12, 2010 in

Sydney Morning Herald, p 3, "Pluto's reputation further dwarfed"

West Australian, p 16, "Things go from bad to worse for Pluto"

Dr C.H. LINEWEAVER was interviewed about his research on dwarf planets and Pluto by Monica Garriga for Agency EFE, the major multimedia news agency in Spanish language and the fifth of the world. The story was picked up by over 100 outlets which can be found by an advanced search on Google in Spanish "EFE Lineweaver Pluton" or "Lineweaver Pluto" in German.

Cosmos magazine article on Lineweaver & Norman's research on dwarf planets and Pluto by Aaron Cook, April 12, 2010 "Pluto joined by up to 50 more dwarf planets" www.cosmosmagazine.com/news/3399/pluto-joined-50-more-dwarf-planets

Cosmos magazine article on Jones & Lineweaver's research on uninhabited water on Earth "Water not always a guide to finding life" May 19, 2010 by Lindsey Doermann www.cosmosmagazine.com/news/3452/water-not-always-a-guide-finding-life

Australian Geographic article on Lineweaver and Norman's research on dwarf planets is reported on in "Dwarf planets accumulate in outer Solar System" by Heather Catchpole, April 8, 2010 www.australiangeographic.com.au/journal/dwarf-planets-accumulate-in-outer-solar-system.htm

ScienceWise (ANU science magazine) Report on Lineweaver and Norman's research on dwarf planets Winter 2010 issue "Pluto and the potatoes: Could there be ten times as many dwarf planets as we currently think?" [sciencewise.anu.edu.au/articles/Pluto and the potatoes](http://sciencewise.anu.edu.au/articles/Pluto%20and%20the%20potatoes)

ScienceWise (ANU science magazine) Report on Jones' and Lineweaver's phase diagram analysis of habitability on Mars, Spring 2010 issue "Do Martians Live Underground" (cover story) [sciencewise.anu.edu.au/articles/martians underground](http://sciencewise.anu.edu.au/articles/martians%20underground)

Australasian Science article on Egan and Lineweaver's Entropy research "Entropy Theories in State of Disorder" by Stephen Lutz, June 2010. www.australasianscience.com.au/article/issue-june-2010/entropy-theories-state-disorder.html

Australasian Science article on Lineweaver and Norman's Dwarf Planet research "Dwarf Planets are Not So Rare" by Stephen Lutz, June 2010 www.australasianscience.com.au/article/issue-june-2010/dwarf-planets-are-not-so-rare.html

ABC Science Online: Quotes, interviews and reports of Lineweaver's research appear at

www.abc.net.au/science/articles/2010/10/28/3049628.htm
www.abc.net.au/science/articles/2010/07/29/2967908.htm?
www.abc.net.au/science/articles/2010/10/08/3028955.htm?
www.abc.net.au/science/articles/2010/04/13/2871245.htm?
www.abc.net.au/science/articles/2010/05/13/2898466.htm?
www.abc.net.au/science/articles/2010/03/11/2841781.htm

Australia and New Zealand Science Alert: Quotes, interviews and reports of Lineweaver's research appear at:

www.sciencealert.com.au/news/20102601-20534.html
www.sciencealert.com.au/features/20102610-21496.html
www.sciencealert.com.au/news/20100904-20824.html
www.sciencealert.com.au/features/20100810-21405.html
www.sciencealert.com.au/news/20101405-20948.html

Dr C.H. LINEWEAVER gave a Café Scientifique lecture on the big bang at Telopea Park School, Canberra to high school students from 4 – 5:30 pm, March 10, 2010, organized by Oliver Ngo.

Dr C.H. LINEWEAVER gave a public lecture at the Sydney Observatory for Earth Day, 7:45 pm, March 27, 2010, on "50 years of SETI", organized by Andrew Jacobs.

Dr C.H. LINEWEAVER gave the after-dinner speech at the National Convention of Amateur Astronomers, Rydges Hotel, 8-9pm, April 3, 2010, organized by Margaret Streamer.

Dr C.H. LINEWEAVER participated in a panel discussion on science and the media organized by ANU Media Office/Science Communicators, evening, April 9, 2010, Manning Clark Theatre 6, ANU.

Dr C.H. LINEWEAVER participated with Fred Watson and Carol Oliver in an ABC TV sponsored panel discussion on the existence of extraterrestrial life, May 3, 2010, 6-8 pm in "The Basement" (jazz nightclub) in Sydney.

Dr C.H. LINEWEAVER gave a lecture on the big bang origin of the universe at Melrose High School, organized by Geoff McNamara, 2:15 – 3:15 pm, October 19, 2010.

Dr C.H. LINEWEAVER gave a lecture "50 years of SETI" at Swinburne University, organized by Glen Mackie and Sarah Maddison, Astronomy Department, November 19, 2010, 7-8 pm.

Dr C.H. LINEWEAVER gave a seminar to the UNSW Physics and Astronomy Department on his latest paper on the entropy of the universe, 4pm March 9, 2010.

Dr C.H. LINEWEAVER gave a seminar at the Australian National Institute of Theoretical Astrophysics (ANITA) 2-Day Workshop at Swinburne University, on entropy, 4 pm on March 23, 2010.

Dr C.H. LINEWEAVER gave the keynote "inspirational" talk at the UNSW Astronomy PhD Student Symposium, for astronomy PhD students in the Sydney area, held in the UNSW School of Business, 10 am, June 18, 2010.

Dr C.H. LINEWEAVER gave a lecture at UNSW Australian Centre for Astrobiology, on Stephen Hawking's new book "The Grand Design", organized by the Malcolm Walter, Director, entitled "Stephen Hawking, Gods and Astrobiology: the Sisyphean Task of Marginalizing the Supernatural" 1-2pm, November 4, 2010.

Mr S. McKIBBIN assisted with RSES's stall at CSIRO's Discovery Week event.

Mr R. SCHINTEIE attended a seminar on the "Introduction to the petroleum industry" (Australian Production & Exploration Association Limited) and the "Graduate short course in science communication" (Australian National Centre for the Public Awareness of Science) at ANU late September.

Dr I.S. WILLIAMS hosted a visit to the SHRIMP laboratory by students attending the National Youth Science Forum, 13th and 27th January.

Dr I.S. WILLIAMS visited the Indian Institute of Science, Bangalore, 15-18 January, and gave a lecture on the SHRIMP II and its geological applications.

Dr I.S. WILLIAMS visited the Polish Geological Institute, Warsaw, 10-16 August, and gave two invited lectures on the SHRIMP II and its geological applications.

Dr I.S. WILLIAMS visited the University of São Paulo, Brazil, 15-30 September, and gave an invited lecture on SHRIMP II and its geological applications.

Dr I.S. WILLIAMS was an invited speaker at the 5th SHRIMP Workshop and the Zircon Geochronology Training Course in Beijing, 8-20 October, where he gave lectures on - The expanding application of the SHRIMP II to oxygen isotopic analysis, and SHRIMP U-Th-Pb geochronology and the interpretation of mineral ages. He also ran a practical training course in SHRIMP operation for selected Geochronology Course participants.

Dr I.S. WILLIAMS assisted in providing advice to prospective students at the ANU Open Day, 28 August.

Earth Environment

Prof P. DE DECKKER participates on the Lakes Advisory Committee for the Corangmite Shire, Victoria.

Ms A. DE LEON spoke at Eden Marine High School to year 9-11 students in March 2010.

Ms A. DE LEON presented at the ANU Marine Science Forum, 1 October.

Dr M.K. GAGAN served as a member of the Science Advisory Board for the Earth Observatory of Singapore (Nanyang Technological University), whose mission is to study and forecast natural phenomena threatening Southeast Asia.

Dr M.K. GAGAN and Expedition Scientists were interviewed and filmed for media coverage related to the Onshore Science Party for Integrated Ocean Drilling Program (IODP) Expedition 325 (Great Barrier Reef Environmental Changes), held in July at the Bremen Core Repository (Germany).

MR S. HUI assisted as a demonstrator at the CSIRO Discovery Centre for National Science Week, RSES stall, 20 August 2010.

MR S. HUI featured in the ANU Sciencewise Magazine Autumn edition 2010: "Cosmic Time Machine".

MR S. HUI featured in the ANU Reporter Winter edition 2010: "Cosmic Time Machine".

MR S. HUI submitted an article in the Canberra Times newspaper and website: 21/7/2010 – "Dirt reveals story of asteroid belting".

MR S. HUI was interviewed for an ANU Podcast: Sciencefeed by Matthew McGann and Jamie Freestone.

Ms T.E. KELLY had her research reported in the CSIRO children's magazine, Scientriffic, "Wombats get their teeth into climate change", Scientriffic, Issue 68, July – August 2010.

Ms T.E. KELLY participated in Science Meets Parliament, sponsored by the Australian Academy of Science, March 9-10 2010.

Ms T.E. KELLY contributed to the RSES Research Highlights booklet.

Prof B.J. PILLANS, Chair of Organising Committee, Australian Earth Sciences Convention, Canberra, 4 – 9 July 2010.

Profs. A.P. ROBERTS & R. GRÜN were extensively quoted in the international media in relation to a New and Views piece reported in Nature on the earliest evidence for humans in Britain.

Prof. A.P. ROBERTS opened the Sapphire Coast Marine Discovery Centre in Eden, NSW, August.

Miss C.M. THOMPSON spoke to Eden Marine Science High School grade 11 students about tertiary study and marine science at ANU, 19 March 2010.

Miss C.M. THOMPSON volunteered at the RSES display during CSIRO National Science Week, 20 August 2010.

Miss C.M. THOMPSON volunteered at the RSES display at ANU Open Day, 28 August 2010.

Miss C.M. THOMPSON participated in the RSDC Graduate Training Program, 21 July 2010 to 3 November 2010.

Miss C.M. THOMPSON participated in the RSDC 'Taking the Stage' workshop, 19 November 2010.

Earth Materials & Processes

Prof R.J. ARCULUS was interviewed on commercial and ABC radio stations concerning Icelandic and Indonesian volcanic eruptions.

Dr A.G. CHRISTY wrote an article " Australian new minerals: 2008-present" for the June 2010 newsletter of the Specialist Group for Geochemistry, Mineralogy and Petrology, Geological Society of Australia.

Prof S. COX contributed lectures and field supervision for the First EGU summer school which was held over 6 days in the South Tyrol, Italy during August. He also presented a 2-day workshop in September to postgraduate students at CODES at the University of Tasmania, and presented a lecture to Gold Fields geoscientists at Kambalda in September.

Prof S. COX presented in August, a lecture on Earth Sciences to senior students at Orana School in Canberra, and also helped guide a field trip with students of that school on the NSW South Coast during two days in October.

Prof D. ELLIS collaborates with the NSW Education Department, through the Bournda Education centre communicating Coastal Earth and Marine Science to secondary school students.

Dr A. HALFPENNY gave a talk and discussion session at the HKL users group meeting on the use of electron backscatter diffraction

Dr J. HERMANN coordinated two visits (13 and 27 January) of students from the National Youth Science Forum at RSES.

Mr K.N. HORNER volunteered at a geoscience career day held at Geoscience Australia as part of the Australian Earth Sciences Convention 2010.

Mr K.N. HORNER co-ordinated a student social event held during the Australian Earth Sciences Convention 2010.

Mr K.N. HORNER volunteered at the Geological Society of Australia's exhibition booth at CSIRO Discovery Centre as part of National Science Week activities.

Dr D.C. "Bear" McPhail, Radio interview about groundwater in Australia. Interview with Ms D. Martin (ABC Radio National) for "Walking on Water", broadcast on 24 October 2010.

Dr C.H. LINEWEAVER was interviewed on television about the relaunch of NASA's Space Shuttle. Approximately 3 minute interview with Leigh Hatcher, Sky News Australia, broadcast at 5:15 pm 26 July.

Dr O. NEBEL convened the School seminar

Dr O. NEBEL convened a session in exploration targeting at the AESC

Earth Physics

Prof P. CUMMINS was interviewed about Australian earthquakes for an article to appear in Australian Geographic.

Prof P. CUMMINS gave an invited presentation at a workshop in Sri Lanka sponsored by the UN Development Program on tsunami risk in the Indian Ocean.

Prof P. CUMMINS gave an invited presentation on 'The Changing Face of Disaster Risk in the 21st Century' at AusAID's Disaster Risk Reduction Day on 12 October, 2010. Throughout the year, members of the Geophysical Fluid Dynamics 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 Work Experience students from ACT High Schools.

Prof B.L.N. KENNETT gave a number of radio interviews on issues related to earthquakes and tsunamis.

Dr S POZGAY was involved in the RSES Outreach committee, represented RSES at several graduate recruitment activities, created flyers and the website for the new Master of Natural Hazards & Disasters program.

DR. N. RAWLINSON co-convened (together with Prof. Malcolm Sambridge) a workshop on AuScope 2 Geoimaging on October 27.

DR. N. RAWLINSON was on the organising committee of the SEISMIX 2010 conference held in Cairns.

Dr M.L. RODERICK helped to organise and presented an invited lecture at the "Climate Change and Risks to Water Resources of the Murray-Darling Basin" workshop, Canberra, 4 March.

Dr M. SALMON participated in ANU University open day.

Dr M. SALMON supervised a work experience student from Canberra High School for a day in the seismology group.

Dr M. SALMON introduced National Youth Science Forum students and graduate students from Japan to the Seismology Lab.

Prof. M. SAMBRIDGE was interviewed on various local ABC radio stations during the year talking about recent regional earthquakes and also discussing his work on Benford's law.

Prof. M. SAMBRIDGE attended a workshop on uncertainty quantification for resources at the CSIRO division of exploration and mining in Western Australia.

Dr H TKALČIĆ gave invited seminar talks to the National Taiwan University and Academia Sinica, Taiwan.

Dr P. TREGONING was interviewed by the Canberra Times (July 2010) in relation to the funding received for the GRACE Follow On project through the Australian Space Research Program. He was an invited scientist at the Cafe Scientifique held at Telopea Park School in Canberra (May 2010). He gave an invited presentation at Canberra Grammar School (August 2010) as part of their "Australian Studies" program and talked to Year 5 at Telopea Park School (May 2010) as part of their "Global Warming" unit.

Dr P. TREGONING and Dr E.-K. POTTER organised a "GRACE: Science outcomes and future prospects" workshop at the AAS Science Dome in May 2010.

Miss M. YOUNG completed the CPAS Workshop in Science Communication during September 28th to 30th, 2010.

Integrated Ocean Drilling Program (IODP)

Neville Exon attended two meetings related to the potential formation of an Asia Pacific IODP Consortium in Korea and Taiwan. He gave papers at those meetings. He reviewed several research papers during the year and was an author of three IODP review papers (one in ARC Discovery). He helped organize the ANZIC Southwest Pacific Workshop held in Canberra in July, which led to plans for two IODP proposals. He is also a member of the Technical Advisory Group for the new Marine National Facility Future Research Vessel, which will continue to deal with shipboard equipment for at least a year, although the shipbuilding contract is to be awarded soon. Exon and Sarah Howgego have been involved in outreach activities associated with the port calls of the IODP drilling platforms GreatShip Maya to Townsville and JOIDES Resolution to Hobart. These activities involved the Minister for Science, Kim Carr, in Hobart, VIPs, scientists, science students and journalists.

PRISE

Dr R.A. ARMSTRONG gave a talk on "Exploring new avenues with in situ isotope analysis" and participated in a Workshop and field trip on deep continental drilling on the site of a proposed deep drillhole in the Barberton Mountain Land, South Africa. Dr R.A. ARMSTRONG and colleagues were interviewed by journalist Brian Calvert on the archaeological investigations of the body jars of the Cardamom Hills, Cambodia, for broadcast on CBC.

Dr R.A. ARMSTRONG presented a talk on 19th April 2010 on new developments and data from southern Africa to staff of De Beers, in Johannesburg, South Africa

Visiting Fellows

Dr K. A. W. CROOK is a member of the Board of Management of the Eden Killer Whale Museum, Eden NSW. During 2010 he has provided assistance and professional advice on the acquisition and display of replicas of Devonian fish fossils from sites on the NSW Far South Coast, supplied by Dr Gavin Young of Earth & Marine Sciences, RSES.

Dr K. A. W. CROOK has assisted Dr E. A. FELTON (Earth & Marine Sciences, RSES) in 2010 in providing NSW National Parks officers with accurate geological information for signage in coastal national parks on the NSW South Coast.

Dr E. A. FELTON serves on the Board of the Sapphire Coast Marine Discovery Centre, Eden, NSW. She also conducts educational beach geology walks for the general public, and is a volunteer guide in the Discovery Centre.

Dr E. A. FELTON is providing NSW National Parks and Wildlife Service with accurate geological information for signage in coastal national parks in the NSW South Coast. She was also interviewed about coastal geology along the 'Light to Light' walk in Ben Boyd National Park, parts of the interview to be featured on the National Parks website.

Elizabeth Truswell: Six public lectures were presented during 2010. They include a presentation 'Lake George, the ancient history' to the Australian National Botanic Gardens; another, 'Antarctica, Glossopteris and the sexual revolution' to the ACT

branch of the GSA; lectures on the way science informs my art practice to the Australian Federation of University Women and to the UWA Alumni; and on the art and science of early Antarctic voyages to the conference 'Antarctic Visions' in Hobart in June, and to the

Elizabeth Truswell: Australian National Library in May. Ockham's Razor. A session for the ABC program was recorded by Robyn Williams in November – 'Antarctica, Glossopteris and the sexual revolution' focussing on the palaeobotanical contributions of Marie Stopes and her possible influence on Scott's expedition.

Elizabeth Truswell: Committees. I continue to represent the Australian Academy of Science on the Council of the National Science Summer School (the National Youth Science Forum); on the selection committee for the AAS Dorothy Hill Awards, and as a member of the national committee for the UNESCO International Geological Correlation Program (IGCP).

DR GAVIN 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, 2010. He prepared and lodged a nomination for National Heritage Listing for the Wee Jasper-Lake Burrinjuck fossil fish sites to the Australian Government in March, 2010, and gave a presentation on this topic to a 'Symposium on Geodiversity, Geological Heritage and Geotourism' at Port Macquarie NSW (6-10 Sept, 2010). A group of geology students from Radford College visited the department on 10 March 2010 and were demonstrated the research activities in the vertebrate palaeontology lab and palaeontological collections. A year 11 student (Marnie Bucton) and Mr Jeff Hunt (ACT DEPARTMENT OF EDUCATION & TRAINING) were shown through the vertebrate palaeontology lab and collections on 13 August, she was taken on a day's fieldwork on 22 October and worked in the lab for a day during November as part of a work experience project in palaeontology. Fieldwork and fossil discoveries near Eden on the south coast were the subject of filming by Dr Paul Willis and an ABC film crew on 10-11 November (field site) and 9 December (ANU campus) for an ABC Catalyst program for 2011. Research with colleague Dr Kate Trinajstić who received the Prime Minister's Prize for science was mentioned in The Weekend Australian on 20 November.

TEACHING ACTIVITIES

Earth Chemistry

Dr Y. AMELIN gave 3 lectures in the course PHYS8205 "Nuclear Fuel Cycle".

Dr J.J. BROCKS taught the 'Carbon Cycle' as part of the 'Global Cycles' course EMSC3027.

Mr A. CHOPRA presented a guest lecture to ~60 Year 10 Rossmoyne Senior High School students in Perth, WA on the planetary science topics on 23 September.

Dr M.A. FORSTER co-taught the practical sessions with Dr J. Hermann for 3rd year subject EMSC 3024 Magmatism & Metamorphism.

Ms B. FRASL was teaching assistant for the undergraduate course Chemistry of the Earth and Ocean (EMSC2015).

Dr C.H. LINEWEAVER team-taught with Prof T. Ireland, the EMSC 3022, Planetary Science Course, Feb-July, 2010.

Dr C.H. LINEWEAVER gave two guest lectures on astrobiology in Phys 1201 (convenor Dr P. Francis), October 12-13, 2010.

Dr D RUBATTO co-taught a short course on accessory minerals and trace elements at the University of Lausanne, Switzerland, November 3-5 2010.

Dr I.S. WILLIAMS gave 16 undergraduate lectures in July to September as part of the EMSC2015 course on the geochemistry of the Earth.

Dr I.S. WILLIAMS assisted with undergraduate field excursions to the Kosciuszko region in March and Eden region in November.

Earth Environment

Prof P. DE DECKKER taught the second year courses Resources and the Environment (EMSC2016) and Marine Palaeontology and Evolution of Life on Earth (EMSC2019) during second semester.

Dr M.J. ELLWOOD coordinated and taught the third year course Global Cycles II – The modern Ocean (EMSC 3023).

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.K GAGAN co-convened EMSC2015 Chemistry of the Earth and Oceans and delivered 15 lectures, 5 practicals, and examined the course.

Prof R. GRÜN taught a 6 unit course Scientific dating techniques and isotope analysis for archaeology and palaeoanthropology (BIAN3010/6510) at the Department of Archaeology and Anthropology, ANU.

Prof B. PILLANS gave nine lectures in Environmental and Regolith Geoscience (EMSC2016; second year undergraduate course, second semester).

Prof. A.P. ROBERTS contributed to first and second year classes.

Miss C.M. THOMPSON demonstrated for the first year ANU undergraduate course The Blue Planet (EMSC1006), 30 July 2010 to 29 October 2010.

Miss C.M. THOMPSON tutored year 11 Business Course students at Copland College for the ANU Regional Partnerships Program, 15 October 2010 to 5 November 2010.

Earth Materials & Processes

Prof R.J. ARCULUS co-taught EMSC2020 The Lithosphere and 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).

Prof S.F. COX taught EMSC2012 Introduction to Structural and Field Geology, EMSC3002 Structural Geology and Tectonics, and portions of EMSC1007 and ENVS 1004 as part of the RSES Education program.

Prof D. ELLIS jointly convened the second year, first semester Mineralogy course (EMSC 2017); the second year second semester Lithosphere course (EMSC 2020); the third year summer session Coastal Environmental Earth Science course (EMSC 3028)

Prof D. ELLIS was Honours Convener (EMSC 4005, 4008)

Mr B.J. HANGER demonstrated in the first courses The Blue Planet (EMSC1006) and Introduction to Earth Science in the Field (EMSC1007) as well as undertaking the Graduate Teaching Program.

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 a three-hour short course on subduction zone metamorphism at the Ecole Normale Supérieure in Lyon, France.

Dr J. HERMANN taught a three-day short course on accessory phases at the University of Lausanne, Switzerland.

Prof I. JACKSON coordinated and co-taught EMSC8011 Introduction to Earth Materials (with Prof H. O'Neil; and Dr J. Fitz Gerald) and co-taught PHYS3070 Physics of the Earth (with Dr H. Tkalcic), and supervised the M. Sc. project of Mr Y. Li, and the 4th-year engineering project of Mr A. Delmenico.

Prof G. LISTER taught two special units attended by BSc candidate Oleg Koudashev and PhD candidate Yan Zhao. One unit involved a five week long advanced mapping field camp, this year held on the island of Syros, Aegean Sea, Greece. The second unit involved advanced microstructural analysis.

Prof G. LISTER is the Chair of Panel for four PhD candidates, and supervises and co-supervises a total of five PhD candidates: Lloyd White, Clemens Augenstein, Iona Stenhouse, Jia-Urn Lee and Tomas O'Kane.

Dr J. MAVROGENES taught the Earth Science component (50% of the course) of ENVS1004.

Dr J. MAVROGENES taught the EMSC3007 Economic Geology.

Dr J. MAVROGENES taught 50% of EMSC1007 Introduction to Earth Sciences in the Field.

Dr D.C. "Bear" McPHAIL, Convened and taught 3rd-year course: EMSC3025 Groundwater

Dr D.C. "Bear" McPHAIL, Co-convened and taught (50%) 2nd-year course: CHEM2204 Environmental Chemistry

Dr D.C. "Bear" McPHAIL, Convened and taught (20%) 4th-year course: Regolith Geoscience and Mineral Exploration (part of the Minerals Tertiary Education Council Honours program)

Dr O. NEBEL taught the Volcanic hazard course in the ANU program of Master's of Natural Hazards.

Dr O. NEBEL attended the first year field camp at Kiaola.

Prof H. O'NEILL gave part of the second year course Chemistry of the Earth and Oceans (EMSC 2015) and gave a week's course on Chemical Thermodynamics for EMSC 8011 Earth Materials: Crystal Structures, Defect Microstructures and Mechanical Behaviour.

Mr P. STENHOUSE demonstrated for EMSC 3002, Structural geology and tectonics.

Miss D. TANNER tutored Australia's Environment (ENVS1004), Earth Science in the Field (EMSC1007) and Economic Geology (EMSC3007).

Miss D. TANNER completed the Pinnacle Teacher Training Program in second semester 2010.

Earth Physics

Prof P. CUMMINS gave guest lectures in tsunami hazard in the masters courses (EMSC8706) 'Understanding Natural Hazards in the Asia-Pacific Region' and (EMSC8707) 'Understanding Subduction Zones and Geologic Hazards in the Asia-Pacific Region', as well as running an earthquake magnitude practice in (EMSC8002) 'Seismology'.

Dr A.McC. HOGG contributed lectures to The Blue Planet (EMSC1006). Dr HUGHES supervised an add-on research project in EMSC1006.

Drs G.O. HUGHES, A.McC. HOGG and R.C. KERR, and Prof R.W. GRIFFITHS taught Physics of Fluid Flows (PHYS3034) and Current Topics in Geophysical Fluid Dynamics (EMSC8004), and Special Topics course (EMSC3050).

Dr G. IAFFALDANO taught the Honours/Master course EMSC8016 Plate Tectonics and Mantle Dynamics – Lecturer and convener.

Dr G. IAFFALDANO involved with the Undergraduate course EMSC2018 Geophysics – Lecturer (1 of 6) and convener (1 of 2).

Prof B.L.N. KENNETT – Introductory lectures, radiometry and heat flow in EMSC2018 "Geophysics", and delivery of the Masters course EMSC8031 "Research Methods and Management". He also had a number of students taking the on-line course EMSC8015 "Imaging the Earth".

Dr S POZGAY Convened the new Master of Natural Hazards & Disasters program.

Dr S POZGAY taught EMSC8706 Understanding Natural Hazards in the Asia Pacific Region.

Dr S POZGAY coordinated & taught part of EMSC8707 Understanding Subduction Zones & Geological Hazards in the Asia Pacific Region.

Dr. N. RAWLINSON is convener of the honours program in Physics of the Earth.

Dr. N. RAWLINSON taught the Masters in Physics of the Earth course EMSC 8002 (seismology).

Dr M.L. RODERICK convened the Bachelor of Global and Ocean Science (Hons) degree program.

Drs M. RODERICK, A.McC. HOGG, and M.L. WARD taught Ocean-Atmosphere Modelling (PHYS3029/EMSC3029).

Dr M.L. RODERICK taught part of the third year course, Global Cycles and Paleoceanography (EMSC3027).

Dr M. SALMON taught electromagnetic and seismology components of 2nd year Geophysics course (EMSC (GEOL) 2018).

Dr M. SALMON introduced ASTR101 students to the seismology lab.

Prof. M. SAMBRIDGE taught the masters course (PHYS8012) 'Introduction to inverse problems', and co-convened the 2nd year Geophysics course (EMSC2018) with Dr. G. Iaffaldano.

Prof. M. SAMBRIDGE gave a guest lecture in the 3rd year undergraduate course (PHYS3070) 'Physics of the Earth'.

Dr E. SAYGIN taught Geophysics component of EMSC1007.

Dr H TKALČIĆ coordinated and taught an undergraduate course "Physics of the Earth" with Prof I Jackson (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 H TKALČIĆ took a share in teaching EMSC 8002 coordinated by Dr N Rawlinson.

Dr P. TREGONING taught the Master of Science course "Polar melting, climate change and sea level rise" (EMSC8009) and convened the MSc (specialising in Earth Physics) masters program.

Dr E. VANACORE assisted with the tomography practical for the geophysics masters course.

Visiting Fellows

Dr K. A. W. CROOK assisted Prof John Mavrogenes RSES in preparing for the Eden-based on-land component of the 12-day EMSC-1007 fieldwork program on the NSW FAR SOUTH COAST in November 2010.

KEITH SCOTT taught the Exploration Geochemistry component of the Minerals Tertiary Education Council Honours course "Regolith Geoscience and Mineral Exploration" April 12-16, 2010.

KEITH SCOTT supervised a post-graduate special topics project on dust in the Port Hedland region.

Dr GAVIN YOUNG taught the vertebrate palaeontology part of the 'Marine Palaeontology and Evolution' course (EMSC 2019) in the week of 20 September 2010.

HONOURS AND MASTERS SUPERVISION

Earth Chemistry

Dr S.J. FALLON supervised the honours project of Ms R. Norman on the radiocarbon surface water history of Enewetak Lagoon.

Dr M. HONDA supervised the honours project of Ms V. Espanon (University of Wollongong) on "Cosmogenic ^3He and ^{21}Ne dating of young basaltic lavas from southern Mendoza, Argentina".

Dr C.H. LINEWEAVER supervised physics undergraduate C. Waugh on a 3rd year research project: Terraforming Mars, First Semester 2010.

Dr C.H. LINEWEAVER supervised 3rd year physics PhB student K. Cook on an Advanced Study Course research project "Investigating the Elementary Composition of the Earth, Comets and Jupiter" completed July 2, 2010.

Earth Environment

Prof R. GRÜN supervised the Masters project of Ms W. Lees on Sr isotope tracing of human migration in Vanuatu.

Prof R. GRÜN was appointed guest Professor to the State Key Laboratory of Earthquake Dynamics, Institute of Geology, Chinese Earthquake Administration, Beijing.

Dr M.J. ELLWOOD supervised Summer Research Scholar Mr Jake HOWE (University of Otago, Dunedin, New Zealand) during the 2009-2010 summer session.

Earth Materials & Processes

Prof R.J. ARCULUS supervised the honours project of Mr T. Curran on the stability of spinel and sulfide in the Greenhills Layered Igneous Complex, New Zealand.

Prof S.F. COX supervised the projects of Mr P. Le Roux, Ms L. Howat, and Leigh Gibson, and co-supervised Mr A. Lukomskyj with Dr J. Mavrogenes.

Prof D. Ellis supervised the honours project of Mr N. Claydon on The hydrodynamic properties associated with the recovery of an ICOLL after flood conditions. He jointly supervised the honours project of Ms B. Bauer (Fenner School with Dr Beavis).

Dr J.D. FITZ GERALD was awarded a John Sanders medal in July by the Australian Society for Microscopy and Microanalysis, and a Vice Chancellor's Career Achievement Award at the 2010 ANU Staff Awards ceremony.

Dr A. HALFPENNY trained honours students in analytical techniques

Mr K.N. HORNER served as an advisor for three honours projects on groundwater and aqueous geochemistry completed in 2010 by Mr J. Knight, Ms R. Garner, and Mr C.

Zimmerman.

Dr J. MAVROGENES supervised the honours project of Mr N. Tailby on the Spitskopf carbonatite and of Mr M. Stevens on the Plattreef, South Africa.

Dr J. MAVROGENES supervised the honours project of Mr T. Whan on The Magnetite Crisis.

Dr D.C. "Bear" McPHAIL, supervised 3 honours students in 2010: Mr J. Knight on groundwater dynamics and Ms R. Garner on geophysics and groundwater in the Lower Murrumbidgee, New South Wales; and Mr C. Zimmermann on groundwater-surface water interaction in the Peel River, New South Wales.

Dr G.M. YAXLEY supervised the honours project of Mr M.J. Doull on the depletion and metasomatic history of garnet peridotites from the Kaapvaal craton, southern Africa.

Earth Physics

Prof R.W. GRIFFITHS supervised the Honours thesis project of Mr. M. PITTARD on Antarctic ice melting.

Dr A.McC. HOGG and Prof R.W. GRIFFITHS supervised the Honours thesis project of Miss N. MAHER on the dynamics of the Southern Ocean.

Professor K. LAMBECK was elected Foreign Member to the American Academy of Arts and Sciences in April. He was also appointed a Fellow of the Royal Society of New South Wales in November.

Dr S POZGAY sat on the Honours Thesis committee for Nicola Maher, studying ocean circulation with respect to the Antarctic Circumpolar Current.

Dr P. TREGONING supervised the masters research project (EMSC8030) of Mr A. Hanna the comparison of GRACE and soil moisture models in the Australian Great Artesian Basin.

Visiting Fellows

KEITH SCOTT supervised the honours project of Lance Karlson on the characterization of dust in NW Australia. (Awarded 1st class Honours, July 2010)

Dr GAVIN YOUNG supervised Ph.D students Brian Choo, Alice Clement, and Greg Bell, and honours student Nicola Power.

OTHER MATTERS

Earth Chemistry

Dr Y. AMELIN and Dr. V.C. BENNETT oversaw installation of LIEF funded "Triton Plus" thermal ionization mass spectrometer (still in progress).

Dr V.C. BENNETT was a Program Committee Member and the Early Earth Theme Coordinator, Goldschmidt Conference 2010.

Dr V.C. BENNETT continues on the Board of Directors of the Geochemical Society.

Dr V.C. BENNETT is on the Goldschmidt Medal selection committee, Geochemical Society.

Dr V.C. BENNETT is a member of the Kuno Award Committee of the American Geophysical Union.

Dr V.C. BENNETT continues as a member of the ANU Major Equipment Committee.

Dr J.J. BROCKS, Member of the ANU College of Physical and Mathematical Sciences Advisory Board.

Dr J.J. BROCKS, Founding Member and Custodian of NECTAR, a group that supports early Career academics at ANU.

Dr J.J. BROCKS, member of the review panel and Academic Steering Committee for the mass specrometer facility of the Research School of Biology, ANU.

Mr A. CHOPRA, Co-administrator for the voluntary student outreach program at the Research School of Astronomy and Astrophysics, ANU which offers outreach nights to ~600 high school students every year from around Australia.

Mr A. CHOPRA continues to lead the EARTHRISE (Education and Research through Interesting Space Experiments) program at ANU involving low cost balloon borne near-space experiments such as high-altitude photography and atmospheric profiling. The proposal was awarded a \$1600 seed grant by the Directors at RSES and the Research School of Astronomy and Astrophysics, ANU for a demonstration flight. The program offers graduate and undergraduate students project management, teaching and scientific research opportunities.

Dr M.A. FORSTER is the Chair of the RSES OH&S Committee.

Ms B. FRASL served as a student representative on the HDR recruitment committee.

Dr C.H. LINEWEAVER organized a Planetary Science and Astrobiology Workshop in honour of Prof P. Nicholson (Cornell University) and Prof N. Sleep (Stanford University) June 9 and 10, 2010. Co-organizers were A. Chopra, R. Salmeron and R. Petch.

Dr C.H. LINEWEAVER became a member of the NASA National Astrobiology Institute Focus Group on "Thermodynamics, Disequilibrium and Evolution" convened by J.

Martin-Torres (Caltech), M. Russell (JPL) and E. Simoncini (Max Planck, Jena).

Dr C.H. LINEWEAVER chaired the Research School of Astronomy and Astrophysics Colloquium Committee, responsible for weekly speakers at Mt Stromlo Observatory, maintained the Colloquium Online Calendar and helped develop the current ability to record and archive RSAA Colloquia.

Dr D. RUBATTO, Treasurer, Association for Research between Italy and Australasia.

Earth Environment

Dr M.K. GAGAN oversaw the refurbishment of the Earth Environment Stable Isotope Laboratory and the installation of the new ARC LIEF-funded Thermo Finnigan MAT-253, Kiel IV device, and Gasbench II stable isotope facilities in the Jaeger 1 building.

Dr M.K. GAGAN served on the Science Advisory Board for the Earth Observatory of Singapore, Nanyang Technological University, and attended the 2nd annual Board meeting held in January at NTU.

Dr M.K. GAGAN served on the Scientific Organizing Committee for the 10th International Conference on Paleoceanography held in August-September in San Diego, USA.

Dr M.K. GAGAN served on the ANZIC Science Steering Committee for the Australian Integrated Ocean Drilling Program (IODP).

Dr M.K. GAGAN is a member of the Australasian INTIMATE Project (INTEgration of Ice, MARine and TERrestrial records of the Last Glacial Maximum and Termination), which is a core program of the INQUA Palaeoclimate Commission. Prof B.J. PILLANS, President, Stratigraphy & Chronology Commission, International Union for Quaternary Research.

Prof B.J. PILLANS, 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.

Prof. A.P. ROBERTS, Member, Governing Council, Australia-New Zealand Integrated Ocean Drilling Program Consortium.

Prof. A.P. ROBERTS, Member, Review and Advisory Committee, Institute for Rock Magnetism (NSF-funded National Facility), University of Minnesota, USA.

Miss C.M. THOMPSON is co-supervising 2010/2011 summer scholar student Miss A. Robinson (Lincoln University, New Zealand), looking at algal bloom dynamics in Lake Burley Griffin, 22 November 2010 to 28 January 2011.

Miss C.M. THOMPSON served as a member of the 2009 RSES Christmas Party organising committee.

Miss C.M. THOMPSON served as a member of the 2010 RSES Student Conference organising committee.

Miss C.M. THOMPSON served as seminar convener for the Earth Environment group, RSES, December 2009 – ongoing.

Earth Materials & Processes

Dr C. ALLEN attended a Linkage Proposal Sponsors meeting and field trip in Leinster, WA in Nov 2010 and presented a talk entitled: "U-Pb dating of zircon using LA-Q-ICP-

MS for provenance studies of Archean sandstones." The linkage grant is to Squire, Cas and Campbell.

Dr C. ALLEN gave a talk at QUT in Brisbane in December 2010 entitled: The joys and pitfalls of LA-ICP-MS analysis, focusing on geological applications.

Mr A. ARAD has suspended his PhD program and scholarship for six months in order to attend an industrial internship at Shell Exploration, Houston, Texas, commencing October 2010.

Prof R.J. ARCULUS served as a member of the Steering Committee of the Marine National Facility.

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 new Hydrotalcite 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.

Dr A.G. CHRISTY is Treasurer of the Australian Microscopy and Microanalysis Society from October 2010.

Dr A.G. CHRISTY seconded to a Senior Lectureship / Earth Science Microscopist position in the Centre for Advanced Microscopy, ANU, for three years from July 2010.

Prof S. COX continued in the position of Associate Director (Education) for RSES.

Dr A. HALFPENNY was responsible for the maintenance, supervision and new users training of the optical cathodoluminescence microscope

Mr K.N. HORNER serves as the post-graduate student representative on the council of the ACT Chapter of the Geological Society of Australia.

Mr K.N. HORNER was commissioned to write an unrefereed article on current trends in Australian hydrogeology research for The Australian Geologist, a quarterly geoscience magazine produced by 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, as a member of the Scientific Program Committee for the 2011 IUGG General Assembly in Melbourne, and as con-convener of two symposia for that forthcoming meeting.

Ms K. KISEEVA attended student's field trip to Victoria 28.04.10 – 05.05.10

Prof G. LISTER is the Chair of the committee charged with developing the Reconciliation Action Plan (RAP) for the College of Physical and Mathematical Sciences.

Dr J. MAVROGENES was a member of the Organizing Committee for 2010 Australian Earth Science Convention in Canberra.

Dr D C "Bear" McPHAIL, Minerals Council of Australia (MCA): Member of the Steering Committee for the Minerals Tertiary Education Council (MTEC) Honours program, coordinator and presenter of the MTEC Honours course on Regolith Geoscience and Mineral Exploration

Dr D.C. "Bear" McPHAIL, Australian Institute of Mining and Metallurgy (AusIMM): Committee member of the Canberra Central West NSW branch

Dr D.C. "Bear" McPHAIL, Member of the Steering Committee for the ANU Water Initiative

Dr D.C. "Bear" McPHAIL, Fellow of the Australian Institute of Mining and Metallurgy

Dr D.C. "Bear" McPHAIL, Fellow of the Association of Applied Geochemists

Dr D.C. "Bear" McPHAIL, Coordinated ANU sponsorship of Groundwater 2010, international conference for hydrogeology, Canberra.

Dr G.M. YAXLEY, Secretary of the Specialist Group in Geochemistry, Mineralogy and Petrology, of the Geological Society of Australia.

Mr L. WHITE, a member of Mapping and Planning Support (MAPS) assisted the Victorian Police with GIS support during the 2009 Victorian bushfires (DATES).

Earth Physics

Prof P. CUMMINS gave guest lectures in tsunami hazard in the masters courses (EMSC8706) 'Understanding Natural Hazards in the Asia-Pacific Region' and (EMSC8707) 'Understanding Subduction Zones and Geologic Hazards in the Asia-Pacific Region', as well as running an earthquake magnitude practice in (EMSC8002) 'Seismology'.

Dr A.McC. HOGG contributed lectures to The Blue Planet (EMSC1006). Dr HUGHES supervised an add-on research project in EMSC1006.

Drs G.O. HUGHES, A.McC. HOGG and R.C. KERR, and Prof R.W. GRIFFITHS taught Physics of Fluid Flows (PHYS3034) and Current Topics in Geophysical Fluid Dynamics (EMSC8004), and Special Topics course (EMSC3050).

Dr G. IAFFALDANO taught the Honours/Master course EMSC8016 Plate Tectonics and Mantle Dynamics – Lecturer and convener.

Dr G. IAFFALDANO involved with the Undergraduate course EMSC2018 Geophysics – Lecturer (1 of 6) and convener (1 of 2).

Prof B.L.N. KENNETT – Introductory lectures, radiometry and heat flow in EMSC2018 "Geophysics", and delivery of the Masters course EMSC8031 "Research Methods and Management". He also had a number of students taking the on-line course EMSC8015

"Imaging the Earth".

Dr S POZGAY Convened the new Master of Natural Hazards & Disasters program.

Dr S POZGAY taught EMSC8706 Understanding Natural Hazards in the Asia Pacific Region.

Dr S POZGAY coordinated & taught part of EMSC8707 Understanding Subduction Zones & Geological Hazards in the Asia Pacific Region.

Dr. N. RAWLINSON is convener of the honours program in Physics of the Earth.

Dr. N. RAWLINSON taught the Masters in Physics of the Earth course EMSC 8002 (seismology).

Dr M.L. RODERICK convened the Bachelor of Global and Ocean Science (Hons) degree program.

Drs M. RODERICK, A.McC. HOGG, and M.L. WARD taught Ocean-Atmosphere Modelling (PHYS3029/EMSC3029).

Dr M.L. RODERICK taught part of the third year course, Global Cycles and Paleooceanography (EMSC3027).

Dr M. SALMON taught electromagnetic and seismology components of 2nd year Geophysics course (EMSC (GEOL) 2018).

Dr M. SALMON introduced ASTR101 students to the seismology lab.

Prof. M. SAMBRIDGE taught the masters course (PHYS8012) 'Introduction to inverse problems', and co-convened the 2nd year Geophysics course (EMSC2018) with Dr. G. Iaffaldano.

Prof. M. SAMBRIDGE gave a guest lecture in the 3rd year undergraduate course (PHYS3070) 'Physics of the Earth'.

Dr E. SAYGIN taught Geophysics component of EMSC1007.

Dr H TKALČIĆ coordinated and taught an undergraduate course "Physics of the Earth" with Prof I Jackson (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 H TKALČIĆ took a share in teaching EMSC 8002 coordinated by Dr N Rawlinson.

Dr P. TREGONING taught the Master of Science course "Polar melting, climate change and sea level rise" (EMSC8009) and convened the MSc (specialising in Earth Physics) masters program.

Dr E. VANACORE assisted with the tomography practical for the geophysics masters course.

Visiting Fellows

Dr P.J. JONES, Corresponding member of the Subcommittee on Carboniferous Stratigraphy of the International Stratigraphic Commission, International Union of Geological Sciences.

Wolf Mayer was interviewed on ABC Radio National on the subject of the scientific discoveries made by the Baudin expedition to Australia from 1801 to 1803. The subject matter of this interview will form part of the program Hindsight to be broadcast early in the new year.

Dr GAVIN YOUNG is a Titular Member of the International Union of Geosciences Subcommittee on Devonian Stratigraphy, and a committee member for the ACT division of the Geological Society of Australia. As co-leader with Prof ZHU MIN, (Beijing) of IGCP Project 491 ('Middle Palaeozoic Vertebrate Biogeography, Palaeogeography and Climate') he was heavily involved in preparation and editing of the final results volume for that project, published as a special issue of the journal *Palaeoworld* in March 2010.