

Research School of Earth Sciences

Annual Report 2013



Fieldwork on Mount Papandayan, Indonesia
Photo credit: Richard Arculus



Australian
National
University

TABLE OF CONTENTS

DIRECTOR'S REVIEW OF 2013

STAFF, STUDENTS AND AWARDS

Academic Staff

Post-Graduate Students

Theses Submitted

Professional Staff

Honours and Awards

Student Awards

RESEARCH ACTIVITIES

Earth Chemistry

Earth Environment

Earth Materials & Processes

Earth Physics

PRISE

IODP

Visiting Fellows

RESEARCH SUPPORT

Electronics Group

Engineering Group

PUBLICATIONS

NATIONAL AND INTERNATIONAL LINKS

Collaboration with Australian Universities, CSIRO & Industry

International Collaboration

Cooperation with Government and Industry

STAFF ACTIVITIES

Conferences and Outside Studies

Editorial Responsibilities

Outreach and Workshops

Teaching Activities

Honours Supervision

Other Matters

DIRECTOR'S REVIEW OF 2013: A YEAR OF ACHIEVEMENT

2013 was a successful year for RSES with satisfying outcomes in research, student recruitment and research funding, along with welcome external recognition of the quality of the School's research, research training and undergraduate teaching. The attached research highlights testify to the School's diverse and vibrant research culture in which big questions are asked and answered about the origin, structure and evolution of our planet, including the surficial processes of central significance to climate and the origin, evolution and survival of life on Earth. Addressing such questions often requires the development and application of novel experimental, analytical, or computational methods – innovation that is underpinned by the School's skilled technical and workshop staff.

The School is continuing with its influential work on the origin and evolution of the solid Earth, as is evident from the following examples from the attached research highlights. Amelin et al. have dated at 4.562(4) billion years a newly-found ungrouped achondrite meteorite possibly from the planet Mercury. An understanding of diffusion on sub-mm spatial scales is helping unravel the nature of hydrogen transport in upper-mantle olivine (Padrón-Navarta et al.) and allowing robust inference of ages from the often complex fabrics of exhumed metamorphic rocks (Forster & Lister). Trace-element and isotopic measurements are similarly helping attach timescales to deep prograde alpine metamorphism (Gauthiez-Putallaz et al.), whereas the distinctive textures of mineralized accretionary breccias from Porgera, PNG are being interpreted as the result of fluidization of fault damage products in a transitory high fluid flux regime (Cox & Munroe). At larger scales, modern GPS techniques are being used to interpret the contemporary tectonics of SW Turkey (McClusky et al.). The seminal contribution of K-Ar dating to the plate tectonic revolution, by establishing age-progressive island-chain volcanism and providing a time scale for magnetic reversals, has been newly reviewed by one of its pioneers (McDougall). Parallels between the tectonic settings offshore from Tohoku, Japan and Java, Indonesia are being explored in order to better understand the risk of mega-earthquakes and associated tsunamis in the Indonesian region (Cummins et al.). Meanwhile, the merits of a versatile new strategy called Parallel Tempering have been explored in the context of seismic receiver functions and their inversion for earth structure (Sambridge).

In the broad realm of ocean and climate geoscience, progress is similarly being made on many fronts as indicated by the following representative research

highlights. The energy budgets and dynamics of turbulent convection are being studied through numerical simulations at very high Rayleigh number (Gayen et al.). Ice cores from the Antarctic peninsula have revealed a dramatic increase in the rate of summer ice melting – particularly during the last 50 years (Abram & Mulvaney). Stable isotope studies of carbonates from cave deposits in SE Asia have been refining our understanding of the response of the Australasian monsoon to various kinds of climate forcing including the potential for anthropogenic influence on the vital rainfall brought by the monsoon (Krause et al.). A new activity involves the measurement of iron isotopic composition of dissolved and particulate material to monitor changes in the biogeochemical cycling of iron associated with annual subtropical spring bloom east of New Zealand and in the marine realm more generally (Ellwood et al.). Study of a particularly well preserved section of the Bitter Springs sedimentary formation in central Australia has revealed a dramatic change in carbon isotopic composition near 800 Ma suggestive of relatively deep, partly stratified and anoxic waters, with remains of anaerobic predatory eukaryotes, possibly the oldest genuine biomarker signal of modern eukaryotes in the geological record (Brocks and Jarrett).

Within the context of the ANU's new transparent funding model, the School is making substantial progress, against the odds, in the reduction of its recurrent account deficit. The traditional block grant income to the School, which now accounts for about 40% of the total budget and is spent mainly on salaries, continues to decline in value. However, for RSES, this decline is being substantially offset by increased returns based on research grant income, undergraduate student numbers and Ph D completions. Moreover, the School has done well in the latest rounds of ARC funding. The School enjoyed a remarkable 50% success rate in Discovery Project funding from the Australian Research Council (ARC) as well as success in the Laureate Fellowship (Prof Hugh O'Neill), Future Fellowship (Drs Mark Kendrick of the University of Melbourne and Penny King), Discovery Early Career Research Award (Dr Bishakhdat Gayen) and Linkage Infrastructure Equipment and Facilities (LIEF) schemes. The School takes pride in the achievement of lead-investigator Prof Richard Arculus in helping to secure LIEF funding to support Australian participation, initially for 2014 and 2015, in the new Integrated Ocean Discovery Program.

In 2013, Emeritus Professor Kurt Lambeck became only the second Australian recipient (after Ted Ringwood) of the Wollaston Medal of the Geological Society of London and was also accorded the rare distinction of appointment as a Chevalier of the French Légion d'Honneur. Immediate past-Director Professor Andrew Roberts was elected to Fellowship of the American Geophysical Union (along with School 'alumni' Michael Perfit of the University of Florida and Peter Zeitler of Lehigh University) and to Honorary Fellowship of the Royal Society of New Zealand.

Professor Ian Jackson was elected to Fellowship of the Australian Academy of Science. Dr Vickie Bennett (2013), Professor Richard Arculus (2014) and Dr Yuri Amelin (2014) were newly elected as Geochemical Fellows by the Geochemical Society and the European Association of Geochemistry. Dr Andrew Christy was awarded a lifetime Honorary Fellowship of the Mineralogical Society. Dr Michael Roderick was awarded the 2013 Dalton Medal of the Hydrology Division of the European Geosciences Union. The Geodynamics Division of the European Geosciences Union awarded its 2014 Outstanding Young Scientist Award to Dr Rhodri Davies and its Augustus Love Medal to School 'alumnus' Shun-ichiro Karato (of Yale University). Two others of the School's early-career researchers won prizes this year for outstanding Ph D theses: Dr Yvan Dossmann the Prix Paul Sabatier Physique from L'Académie des Sciences de Toulouse and Dr Bishakhdat Gayen the Andreas Acrivos Dissertation Award of the American Physical Society. Emma Howard and Richard Skelton were awarded ANU University Medals in Physics of the Earth.

2013 saw the arrival of the VC's Strategic Appointee and 2012 Laureate Fellow Prof Eelco Rohling and his research group, and the new School Manager Geoff Pearson. Drs Daniela Rubatto and Ian Williams were promoted to Professor, Daniela thus becoming the School's first female professor – a significant step for RSES on the long road to gender equality. Drs Richard Armstrong, Michael Ellwood, Graham Hughes, Simon McClusky, Nick Rawlinson, and Hrvoje Tkalčić were promoted to Senior Fellow and Dr Bishakhdat Gayen to Research Fellow. During the year, there were also several departures from the School, notably Sherryl Kluver after many years of committed service as administrator for the Earth Physics area, and Tony Beasley, and Drs John Foster, and Graham Mortimer who have each made exemplary contributions as long-serving specialised technical staff in their respective research areas. Dr Andrew Christy is leaving after many years' contribution to the ANU particularly in support of the teaching and research activities of the former Department of Earth and Marine Sciences, and Dr Nicholas Rawlinson left mid-year to take up a Chair at the University of Aberdeen. Three distinguished and long-serving professors (Patrick De Deckker, David Ellis, and Ross Griffiths) made the transition at the end of 2013 to Emeritus Status. In the absence of compulsory age retirement, timely retirements like those facilitated this year by the ANU's Voluntary Early Retirement Scheme, are critical to the School's future - by funding our program of ongoing renewal. The School is actively seeking to maintain a strong continuing association with each of our retirees who have so much more to contribute.

Following extensive discussion, the School will trial in 2014 a modified internal structure involving three clusters of research groups, each led by an Associate Director (AD) and supported by an embedded cluster administrator. A fourth Associate Director will assume responsibility for School Projects, alongside those with ongoing responsibilities for Education (coursework) and for Graduate Research

Training (HDR), respectively. Renewed commitment to regular rotation of staff through the AD roles sees Dr Vickie Bennett and Prof Hugh O'Neill stepping down after valuable contributions over many years, to make way for the incoming Associate Directors Drs Greg Yaxley and Steve Eggins.

The past year has also seen a start made on the refurbishment of the heritage brick building, directly opposite the Jaeger buildings across Mills Road, that was formerly part of the John Curtin School of Medical Research. This project will provide space on the ground floor and basement for the micropalaeontology and marine geoscience labs, and to house the School's extensive geological collection. The availability of this new space from late 2014 will complete the consolidation of all geoscience activities of the modern School on the Jaeger site. In addition the School has re-established its sovereignty over the Old Hospital Building providing office accommodation for final-year Ph D students with flow-on flexibility throughout the School.

Substantial progress has been made during 2013 in cultivating a shared sense of community among our alumni – both students and staff – whose ongoing support is critical in maintaining and enhancing the School's illustrious reputation. The 40th birthday of the Research School of Earth Sciences was celebrated at a morning tea in July at which Denise Hales, the widow of Foundation Director Anton Hales, presented to the School a wonderful portrait of Anton by their granddaughter Megan Hales. In October, a reunion held to mark more formally the 40th birthday, attracted more than 300 staff and students – past and present – including many representatives of the earliest years of the much longer ANU geoscience tradition: Mervyn Paterson, Frank Stacey, Ian McDougall, Bill Compston, Ross Taylor, David Green, Ken Campbell, Mike Rickard and Tony Eggleton. During the December meeting of the American Geophysical Union in San Francisco, the School was delighted to welcome about 80 of its alumni to its first such overseas reception. The philanthropic highlight of the year was receipt from the family of the late Bruce Chappell of a generous \$1.2M bequest from his estate. The School is seeking to augment its already significant endowment through a School Futures Fund to support diverse activities including a new scheme of prestigious Alumni Research Fellowships.

Finally, it remains for me to thank all staff and students for their efforts during 2013 in helping the School maintain its proud tradition of leadership in research, research training and undergraduate teaching. We look forward to more of the same in 2014!

Ian Jackson, Director

3 April 2014

ACADEMIC STAFF

Director

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

Associate Directors

Prof R. Grün, Diplo Geol, Dr.rer.nat.habil Köln, DSc ANU, FAAH - Earth Environment

Prof J. Hermann, Dip PhD ETH Zürich – Education (Undergraduate)

Prof H.St.C. O'Neill, BA Oxford, PhD Manchester, FAA – Earth Materials & Processes

Prof M.S. Sambridge, BSc Loughborough, PhD ANU, FRAS – Earth Physics

Dr V.C. Bennett, BSc PhD UCLA – Earth Chemistry

Dr D. Rubatto, BSc MSc Turin, PhD ETH Zürich – Education (HDR)

Distinguished Professor

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. DeDeckker BA 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

T.R. Ireland, BSc Otago, PhD ANU

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

B.J. Pillans, BSc PhD ANU, HonFRSNZ

A.P. Roberts, BSc Massey, BSc (Hons) PhD DS Victoria University (Wellington)

Senior Fellows

Y. Amelin, MSc PhD Leningrad State University

A.J. Berry, BSc (Hons) Sydney, DPhil Oxford

J.J. Brocks, Dip Freiburg, PhD Sydney

S.M. Eggins, BSc UNSW, PhD Tasmania

C.M. Fanning, BSc Adelaide

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

A.M. Hogg, BSc ANU, PhD UWA

M. Honda, MSc PhD Tokyo

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

C.H. Lineweaver, BSc Munich, PhD Berkeley

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

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

M.D. Norman, BSc Tennessee Technological University, MSc Tennessee, PhD Rice

H. Tkalčić, Dip Engineering in Physics, Zagreb, PhD California Berkley

P. Tregoney, BSurv PhD UNSW

I.S. Williams, BSc PhD ANU

G.M. Yaxley, BSc PhD Tasmania

Fellows

N. Abram, BSc Advanced (Hons) Sydney, PhD ANU
R. Armstrong, BSc MSc Natal, PhD Witwatersrand
M. Ellwood, BSc (Hons) PhD Otago
S. Fallon, BA MS San Diego, PhD ANU
M. Forster, BSc MSc PhD Monash
D. Heslop, BSc Durham, PhD Liverpool, Dr habil Bremen
G. Hughes, BE ME Auckland, PhD Cambridge
P King, BSc (Hons) ANU, PhD Arizona State
S. McClusky, BSurv PhD NSW
O. Nebel, Diplom Geology Dr rer. nat. Munster
B.N. Opdyke, AB Columbia, MS PhD Michigan
N. Rawlinson, BSc PhD Monash
R. Strzepek, BSc McGill, PhD British Columbia
J. Yu, BSc MSc Nanjing University, PhD Cambridge

Research Fellows

L. Chang, BSc Peking, PhD Southampton
R. Davies, MSc PhD Cardiff, UK
J. Dettmer, Diplom Geophysiker Hamburg, PhD University of Victoria (BC, Canada)
S. Downes, BSc (Hons) UNSW, PhD UTas
G. Iaffaldano, BSc Rome, PhD Munich
A. Klocker
J. Montillet, BSc MSc Ecole Centrale d' Electronique, MSc Aalborg, PhD Nottingham
U. Proske, BSc Diplom, PhD Bremen
A. Purcell, BSc (Hons) PhD ANU
R. Salmeron
M. Salmon, BSc (Hons) PhD Victoria University (Wellington)
E. Saygin, BEng Istanbul Technical University, PhD ANU

Postdoctoral Fellows:

A. Abrazhevich, Dip Geology & Geophysics St Petersburg, MPhil Hong Kong, PhD Michigan
J. Avila, BSc MSc UFRGS, PhD ANU
N. Balfour, BSc (Hons) MSc Victoria University (Wellington), PhD University of Victoria (British Columbia)
A. Benard
N. Darbeheshti, BSc MSc K.N. Toosi University of Technology, PhD Curtin
E. David
M. Davies, MSc Washington, PhD Oregon State
B. Gayen
K. Grant, BSc Southampton, MSc JCU, PhD Southampton
A. Kouilal
L. Lescarmontier, PhD Tasmania in cotutelle with University Paul Sabatier (France)
G. Marino, MSc (cum laude) University 'Federico II' of Naples; PhD, Utrecht University
J. Park, BSc, MSc Korea Uni (Seoul, South Korea), PhD ANU
C. Sippl, Dipl.-Geophys. UMunich, PhD FU Berlin

J. Stipcevic

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*

P. Cummins, BA(Physics), PhD UC, Berkeley

G.F. Davies, MSc Monash, PhD CalTech

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

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

I. McDougall, BSc Tasmania, 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 Sydney, PhD Cambridge, FIP, FAIP, FAA, FRS*

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

* Emeritus Professor

Research Officers

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

P. Holden, BSc Lancaster, PhD St. Andrews

G. Luton, BSurv UNSW

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

R. Rapp, BA State University of New York, PhD Rensselaer Polytechnic Institute

M. Ward, BSc (Hons) Florida, CAS Cambridge, PhD Florida State

R. Wood, BSc (Hons) Durham, MSc DPhil Oxford

Research Assistants

A. Arcidiaco, BAppSc GradDip SAInst

J. Shelley, BSc MSc Canterbury (NZ)

POST-GRADUATE STUDENTS

PhD Candidates

Arad, Alon, (Dr A. Christy & Dr M. Knacksted (RSPE)), Investigation of seismic anisotropy in reservoir sandstones using 3-D imaging and modelling.

Augenstein, Clemens, (Prof G. Lister, Dr M. Forster & Prof J-P. Burg (ETH, Zurich)), Essays on Alpine orogeny.

Benavente Bravo, Roberto, (Prof P. Cummins), Seismic source inversion in megathrust earthquakes.

Boston, Katherine, (Dr D. Rubatto & Prof J. Hermann), Allanite and monazite geochronology of the Lepontine Alps.

Bretegani, Luna, (Dr B. Opdyke & Dr M. Ellwood), A millennial round of calcareous nanoplankton in short cores from the Australian: A test for environmental changes.

Brownlow, Jeffery (withdrew), (Prof R. Arculus), Mantle role in Permian-Triassic crustal development in NE NSW: reconnaissance assessment of systems, signatures, incidences and extents.

Bruisten, Benjamin, (Dr J. Brocks), Molecular fossils, iron speciation and mineralization.

Castillo Gonzalez, Paula, (A/Prof C.M. Fanning), Age and isotopic characteristics of Permian-Triassic magmatism and metamorphism on the Pacific margin of Gondwana.

Chapman, Christopher, (Dr A. Hogg), Investigating the dynamics of the Southern Ocean using idealised models.

Chopping, Richard, (Prof B. Kennett), Quantifying the physical properties of the Australian lithosphere and their uncertainties.

Chopra, Aditya, (Dr C. Lineweaver, Dr J. Brocks, Dr S. Eggins, Prof T. Ireland & Prof J. Baross (Univ. Washington, USA)), What do the elemental abundances tell us about the origin and evolution of life?

Cipta, Athanasius, (Prof P. Cummins), Incorporating site effects into PSHA and assessing its uncertainty.

Cocker, Helen, (Prof I. Campbell), Platinum group elements in barren and ore-bearing felsic rock suites.

Dai, Yuhao, (Dr J. Yu), Evaluate dissolution effect on B/Ca ratios of planktic foraminiferal shells and correction method.

David, Anthony, (Dr B. Opdyke), Modelling early diagenesis of carbonate sediments in the Curtis channel.

De Leon, Andrea, (Dr S. Eggins & Dr M. Ellwood), Palaeo-pH reconstruction using the B isotope composition of marine sponges and diatoms.

D'Olivo Cordero, Juan Pablo, (Dr S. Eggins), Environmental and climate variability in seawater pH reconstructed from B isotopes in corals from the Pacific Ocean.

Doull, Matthew Jason, (Dr G. Yaxley & Dr M. Norman), Petrology and geochemistry of peridotite and pyroxenite xenoliths from Ka'ula, Hawaii.

Fang, Fang, (Prof R. Grün), Thermal evolutionary history study by using paramagnetic centers in quartz: A case study in eastern Himalayan syntaxis.

Gauthiez-Putallaz, Laure, (Dr D. Rubatto & Prof J. Hermann), Tracing fluids and trace elements in subduction environments by combining microscale oxygen isotope analysis with geochronology.

Gowan, Evan, (Dr P. Tregoning), Glacio-isostatic adjustment in North America.

Gueneli, Nur, (Dr J. Brocks), Biogeochemical evolution of life and ocean in the Proterozoic.

Haber, Thomas, (Dr V. Bennett & Dr M. Norman), Correlation between age of lunar impact sites and impactor signatures.

Hanger, Brendan, (Dr G. Yaxley & Dr D. Kamenetsky (Univ Tasmania)), Investigating redox conditions in the cratonic upper mantle.

Hoffmann, Janosch, (Dr P. Tregoning), Mass balance of the Totten drainage basin in East Antarctica.

Holland, Katherine, (Dr S. Eggins & Dr M. Ellwood), Relationship between external and calcification Ph and the boron isotope composition of foraminifers and corals.

Hossen, Md. Jakir, (Prof P. Cummins), Sensitivity analysis of tsunami numerical models.

Huyskens, Magdalena, (Dr Y. Amelin), Understanding mass extinctions: High-precision timescale calibration of the Late Permian-Early Triassic of Australia.

Ingham, Elizabeth, (Prof A. Roberts, Prof M. Sambridge, Dr A. Abrazhevich & Dr D. Heslop), How does the Earth's magnetic field behave during geomagnetic excursions?

Jarrett, Amber, (Dr J. Brocks), Microbial evolution in Neoproterozoic oceans.

Johnson, Emma, (Prof I. Campbell), Rutile: a further constraint on sediment provenance and its use as a potential proxy for tectonic dynamics during periods of super-continent amalgamation.

Jollands, Michael, (Prof J. Hermann & Prof H. O'Neill), Diffusion in silicates.

Jones, Timothy, (Dr D.R. Davies & Dr G. Iaffaldano), Reconciling the geophysical and geochemical mantle.

Kallenberg, Bianca, (Dr P. Tregoning), Modelling of the Antarctic ice sheet using geodetic techniques - implications for mass balance.

Khavaninzadeh, Naghmeh (withdrew), (Dr P. Tregoning), Monitoring deformations due to seismic/tsunami hazard of east Indonesia.

Kimbrough, Alena, (Dr M. Gagan), Reconstructing Australian-Indonesian summer monsoon and landscape response over glacial terminations II and III.

Koefoed, Piers, (Dr Y. Amelin), Sequencing early stages of planetary accretion using high precision chronology of non-HED achondrites.

Komugabe, Aimee, (Dr S. Fallon), Environmental records from black corals.

Koudashev, Oleg, (Dr M. Forster & Prof G. Lister), Linking mineralisation in SE Asia to the timing of tectonics and magmatic activity.

Krause, Claire, (Dr M. Gagan & Dr N. Abram), Reconstructing the Australasian monsoon and Indian Ocean dipole over the last glacial-interglacial cycle using speleothems and palaeoclimate modelling.

Lakey, Shayne, (Prof J. Hermann), The subduction of carbonate rocks - is carbon sequestered or liberated at depth: implications for anthropogenic global warming.

Li, Yang, (Prof I. Jackson & Prof D. Schmitt (Univ Alberta, Canada)), Seismic properties of cracked and fluid-saturated rocks.

Long, Kelsie, (Prof R. Grün & Dr I. Williams), Fish otolith geochemistry, environmental conditions and human occupation at Lake Mungo.

Mare, Eleanor, (Prof H. O'Neill & Dr A. Berry), Cation coordination changes in silicate melts with pressure.

Masoumi, Salim, (Dr S. McClusky), Assimilation of real-time terrestrial GPS/GNSS and GPS radio occultation observations for improving meteorology/weather forecast models.

Mazerat, Julie, (Dr M. Gagan & Dr L. Ayliffe), Coral and speleothem reconstructions of early Holocene ocean-atmosphere dynamics in Southern Australasia.

McAlpine, Sarlae, (Prof R. Arculus & Prof H. O'Neill), A petrological study of mantle xenoliths from the West Bismarck Arc, Tabar-Lihir-Tanga-Feni Arc & The Solomon Islands.

McConnochie, Craig, (Dr R. Kerr, Dr G. Hughes & Prof R. Griffiths), Melting and circulation in Antarctic ice shelf cavities.

McCoy-West, Alexander, (Dr V. Bennett & Prof T. Ireland), Re-Os constraints on the formation and age structure of the lithospheric mantle in the Southwest Pacific.

McCulloch, Iain, (Prof B. Pillans & Prof N. Spooner (Univ Adelaide)), Geomorphology of sediment cones at Narracoorte Caves, South Australia.

Meyerink, Scott, (Dr M. Ellwood), Trace metal effects on silicon isotope fractionation in marine diatoms.

Moore, Michael, (Dr S. McClusky), Mitigation of site specific errors from geodetic time series.

Morrison, Adele Kim, (Dr A. Hogg), Southern Ocean overturning and its relationship to past and future climates.

Mustac, Marija, (Dr H. Tkalic), Earthquake source kinematics and core structure studies using broadband seismology and bayesian inference.

Naguit, Muriel, (Prof P. Cummins), Effects of local geology in the development of earthquake ground motion models in the Philippines.

Nand, Vikashni, (Dr M. Ellwood & Dr S. Eggins), Ocean acidification and its effect on coral calcification.

Nash, Graham, (Dr S. Eggins), Joining the dots - molluscs as high resolution environmental archives.

O'Kane, Tomas, (Prof G. Lister), 4D tectonic reconstruction and the location of copper and gold epithermal and porphyry system mineral deposits.

O'Neill, Cameron, (Dr S. Eggins & Dr A. Hogg), Physical and biochemical aspects of the last deglaciation: what the models and measurements are telling us.

Owens, Ryan, (Dr B. Opdyke), Trace element ratios in foraminifera: Advancement and application of proxies for the marine carbonate system.

Pachhai, Surya, (Dr H. Tkalcic), The study of deep Earth structure using body waves and normal modes.

Papuc, Andreea, (Dr G. Davies), Internal evolution of Venus.

Pejic, Tanja, (Dr H. Tkalcic), Attenuation of the Earth's inner core and lithospheric structure of Iceland.

Pilia, Simone, (Dr N. Rawlinson, Prof P. Cummins & Dr A. Reading (Univ Tasmania)), Beneath Bass Strait - linking Tasmania and mainland Australia using a novel seismic experiment.

Rajabi, Sareh, (Dr M. Forster & Prof G. Lister), The nature and origin of the Phojal Fold, NW Himalaya.

Richardson, Laura, (Dr B. Opdyke & Prof J. Middleton (SARDI, Adelaide)), Water mass distribution and hydrography of the South Australian Seas region (south of Adelaide).

Roberts, Jenna, (Prof D. Ellis, Dr C. Hepplewhite (Univ Adelaide), Dr A. Christy & Dr S. Beavis), Fate and transport of contaminants from treated effluent in the ACT.

Rosso, Isabella, (Dr A. Hogg & Dr P. Strutton (Univ Tasmania)), The vertical transport of nutrients in the ocean: a pump driven by submesoscale structures.

Sagar, Stephen, (Prof M. Sambridge & Prof P. Cummins), Development of a spatial framework to examine model and parameter uncertainty in the inversion of remote sensing data in shallow water environments.

Saltanatpouri, Atefeh, (Prof G. Lister), Development of an unified dynamic model to understand the process of the closure of the ancient Tethys Ocean.

Samanta, Moneesha, (Dr M. Ellwood), Isotopic composition of dissolved zinc from different depths of the water column in high and low chlorophyll regions of the South Pacific Ocean.

Sapah, Marian, (Prof T. Ireland & Prof Y. Amelin), Checking the chronological consistency of a set of isotope chronometers applied to calcium aluminium inclusions (CAIs).

Scicchitano, Maria, (Dr D. Rubatto & Prof J. Hermann), Tracing fluids and rare elements in the crust by combining microscale oxygen isotope analysis with geochronology.

Scroxtton, Nicholas, (Dr M. Gagan), What killed the Hobbit? Pleistocene climate and volcanism in the Indonesian Archipelago as recorded in the speleothem climatic archive.

Sebastian, Nita, (Dr H. Tkalcic), Structure of Australasian Lithosphere by receiver function methods.

Short, Michael, (Dr D.C. "Bear" McPhail & Prof B. Pillans), Groundwater dynamics in the Lake George catchment.

Smith, Tegan, (Prof R. Grün, Dr S. Haberle, Dr S. Eggins & Prof B. Pillans), Landscape evolution and palaeo environmental reconstruction of Lake Mulurula, Willanda Lakes World heritage area.

Snow, Kate, (Dr S. Downes, Dr A. Hogg & Dr B. Sloyan (CSIRO, Hobart)), To improve modeling and further understanding of overflow and bottom water production and dynamics in the Southern Ocean in the Modular Climate Model (MOM4pl) through parameter sensitivity analysis and observational data comparison.

Sossi, Paolo, (Prof H. O'Neill), Experimental investigation of fractionation of non-traditional stable isotopes.

Stenhouse, Iona, (Prof G. Lister), Diffusion modeling of garnet and its applications to geospeedometry.

Stenhouse, Paul, (Prof S. Cox), Reactive transport and fluid pathways in fracture-controlled flow systems.

Stott, Rachel, (Prof H. O'Neill), Experimental studies of water in olivine.

Stotz, Ingo, (Dr G. Iaffaldano), Global coupled model of the lithosphere and mantle system.

Strzepek, Kelly, (Dr S. Fallon), Environmental archives in deep-sea corals.

Tambiah, Charles, (Prof R. Arculus), The research and practice of science-photography and the production of science-art, through explorations, creativities, and reflective learnings from within the Earth and Environmental Sciences.

Tanner, Dominique, (Dr J. Mavrogenes), Formation and modification of magmatic platinum group element deposits.

Thompson, Claire, (Dr M. Ellwood), Characterising copper biogeochemistry in marine systems.

Thorne, Jane, (Prof T. Ireland & Dr P. Holden), Isotope geochemistry of Hadean zircons from Mt Narryer, Western Australia.

Tolley, James, (Dr A. Berry), Mantle metasomatism and the survival of diamonds

Tynan, Sarah, (Dr B. Opdyke), Interpreting environmental information from the geochemistry of carbonate bivalve shells.

Uren, Ashley (withdrew), (Dr Y. Amelin & Prof I. Campbell), Prospectivity of Late Archean basaltic and gabbroic rocks associated with major gold and base-metal deposits.

Vasilyev, Prokopi, (Dr G. Yaxley & Prof J. Hermann), Experimental study of the fate of subducted carbon.

Vreugdenhil, Catherine, (Prof R. Griffiths), Effects of rotation on ocean convection.

Whan, Tarun, (Dr J. Mavrogenes), Investigation of the affect of reduction induced sulfide saturation on the evolution of arc magmas.

Willmes, Malte, (Prof R. Grun & Dr R. Armstrong), Tracing prehistoric human migration in France using stable isotopes.

Wurtzel, Jennifer, (Dr N. Abram & Dr M. Gagan), High resolution reconstructions of Sumatran rainfall variability during the Holocene.

Wykes, Jeremy, (Dr J. Mavrogenes, Prof H. O'Neill & Prof J. Hermann), Chalcophile elements in silicate melts.

Xue, Yunxing, (Prof I. Campbell), St Ives gold: a syenite sanukitoid connection.

Young, Mallory, (Dr H. Tkalcic & Dr N. Rawlinson), Earth structure using seismic body waves and ambient noise.

Yuguru, Samuel, (Dr J. Mavrogenes & Dr R. Henley), An experimental investigation of aqueous species in low density magmatic fluids beyond the critical point.

Zannat, Umma Jamila, (Dr P. Tregoning), Adjusting the International Terrestrial Reference Frame for great earthquakes.

Zhukova, Irina, (Prof I. Campbell & Prof H. O'Neill), Experimental study of the diffusion of platinum group elements and gold in rock forming minerals.

MPhil Candidates

Burne, Robert, (Dr M. Gagan & Dr S. Eggins), Deciphering the environmental record preserved in modern microbialites.

Gunawan, Indra, (Prof P. Cummins), Spectral Characteristics of Indonesian Earthquake Ground Motion.

Hayward, Kathryn, (Prof S. Cox), Experimental investigation into the impact of reactive fluids on fault mechanics near the seismic-aseismic transition in the continental crust.

Higgins, Andrew, (Dr S.G. Beavis (FSES), Prof D. Ellis & Dr P. Shand (Flinders)), Sulfate reduction in wetlands.

Leonard, Yosafat, (Dr P. Tregoning), Crustal deformation study along the Java Trench, Indonesia, from GPS measurement.

McDonald, John, (Dr M. Norman & Dr D.C. "Bear" McPhail), Strontium and uranium isotopes in groundwater in the Lower Murrumbidgee basin.

Omang, Amalfi, (Prof P. Cummins), Sensitivity of Seismic Hazard to Fault Slip Rates and Site Amplification.

Rudyanto, Ariska, (Prof P. Cummins), Analysis of Indonesian Earthquake Ground Motion.

Wang, Boyi (Fred), (Dr D.C. "Bear" McPhail & Dr M. Norman), Speciation and Isotopic Composition of Uranium in Regolith and Groundwater.

THESES COMPLETED

Darrenougue, Nicolas, (Prof P. DeDecker & Dr S.M. Eggins), Rhodoliths as Environmental Archives in the Tropics

Frasl, Barbara, (Prof T.R. Ireland & Dr M. Honda), Oxygen and Light Noble Gas Isotopic Compositions of the Lunar Surface

Horner, Kyle, (Dr D.C. "Bear" McPhail & Dr M. Norman), New Environmental Tracer Methods for Quantifying Solute Sources in Semi-Arid Alluvial Aquifers

Kang, Jung Ok, (Dr S.M. Eggins), Coral Calcification Response to Ocean Warming and Acidification in the Southern Great Barrier Reef

Lee, Jia-Urnn, (Dr M.A. Forster & Prof G.S. Lister), Mapping in space and time: Tectonic mode switches in the Western Himalaya, NW India

Mikkelson, Nicole, (Prof D.J. Ellis & Dr S.G. Beavis (FSES)), The Hydrogeochemistry of an Unconfined Coastal Aquifer - Merimbula, New South Wales, Australia - Implications for the Migration of Treated Effluent

Millsted, Paul, (Dr J. Mavrogenes), The Role of Halogens with Sulfide Melting at Broken Hill, New South Wales, Australia

Moffat, Ian, (Prof R. Grün) Spatially Resolved Strontium Isotope Micro-Analysis of Lower and Middle Palaeolithic Fauna from Archaeological Sites in Israel and Southern France

PROFESSIONAL STAFF

School Manager

M. Avent, GradCertMgmt GradDipAdmin University of Canberra (to 17/7/2013)

G.F.M. Pearson, BA UB, BTh Melbourne, GradDipEd ACU, GradDipAppSc Monash, MBA USQ, MACE, MAPS, FAIM (from 14/1/2013)

Executive Assistant to the Director and the School Manager

M. Farrer

Information Technology Manager

P. Davidson, BSc MSc Auckland, PhD ANU

Information Technology Officers

D. Bolt, BSc Sydney

B. Harrold, BSc ANU

H. Mendis, BInfTec Deakin (to 29/7/13)

Philanthropic Development Manager

M. King, DipTeach ACU, BA Deakin, GradDipRE ACU, MEd (Leadership) UNSW

PRISE Business Officer and School Projects Officer

B.J. Armstrong, BSc UNISA

Building and Facilities Officer

E. Ward, Cert V Frontline Management, Quest/ANU

Assistant Building and Facilities Officer

N. Craddy

Receptionist

S. Avalos

Student Administrator HDR

M. Coldrick

Student Administrator Coursework and Honours

J. McDermid, BCom Victoria University (Wellington), MAppSc (Lib&InfoMgt) CSU

Area Administrators

M. Hapel - Earth Materials & Processes

S. Kluver, Assoc Dip Graphic Communications, Australian Army - Earth Physics
J. Magro - Earth Chemistry
R. Petch - Earth Environment

IODP Administrator

C. Beasley

Electrical Engineering Workshop Manager

A. Latimore, BEng University of Canberra

Electrical Engineering Workshop

D. Cassar, AdvDipEng CIT
D. Corrigan
D. Cummins, AdvDipEng CIT
T. Redman AssocDip(Elect Eng) CIT
H. Sasaki, AssocDip CIT
N. Schram, DipEIE SAIT

Mechanical Engineering Workshop Manager

A. Wilson, AssocDipMechEng CIT, Cert III Engineering (Mechanical) Trade

Mechanical Engineering Workshop

B. Butler, Cert III Mechanical Engineering Sydney Institute, Cert III Engineering-Mechanical Trade (Toolmaking)
D. Thomson, Cert-Fitting and Machining Trade
C. Were, AdDipMechEng CIT, Cert III Engineering (Mechanical) Trade
G. Woodward, Cert-Fitting and Machining Trade

School Laboratory Manager

J. Cali, BAppSc QIT

Technical Officers

C. Allen, AB Princeton, MSc Oregon, PhD Virginia Tech (2013???)
A. Beasley, AssocDip CIT
D. Clark, Cert III Metal Fabrication AdvDipEng CIT
J. Cowley, BSc ANU
D. Edwards
R. Esmay
J. Foster, BSc Sydney, MSc PhD ANU
L. Fraser, MInfoTec University of Canberra (to 14/2/2013)
B. Fu, BSc Chungchun, MSc Nanjing, PhD Vrije
H. Gao

J. Hope
B. Jenkins, BSc UTS, PhD ANU
L. Kinsley, BSc GradDipSc ANU
H. Kokkonen, Certificate in Lapidary ACT TAFE, BAppSc Canberra College of Advanced Education
P. Lanc
Q. Li
K. Marshall
L. McMorrow, AssocDipSc NTU
H. Miller, AdDipMechEng CIT
G. Mortimer, BSc PhD Adelaide
S. Paxton
A. Percival
S. Rayapaty
J. Rousseau
D. Scott, AssocDipMechEng CIT
H. Scott-Gagan, BSc Sydney
B. Tranter, Cert II Auto Radiator Services John Batman Institute TAFE, Auto Climate Control/Air conditioning Casey Institute of TAFE
U. Troitzsch, Diplom Technische Universität Darmstadt, PhD ANU
D. Vasegh
X. Zhang, PhD LaTrobe
X. Zhao, BSc Jilin University, PhD Southampton
L. Zhou
S. Zink
C. Zirk, BA Victoria University (Melbourne)

HONOURS AND AWARDS

Prof R. ARCULUS was elected as a Fellow of the Geochemical Society.

Dr V.C. BENNETT was awarded a Fellow of the Geochemical Society and European Association of Geochemistry.

Dr R.A. BINNS (Visiting Fellow) was nominated (with colleague Steven Scott, Toronto) for the 2014 Thayer Lindsley Medal of the Prospectors and Developers Association of Canada. This medal is awarded for discovery of a significant new mineral deposit, in this case the Solwara-1 seafloor massive sulfide deposit slated for mining imminently by Nautilus Minerals Inc in the Bismarck Sea, PNG.

Mr. A. CHOPRA was selected as a Student of the Year Finalist at the 2013 ANU Alumni Awards.

Mr. A. CHOPRA was selected as a member of the Australian delegation to the 2013 Lindau Nobel Laureate Meeting by the Australian Academy of Science.

Mr. A. CHOPRA was selected by the State of Baden-Württemberg for the 2013 Post-Lindau Program to visit research institutions in southwestern Germany.

Dr K. A. W. CROOK (Visiting Fellow) had a new-to-science fossil sarcopterygian fish from the Devonian at Eden NSW named after him: Edenopteron keithcrooki.

Dr D.R. DAVIES received an 'Outstanding Young Scientist Award' from the Geodynamics Division of the European Geosciences Union.

Dr Y. DOSSMAN was awarded the thesis prize for physics (Prix Paul Sabatier Physique) by L'Académie des Sciences de Toulouse.

Dr B. GAYEN was awarded the 2013 Andreas Acrivos Dissertation Award by the American Physical Society and presented the Award Lecture at the annual meeting of the American Physical Society – Division of Fluid Mechanics, Pittsburgh, November.

Prof R.W. GRIFFITHS presented a Silver Jubilee Public Lecture at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India, in the 25th anniversary of the Centre.

Prof B.L.N. KENNETT delivered the Selwyn lecture at the Selwyn Symposium of the Victorian Division of the Geological Society of Australia in October.

Dr P. KING received a NASA Group Award for the MSL (Mars Science Laboratory) APXS (alpha particle X-ray spectrometer) Instrument Development and Science Team.

Dr P. KING's paper (King and Larsen 2013) was an Editor's Pick Notable Paper for American Mineralogist.

Dr P. KING gave an invited talk at the ANU Conferring of Degrees ceremony for the Colleges of Sciences.

Dr C.H. LINEWEAVER was recognized as one of the one hundred most influential Australian scientists in the CSIRO "Faces of Science" photo exhibition, 4 December, CSIRO Discovery Centre.

Dr J MAVROGENES was awarded the Meierjurgan Fellowship for Visiting Scientists at the University of Oregon, 1 January – 1 July.

Dr J MAVROGENES was awarded a Benjamin Meaker Visiting Professorship at the University of Bristol, 1 October – 15 December.

Prof A.P. ROBERTS was appointed an Honorary Fellow of the Royal Society of New Zealand

Prof A.P. ROBERTS was elected a Fellow of the American Geophysical Union

Prof M.L. RODERICK received the John Dalton Medal from the European

Geosciences Union for research on changes in evaporation and water availability.

Prof E.J. ROHLING commenced an Australian Laureate Fellowship.

Dr M. SALMON, Dr N. BALFOUR, Prof M. SAMBRIDGE and Dr U. PROSKE, comprising The Australian Seismometers in Schools team, were awarded first place in the Australian Innovation Challenge in the Education category for the outreach program Australian Seismometers in Schools.

Mr. N. SCROXTON was awarded a grant of €2000 to attend the PAGES 2nd Young Scientists Meeting in Goa in February.

Ms K. SNOW was awarded a Pre-doctoral Fellowship from the Woods Hole Oceanographic Institute, to attend the 55th Geophysical Fluid Dynamics Summer Program, Woods Hole, USA, August.

STUDENT AWARDS

A.L. Hales Honours Year Scholarship: Emma Howard, Jessica Lowczak

ARC Centre of Excellence for Climate System Science Honours Scholarship: Wing Chan

RSES Science Honours Scholarship: Morgan Williams

Action Trust Honours Scholarship: Anushka Sandanam

Regolith Honours Scholarship: Sarah Buckerfield

KSW Campbell Prize: Michael Jollands

Mervyn and Katalin Paterson Travel Fellowship: Shared between Claire Krause (visited NASA Goddard Institute for Space Sciences in New York and attended the AGU Meeting of the Americas in Mexico) and Surya Pachhai (visited Harvard University)

D.A. Brown Travel Scholarship: Alex McCoy-West (attended the Goldschmidt Conference in Florence).

Robert Hill Memorial Prize: Kelly Strezepek

A.E. Ringwood Scholarship: Marija Mustac

John Conrad Jaeger Scholarship: Eleanor Mare

Allan White Scholarship: Maria Scicchitano

RESEARCH ACTIVITIES

EARTH CHEMISTRY

Introduction

The research activities within the Earth Chemistry group span the extremes of the geologic timescale from the study of rare pre-solar grains preserved in meteorites pre-dating the beginning of the solar system through to high precision age determinations of young biogenic materials, and in scale from planetary systems to individual molecules. Active areas of research within the Earth Chemistry area include planetary and early Earth studies, metamorphic and igneous geochemistry, the role of fluids in crustal processes and the geochemistry of life processes; these diverse research activities are linked through reliance on the development and application of novel analytical methods and instrumentation for isotopic measurements.

2013 was a year of strong research productivity with a continuing flow of publications from students and faculty in the highest ranked national and international journals. Earth Chemistry faculty and students were also prominent at national and international conferences, as meeting organizers, session conveners and presenters including keynotes at the Goldschmidt Conference, held in Florence Italy in August, the Lunar and Planetary Science Conference in Houston in March and the American Geophysical Union meeting in December in San Francisco.

The past year was gratifying in seeing the research payoffs emerging from multi-year development projects. Under the direction of Prof Trevor Ireland, the newest generation large ion-probe, the stable isotope SHRIMP SI came into its own in 2013, now routinely producing oxygen isotope data from a range of sample matrices and with the first demonstration of in situ measurement capability for all four sulphur isotopes, a unique capability in the ion probe world. The first publications arising from data generated by the SHRIMP SI are now accepted for publication. January saw the arrival of the long-awaited ARC funded Helix MC, the first of a new generation mass spectrometer for high resolution noble gas isotopic measurements. Through the efforts of Dr Masahiko Honda and Mr Xiaodong Zhang, the first results from testing of the Helix MC were presented at the AGU meeting in San Francisco in December.

We congratulate Dr Daniela Rubatto and Dr Ian Williams on their promotions to Professor and Dr Raquel Salmeron on her promotion to Fellow in the 2013 round.

Dr Vickie Bennett was awarded a Fellow of the Geochemical Society and European Association of Geochemistry recognizing her long-term contributions to understanding early Earth geochemistry, with the award presented at the Goldschmidt Meeting in Florence, Italy.

Congratulations to Dr Barbara Frasl (PhD supervisor Prof Trevor Ireland) on successful completion of her PhD program.

In 2013 we welcomed new technical staff member, Mr Hongtao Gao who started a position in January assisting Shane Paxton in the Mineral Separation Laboratories. Dr

John Foster celebrated 50 years of continuous service to the ANU in May with much of this time devoted to the development and improvements to the SHRIMPs. John elected to retire in December, but will continue his association with the SHRIMP group as a School Visitor and as a consultant for Australian Scientific Instruments. Dr Mark Kendrick, a Queen Elizabeth II Fellow at University of Melbourne was successful in the 2013 ARC Future Fellow round and we welcome his move to the ANU in early 2014 to establish a new research program looking at the global scale cycling of noble gases and halogens.

Earth Chemistry staff enjoyed outstanding success in this year's Discovery round with Prof Trevor Ireland, Dr Masahiko Honda, Dr Stewart Fallon and Dr Yuri Amelin each being the senior Chief Investigator on successful 3 year ARC Discovery grants with funding starting in 2014.

The success of Earth Chemistry in 2013 would not have been possible without the dedicated and cheerful efforts of our technical staff. After almost 4 years, as I come to the end of my term as Earth Chemistry area head, I am particularly grateful to Ms Josephine Magro for her continuing patient and highly competent handling of administrative matters on behalf of Earth Chemistry staff and students and especially her support of the Associate Director. We wish her all the best in her new role as area administrator for the new Geochemistry Cluster.

Dr Vickie C. Bennett,
Associate Director, Earth Chemistry

U-Pb age of a newly found ungrouped achondrite NWA 7325

A meteorite possibly originating from Mercury?

Yuri Amelin¹, Piers Koefoed¹, Tsuyoshi Iizuka² and Anthony Irving³

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

² *Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan*

³ *Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA*

Recently discovered ungrouped achondrite NWA 7325 is a reduced, Fe-poor cumulate olivine gabbro composed of calcic plagioclase which differs from all other known meteorites in mineralogy and chemical composition. The chemical similarity (Al/Si, Mg/Si and Fe/Si ratios) between this rock and the composition of the Mercury's surface revealed by MESSENGER X-ray and gamma-ray spectrometer mapping, and an oxygen isotopic composition distinct from those for other achondrites, has led to suggestion of the possible origin of this rock from Mercury (Irving A.J. et al. (2013) Abstract #2164. 44th LPSC). We have determined U-Pb age of this unusual meteorite.

A notable feature of this rock is the extremely low concentration of U, Th and radiogenic Pb, consistent with the previously reported extreme depletion in REE. Five Pb-isotopic analyses of acid-washed diopside fractions containing 20-40 pg Pb yield an isochron age of 4562.5 ± 4.4 Ma (MSWD=1.9, assuming currently accepted $^{238}\text{U}/^{235}\text{U} = 137.79$). U-Pb data for acid-washed diopside are nearly concordant, confirming closed system behavior. Pb-isotopic age of NWA 7325 is indistinguishable from the ages of quenched angrites, and of ungrouped achondrites NWA 2976 (Bouvier A. et al. (2011) *GCA* 75, 5310–5323) and NWA 6704 (Iizuka T. et al. Abstract #1841. 44th LPSC). Still, these achondrites have clearly distinct oxygen isotope compositions, which, along with chemical and mineralogical differences, indicate that they formed on different parent bodies. The differences in their $^{54}\text{Cr}/^{52}\text{Cr}$ ratios [Sanborn M. et al. (2013), MetSoc 2013) further strengthen this conclusion. There is growing evidence that a variety of bodies (planetesimals and maybe planets) accreted nearly simultaneously from chemically distinct domains in the protoplanetary disk, and then differentiated and crystallized within 3-5 Ma after CAI formation. Whether Mercury was among them is currently unclear.

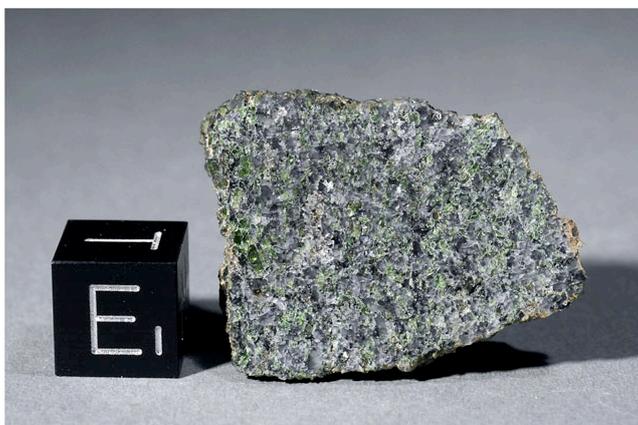


Figure 1. Polished slab of NWA 7325. Green mineral is diopside - the main carrier of uranium in this extremely depleted rock. More abundant grey mineral is plagioclase.

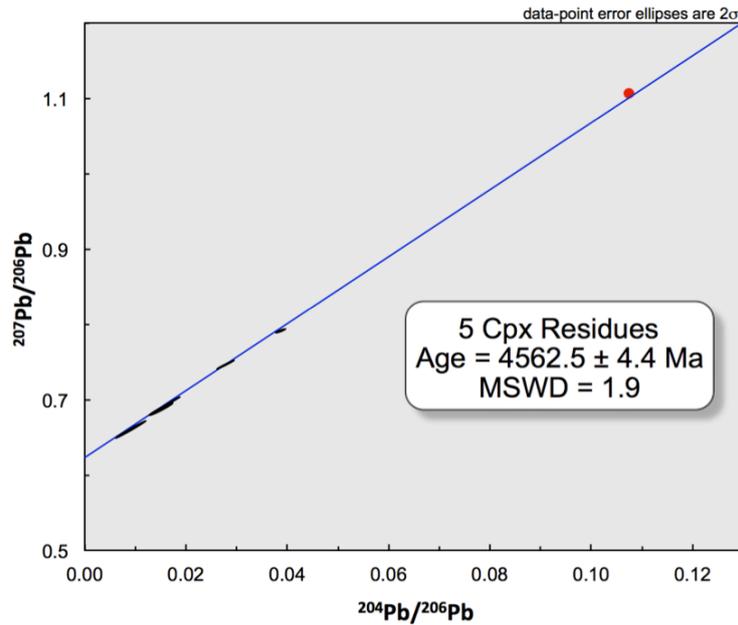


Figure 2. Pb-Pb isochron for NWA 7325. Black ellipses are data for acid-washed diopside. Red circle is primordial Pb isotopic composition of the Solar System.

Preliminary results from the HELIX-MC mass spectrometer: resolution of argon isobaric interferences

M. Honda¹, X. Zhang¹, D. Phillips², E. Matchan², S. Szczepanski², M. Deerberg³, D. Hamilton³, M. Krummen³ and J.B. Schwieters³

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

² School of Earth Sciences, The University of Melbourne, Parkville, Australia

³ Thermo Fisher Scientific, Bremen, Germany

Analyses of noble gas isotopes by multi-collector mass spectrometry substantially improve measurement precision and accuracy, with the potential to revolutionise applications to cosmo-geo-sciences. The Helix-MC noble gas mass spectrometer manufactured by Thermo-Fisher is a 350mm, 120 degree extended geometry, high resolution, multi-collector mass spectrometer for the simultaneous analysis of noble gas isotopes. The detector array includes a fixed axial (Ax) detector, 2 adjustable high mass (H1 and H2) detectors and 2 adjustable low mass (L1 and L2) detectors. Each detector is equipped with a Faraday/ion counting multiplier CFM (Combined Faraday and CDD Multiplier) detector. Mass resolution and mass resolving power on the H2, Ax and L2 detectors of the Helix-MC installed at the Australian National University (ANU) are approximately 1,800 and 8,000, respectively (see Figure 1). The noble gas handling system on-line to the Helix-MC consists of: (1) a resistively-heated, double-vacuum, tantalum furnace system, (2) air actuated vacuum crusher, (3) Photon-Machines diode laser heating system, (4) Janis He cryogenic trap assembly, (5) gas purification system and (6) standard gas pipette tanks, which are

totally automated and controlled by the Qtegra software platform developed by Thermo-Fisher.

Ten repeat measurements of atmospheric Ar using the H2 Faraday (1E11 ohm resistor) and L2 CDD collectors on the Helix-MC, yield a mean $^{40}\text{Ar}/^{36}\text{Ar}$ ratio of 285.15 ± 0.22 (0.076%) with a 5,400 fA ^{40}Ar beam current. This result compares favourably with the precision achieved by the Argus VI at the University of Melbourne (318.12 ± 0.17 ; 0.052%; $n = 10$) with a similar beam size of 4,200 fA. The high mass resolution of the L2 collector, permits complete separation of the ^{36}Ar and interfering, $3 \times 12\text{C}$ (required mass resolution (MR) of 1,100) and partial separation of $\text{H}35\text{Cl}$ (MR = 3,900). This capability enables evaluation of the significance of Ar isotopic interferences related to the correction of atmospheric Ar from the total Ar measured in geological samples, including the MD-2 biotite standard and young basalts.



Figure 1. Helix-MC multi-collector noble gas mass spectrometer installed at RSES.

Timing of metasomatism using SHRIMP U-Pb dating and oxygen isotopes

Laure Gauthiez-Putallaz, Daniela Rubatto and Jörg Hermann

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

The timing and duration of metamorphic evolution to and from high-pressure (HP) or ultra-high pressure (UHP) is the object of a long-lived debate. While cooling ages and fission-track data allow well constraining exhumation paths, determining the

duration of prograde metamorphism is not trivial. In situ zircon and monazite dating tied to garnet crystallisation using trace element equilibrium partitioning allows for precise and robust estimates of the timing and duration of prograde evolution from HP to UHP. Moreover, oxygen isotopes can be measured accurately at the microscale in the same mineral zones and provides insights into the fluid history.

The widely-studied coesite and pyrope-bearing whiteschists from the Dora Maira unit, Western Alps, underwent metamorphism to UHP conditions and subsequent rapid exhumation. They represent a metasomatised granite, the timing of the metasomatic event being debated. We analysed U-Pb and oxygen isotopes in zircon (Fig. 1) and monazite with the SHRIMP ion-microprobe, and trace elements by Laser-Ablation ICP-MS in order to better constrain the timing and duration of metamorphism as well as fluid influx.

Trace-elements results indicate simultaneous crystallisation of garnet, zircon and monazite during the prograde HP to UHP evolution, between 25 kbar (~80km depth) to 45 kbar (~150km depth). Pre- and syn-garnet zircon rims yield the same age within uncertainty. We conclude that subduction from a depth of 80 km to a depth of 150 km occurred over a short time-interval of 1-2 million years. This corresponds to a subduction speed of a few centimetres per year. Moreover, all metamorphic zircon rims and monazite yield the same low, post-metasomatic oxygen isotope composition. It indicates that UHP fluids were mostly of internal nature, and that the whiteschists underwent metasomatism either during early prograde Alpine subduction (at pressures lower than 25 kbar) or most probably during seafloor alteration in their previous rifting history.

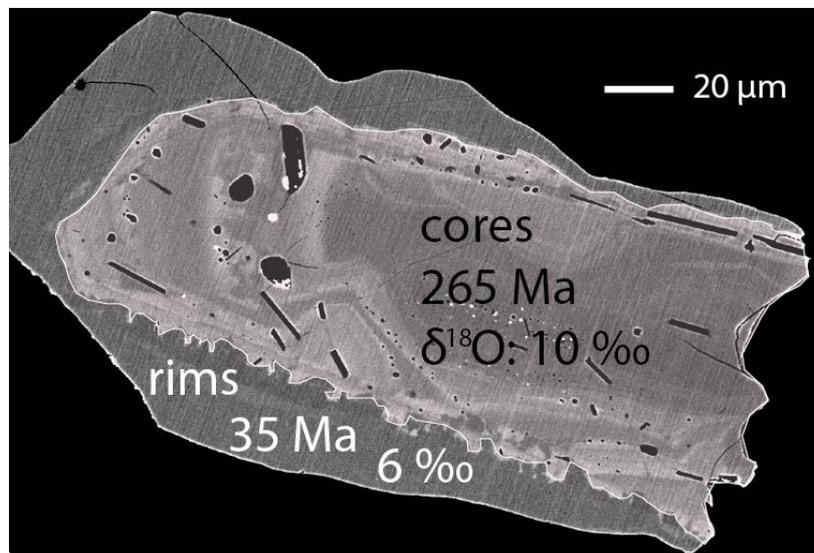


Figure 1. Back-Scattered Electrons image of a zircon grain with outlined: partially dissolved magmatic core, surrounded by metamorphic rims that crystallised before and during garnet growth.

Gauthiez-Putallaz L., Rubatto, D., Hermann, J. (2013): Metasomatism in the Dora Maira Whiteschists investigated by SHRIMP oxygen isotopes and U-Pb geochronology. *Mineralogical Magazine*, 77(5) 1148.

U-Th-Pb dating of collision in the external Alpine domains using low temperature allanite and monazite

Emilie Janots² and Daniela Rubatto¹

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

² *University of Grenoble 1, ISTerre, 38040 Grenoble, France*

Dating metamorphism in external domains of orogenic belts is a challenging task due to the few chronometers available and common inheritance or disturbance of the isotopic systems at low-temperature metamorphic conditions. In the external domains of the Central Alps (Urseren zone), the occurrence of distinct populations of monazite and allanite in one single outcrop offers a unique chance to evaluate the potential of these two rare-earth-element (REE) minerals to date successive metamorphic stages within a collisional cycle. The studied outcrop exposes Mesozoic metasediments that were metamorphosed under greenschist-facies conditions (450°C). Under these conditions, REE-mineral grains (or domains) are typically small (~5–50 µm), and in this case also occur as porphyroblast in pelites at the contact with carbonate layers or veins. Based on the texture and mineral assemblages, REE-mineral growth occurred in different stages: detrital (Mnz1), syn-kinematic (Mnz2 and Aln1), post-kinematic at the thermal peak (Aln2) and retrograde during late-stage deformation (Mnz3). To constrain temporally the successive crystallization conditions, REE-minerals have been dated using the SHRIMP ion microprobe. U-Th-Pb analyses show that the Alpine REE-minerals have a high Th/U and, while most of the U-Pb system is dominated by non-radiogenic components, Th–Pb ages can be obtained using isochrons. The age of different generations of allanite and monazite constrains the timing of successive collisional stages: for the prograde accretion at 22.5 ± 1.5 Ma (Mnz1 and Aln1), thermal peak at 19.3 ± 2.0 Ma (Aln2) and late stage hydrothermal veining at 13.6 ± 1.4 Ma (Mnz3). These novel geochronological data confirm the regional diachroneity across the Central Alps with younger ages (burial, thermal peak and exhumation) toward the external domains. The similarity between metamorphic ages of samples taken in the Urseren zone and the nearby crystalline massifs suggests that the metasedimentary cover of the Urseren zone remained closely juxtaposed to the external crystalline basement during the Alpine collision cycle. The monazite age of the late stage vein testifies for active tectonic deformation at 13.6 ± 1.5 Ma, which likely played a crucial control on the exhumation of the external massifs in the Middle Miocene.

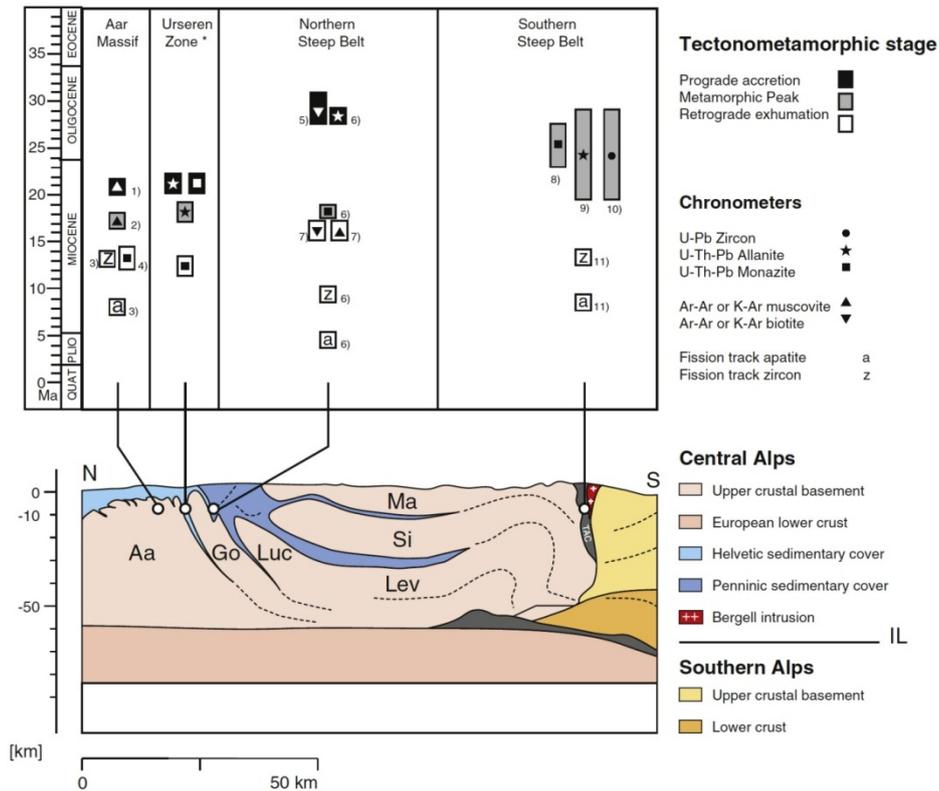


Figure 1. Schematic N-S cross-section through the Central Alps with a compilation of published geochronological data according to their metamorphic timing: prograde accretion, metamorphic peak and retrograde exhumation. Abbreviations are Aa: Aar, Go: Gotthard, Luc: Lucomagno, Lev: Leventina, Si: Simano, Ma: Maggia, IL: Insubric Line; TAC: tectonic accretion channel. See full paper for references.

Time-resolution in herbivore tooth enamel evaluated via O & Sr isotope profiles by SHRIMP and LA-(MC-)ICPMS

Wolfgang Müller¹, Ian S. Williams², Luca Bondioli³, Paola F. Rossi³ and Robert Anzkiewicz⁴

¹ Department of Earth Sciences, Royal Holloway University of London, Egham, U.K.

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

³ Museo Nazionale Preistorico Etnografico "L. Pigorini", Antropologia, Roma, Italy

⁴ Institute of Geological Sciences, Krakow Research Centre, Polish Academy of Sciences, Krakow, Poland

Mammalian tooth enamel is of interest in palaeoecology and anthropology for two main reasons: Firstly, enamel is the hardest and densest mammalian tissue and as such the least susceptible to post-mortem chemical alteration. Secondly, enamel mineralizes sequentially over several years and thus captures secular environmental variability on (sub-)seasonal time-scales (e.g. in humans for more than 15 years). Moreover, unlike bones and parts of dentine, enamel does not 'turn over' compositionally after formation and thus locks in the chemical/isotopic signal initially acquired.

Because enamel mineralization represents a complex two-stage process, however, whereby initially secreted enamel is only fully mineralized during a second maturation stage, it remains unclear i) how much an initially varying input signal is overprinted by later enamel maturation, ii) how much time lag there is between secretion and maturation, iii) whether this differs for different elements (e.g. O, Sr, Pb) and iv) which enamel sampling strategy should be used to reconstruct an initial input signal most accurately.

In order to help resolve the above mentioned questions, three main types of histologically-defined, spatially-resolved isotopic/compositional profiles from enamel (fauna and human), have been measured by both SHRIMP and LA-(MC-)ICPMS. By focusing on two nominally time-equivalent, yet topographically contrasting profiles, namely along the enamel-dentine junction (EDJ) and along the enamel prisms (P), we have evaluated the effect of enamel secretion vs. maturation throughout varying enamel thickness. These two time-equivalent profiles were compared with those along nominal isogrowth layers, namely neonatal / Retzius lines (NNL / R) that connect the other two time-equivalent profiles. We analyzed the isotopic composition of the key elements oxygen (O) and strontium (Sr), owing to their importance in identifying the season of enamel growth ($\delta^{18}\text{O}$) and different bedrock/soil ($^{87}\text{Sr}/^{86}\text{Sr}$ ratios).

Our initial $\delta^{18}\text{O}$ data (Figs. 1, 2) from both a modern goat and a Neolithic goat/sheep from the N-Italian Alps (the latter from a site closest to the Neolithic Alpine Iceman's discovery site) show a large degree of intra-enamel variability. The Neolithic sample appears to contain up to two years of enamel growth as indicated by an approximately sinusoidal variation in $\delta^{18}\text{O}$ values between ~ 13 and 19‰ (Fig. 1). The modern goat resembles one annual cycle of high-to-low $\delta^{18}\text{O}$ values, also ranging between ~ 13 and 19‰ (Fig. 2). This $\delta^{18}\text{O}$ profile broadly correlates with changes in $^{87}\text{Sr}/^{86}\text{Sr}$, reflecting the different areas grazed during different seasons. Sub-sections of the $\delta^{18}\text{O}$ -profile along the EDJ were found to resemble the respective prism counterparts, an unexpected result given that enamel domains towards outer enamel were anticipated to have experienced significantly delayed compositional/isotopic overprint during later maturation, as suggested by previous work using CO_3 -derived oxygen isotope compositions (Balasse, 2003; Passey and Cerling, 2002). Further experiments to investigate this issue are planned.

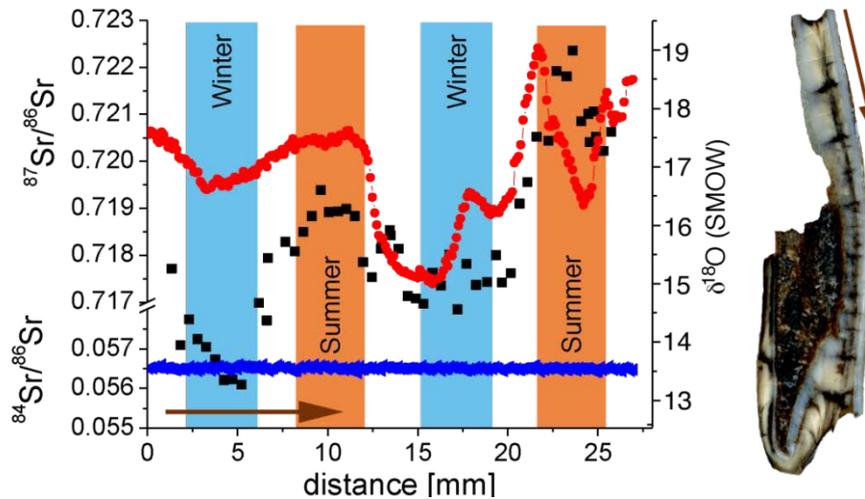


Figure 1. Neolithic sheep/goat: In-situ O- and Sr-isotope EDJ profiles by SHRIMP and excimer LA-MC-ICPMS, respectively.

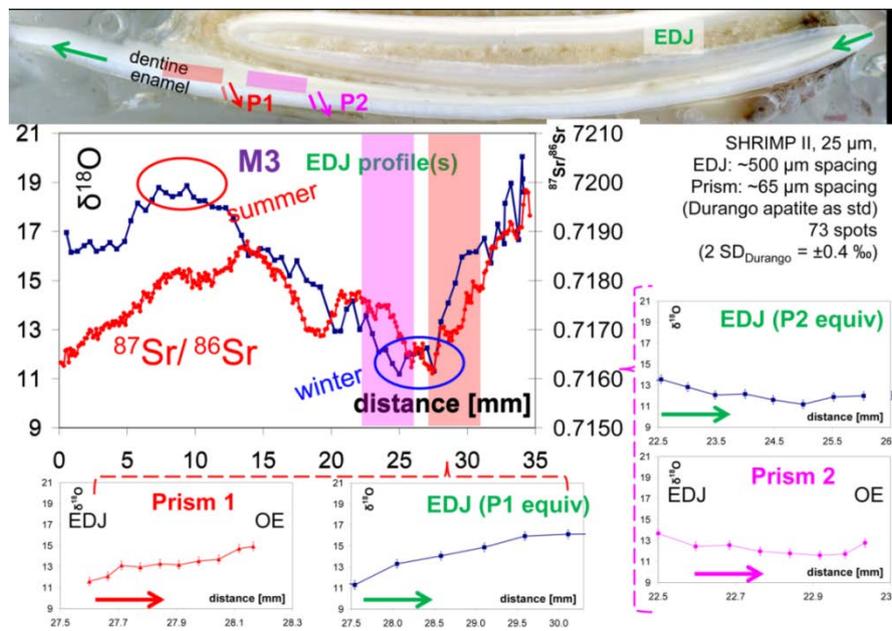


Figure 2. Modern goat MT1, 3rd molar (M3): In-situ O (+Sr)-isotopes by SHRIMP and excimer LA-MC-ICPMS, focusing on time-equivalent EDJ vs prism $\delta^{18}\text{O}$ profiles.

Balasse, M., 2003. Potential biases in sampling design and interpretation of intra-tooth isotope analysis. *Int. J. Osteoarchaeol.* 13, 3-10.

Passey, B.H., Cerling, T.E., 2002. Tooth enamel mineralization in ungulates: Implications for recovering a primary isotopic time-series. *Geochim. Cosmochim. Acta* 66, 3225-3234.

A one-hundred year reconstruction of marine ecosystems along the East Australian seaboard

Carbon and Nitrogen isotopes of deep-sea coral amino acids

K.M. Strzepek¹, A.T. Revill², R.E. Thresher², C.I. Smith³ and S.F. Fallon¹

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

² *CSIRO Marine and Atmospheric Research, Hobart, TAS 7001, Australia*

³ *Faculty of Humanities and Social Sciences, Latrobe University, Melbourne 3086, Australia*

For 60 years the instrumental record has captured physical and chemical changes occurring in the East Australian Current. Attributed to changes in circulation of the South Pacific gyre, the increased volume of warm, nutrient poor water is shifting subtropical habitats further south. However, chronic under sampling in the region prevents an assessment of the biological response to these changes, and any flow on effects to ecosystem function.

My latest research provides century long archives of carbon and nitrogen isotopes from deep-sea coral amino acids that span Australia's eastern subtropical and subantarctic zones. Deep sea corals feed on organisms that live in surface waters and then rain down to the oceans depths when they die. Using this novel technique I can trace the origin of these organisms in each region, as well as species-effects that have important implications for the future interpretation of deep-sea coral records. The compound specific approach enables an unambiguous view of shifting biological surface ecosystems in the northern Tasman Sea, and an east-west distinction over the Tasmanian seamounts. For the first time we are able to assess ecosystem sensitivity to large-scale changes in ocean processes across distinct, climatically sensitive regimes in some of Australia's most economically important and productive waters.

Radiocarbon dating the last Neanderthals in Spain

Rachel Wood¹ and Thomas Higham²

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

² *Oxford Radiocarbon Accelerator Unit, University of Oxford, Oxford, United Kingdom*

Between c.45,000 and 30,000 years ago, Neanderthals disappeared from Western Europe and modern humans appeared. A reliable chronology is required to determine the role of environmental change in these events and whether cultural and genetic exchange may have occurred between the two species. Iberia (modern day Spain and Portugal) is of particular importance because it contains the most secure evidence for a Neanderthal refugium, and therefore is where such interactions may have occurred. The current dating evidence suggests that modern humans arrived in the north by 42,000 but did not immediately spread south, whilst Neanderthals survived in the south until c.37,000 suggesting the two populations lived in close proximity for around 5000 years.

Two thirds of the dates from this period in Iberia are radiocarbon dates. However, the method is particularly sensitive to young contaminants beyond c.30,000 years: 1% modern carbon in a 50,000 BP sample will cause the date to be underestimated by 13,000 ^{14}C years. An improved method of cleaning bone protein involving ultrafiltration was developed in the early 2000s. As part of R. Wood's PhD thesis at the University of Oxford, and since supplemented by dates at RSES, the chronology of the arrival of modern humans in the north (Wood et al., in press) and the latest Neanderthals in the south (Wood et al. 2013) was investigated.

The new dates support the arrival of modern humans at around 42,000 in the north. Preservation of bone in the warmer climate of the south was particularly poor, and only six of several hundred bones screened for protein could be dated. These came from two sites, Zafarraya and Jarama VI, where radiocarbon dating had previously suggested Neanderthals and/ or their stone tool assemblages were <42,000 years old. When dated with the ultrafiltration method, the bone samples were found to be older than 50,000 years. All other 'late' Neanderthal sites in southern Iberia have been dated using similar methods to those found to be problematic at Zafarraya and Jarama VI. Therefore, we strongly question the evidence for the prolonged survival of Neanderthals in the region. Instead there appears to be a gap of around 10,000 years where we have no well-dated archaeological deposits because of the absence of secure chronologies and/or sedimentary horizons in which the archaeological remains could be preserved.



Figure 1. The cave of Jarama VI, in the Jarama Valley, Valdesotos, Guadalajara, Spain. Image courtesy of J.F. Jordá Pardo.



Figure 2. A Neanderthal fossil from Zafarraya. Image courtesy of C. Barroso Ruíz.

Wood, R.E., et al. (in press) The chronology of the earliest Upper Palaeolithic in Northern Iberia: New insights from L'Arbreda, Labeko Koba and La Viña. *Journal of Human Evolution*.

Wood, R.E., Barroso-Ruiz, C., Caparros, M., Jorda. J.F., Galvan Santos, B., Higham, T.F.G. (2013) Radiocarbon dating casts doubt on the late chronology of the Middle to Upper Palaeolithic transition in southern Iberia, *Proceedings of the National Academy of Sciences of the United States of America*, 111(23) E2087

EARTH ENVIRONMENT

Introduction

This year has been a particularly active and productive year for the Earth Environment Area of RSES.

We welcomed several new staff members during the year. Prof Eelco Rohling arrived from University of Southampton. Prof Rohling was awarded a Laureate Fellowship, which along with supporting funds from the Vice Chancellor, is providing for the set up of new stable isotope laboratories and establishment of a large research group that will focus on sea-level change. Three new staff members, Dr Katharine Grant, Dr Gianluca Marino, and Dr Laura Rodriguez Sanz, arrived during 2013 to join Prof Rohling. The expansion of the RSES marine research groups will result in a world-leading research programme for ocean and climate change.

Earth Environment also welcomed Dr Liao Chang and Dr Xiang Zhao to the Palaeomagnetic laboratory facility at the Black Mountain site. The Palaeomagnetic laboratory is now fully established, with new instrumentation installed and becoming operational during 2013. The Palaeomagnetic research group, headed by Dean of the College of Physical and Mathematical Sciences, Prof Andrew Roberts and by Dr David Heslop, is now well-established to achieve significant research outcomes for the future.

Having completed his Masters studies earlier this year, Mr John McDonald continues within the Earth Environment Area as technical staff, conducting laboratory analyses in support of Dr McPhail's groundwater research projects.

We have welcomed a good number of new HDR students in 2013. Seven PhD candidates began their research: Mr Yuhai Dai, to work under the supervision of Dr Jimin Yu; Ms Fang Fang and Ms Kelsie Long, to work with Prof Rainer Grün; Ms Katherine Holland, to work with Dr Stephen Eggins; Ms Vikashni Nand, with Dr Michael Ellwood; Mr Michael Short, with Dr Bear McPhail; and Ms Jennifer Wurtzel, with Dr Nerilie Abram. A Masters student also joined us: Ms Hannah James finished her research thesis under the supervision of Prof Rainer Grün.

Several PhD candidates submitted their theses in 2013: Ms Jung-Ok Kang, supervised by Dr Eggins, Mr Iain McCulloch, supervised by Prof Bradley Pillans, on Geomorphology of sediment cones at Narracoorte caves, South Australia; Mr Ian Moffat, supervised by Prof Grün, on Strontium isotope tracing of human migrations; and Ms Laura Richardson, supervised by Dr Opdyke, on Water mass connectivity and mixing along the southern margin of Australia: hydrographic and stable isotope analyses.

Nine Honours students were also supervised within the Earth Environment Area during 2013: Mr William Bonney (Dr Opdyke); Ms Diana Cato-Smith (Dr Papp); Ms Wing Chan (Dr Eggins); Mr Luke Cousins (Dr Norman); Mr John Daly (Dr McPhail); Ms Hannah Mosely (Prof Grün), Ms Jennifer Pritchard (Dr Norman); Ms Anushka Sandanam (Dr Eggins); and Mr Gerhard Schoning (Dr McPhail).

ARC grants awarded for funding beginning in 2013 have continued to facilitate our exploration in new, exciting avenues of environmental research. The grant successes

showcase the analytical capabilities of the Earth Environment Area and the diverse applications and research interests that are pursued by Earth Environment staff members. During 2013 we received three Discovery grants to led by Dr Abram, Prof Roberts, and Dr Jimin Yu. These projects will start in 2014.

Earth Environment staff received a number of prestigious awards during the year. Prof Roberts was awarded the Fellowship of the American Geophysical Union 'for his pioneering work in environmental magnetism and climate change, and for developing advanced new methods in rock magnetism. Prof Roberts was also elected to Honorary Fellowship of the Royal Society of New Zealand in recognition of his achievements in the fields of palaeo- and environmental magnetism.

The high research profile of Earth Environment continues to be documented by the numerous publications in world leading journals such as Nature, Nature Geosciences, Proceedings of the National Academy of Sciences, Earth and Planetary Science Letters, Quaternary Science Reviews, and Palaeogeography, Palaeoclimatology, Palaeoecology.

Earth Environment staff members have again been prominently involved in the RSES teaching activities in Earth and Marine sciences, teaching the courses Marine Biogeochemistry; Geobiology and Evolution of Life; Groundwater; and Sedimentology and Stratigraphy; as well as assisting with other undergraduate programs. Prof Grün also taught the Anthropology and Archaeology third year course on Scientific Dating at RSES. The continuing large numbers of Honours and Higher Degree Research students based in the Earth Environment Area documents the success of these teaching programs.

None of our 2013 research activities were possible without our experienced and dedicated technical staff, Mr Joe Cali, Mrs Joan Cowley, Mr Les Kinsley, Mr John McDonald, Mrs Linda McMorrow, Dr Graham Mortimer, Dr Laura Rodriguez Sanz, Mrs Heather Scott-Gagan, Mrs Judith Shelley, and Dr Xiang Zhao. Our many casual staff have also greatly assisted our research efforts. I am particularly grateful to our Area Administrator, Mrs Robyn Petch, whose support for the Area's staff, students and visitors during the year has been widely appreciated.

The end of 2013 has also seen the retirement of two long-serving Earth Environment staff. Prof Patrick De Deckker retired in November after a long and successful academic career, including more than thirty years at ANU. Prof De Deckker served as Head of the Earth and Marine Sciences faculty for several years and has been a leading researcher in the field of palaeontology.

Dr Graham Mortimer also retired at the end of 2013 after nearly twenty-five years of outstanding service in managing the Earth Environment clean laboratory facility.

We are pleased that both Prof De Deckker and Dr Mortimer will continue close association with the School.

Work started on the refurbishment of the old John Curtin Building which will house the water laboratories of Earth Environment. The work is expected to be completed in 2014. This will consolidate all of our laboratories some of which are still located in the old DEMS building.

2014 will see a reorganisation within the School merging the core of Earth Environment with the Geophysical Fluid Dynamics group. We expect the development of new synergies from combining state-of-the-art ocean geochemistry and ocean circulation modelling. Dr Steven Eggins will be the Associate Director of this new area. I wish him all the best.

Prof Rainer Grün

Associate Director, Earth Environment

10-fold increase in Antarctic Peninsula summer ice melt

Nerilie Abram¹ and Robert Mulvaney²

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

² *British Antarctic Survey, Natural Environment Research Council, Cambridge CB3 0ET, UK*

Summer ice melting on the Antarctic Peninsula has intensified almost ten-fold in the last 600 years, with the most rapid melting occurring in the last 50. Published in *Nature Geoscience* (Abram et al., 2013), this research adds to the international effort to understand the causes of environmental change in Antarctica and to make more accurate projections about the direct and indirect contribution of Antarctica's ice shelves and glaciers to global sea level rise.

In 2008 an international science team drilled the 364-metre long ice core from James Ross Island, near the northern tip of the Antarctic Peninsula, to measure past temperatures in the area (Mulvaney et al., 2012). This ice core has also now given a unique and unexpected insight into ice melt in the region. Visible layers in the ice core indicate periods when summer snow on the ice cap thawed and then refroze. By measuring the thickness of these melt layers, a history of melting at the ice core site over the last 1,000 years has been recovered.

The ice core shows that summer melting at the site is now higher than at any other time over the last 1,000 years. The coolest conditions on the Antarctic Peninsula and the lowest amount of summer melt occurred around 600 years ago. At that time, temperatures were around 1.6°C lower than those recorded in the late 20th Century and the amount of annual snowfall that melted and refroze was about 0.5%. Today, almost ten times as much of the annual snowfall melts each year.

While temperatures on the Antarctic Peninsula have increased gradually over many hundreds of years, most of the intensification of melting has happened since the mid-20th century. This non-linear response of melting to rising temperatures means that the Antarctic Peninsula has warmed to a level where even small increases in temperature can now lead to a big increase in summer ice melt; a finding that has important implications for ice instability and sea level rise in a warming climate (Abram 2013).

Acknowledgements:

Nerilie Abram is supported by a Queen Elizabeth II fellowship awarded by the Australian Research Council under Discovery Grant DP110101161. This work is part of the British Antarctic Survey programme Polar Science for Planet Earth, funded by the Natural Environment Research Council.



Figure 1. The ice core camp on the summit of James Ross Island. The 364m long ice core was drilled during a 2 month field campaign by a team of 7 scientists and engineers. The project was led by the British Antarctic Survey, with logistical support provided by the UK Royal Navy.

Abram, N.J. (2013). Antarctic ice...going, going,gone? In: *The Curious Country* (ed. L. Dayton). pp. 11-19. From the Office of the Chief Scientist and available as a free e-book through ANU Press.

Abram, N.J., Mulvaney, R., Wolff, E.W., Triest, J., Kipfstuhl, S., Trusel, L.D., Vimeux, F., Fleet, L. and Arrowsmith, C. (2013). Acceleration of snow melt in an Antarctic Peninsula ice core during the twentieth century. *Nature Geoscience*, 6, 404-411, doi:10.1038/NGEO1787.

Mulvaney, R., Abram, N.J., Gagan, M.K., Hindmarsh, R.C.A., Arrowsmith, C. Fleet, L., Triest, J., Sime, L.C., Alemaney, O. and Foord, S. (2012) Recent Antarctic Peninsula warming relative to Holocene climate and ice-shelf history. *Nature* 489, 141-144, doi:10.1038/nature11391.

The Curious Country: <http://www.chiefscientist.gov.au/2013/11/the-curious-country/>

An ice-age rainfall seesaw in Australasia

Linda Ayliffe¹, Mike Gagan¹, Jian-xin Zhao², Russell Drysdale³, John Hellstrom⁴, Wahyoe Hantoro⁵, Michael Griffiths⁶, Heather Scott-Gagan¹, Emma St Pierre², Joan Cowley¹ and Bambang Suwargadi⁵

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

² *School of Earth Sciences, The University of Queensland, Brisbane, QLD 4072, Australia*

³ *Department of Resource Management and Geography, The University of Melbourne, Parkville, VIC 3010, Australia*

⁴ *School of Earth Sciences, The University of Melbourne, Parkville, VIC 3010, Australia*

⁵ *Research Center for Geotechnology, Indonesian Institute of Sciences, Bandung 40135, Indonesia*

⁶ *Department of Environmental Science, William Paterson University, Wayne, New Jersey 07470, USA*

The last deglaciation was the final stage in the most recent of the ~100,000-year cycles of global ice-sheet growth and decay. Recent studies have led to an emerging hypothesis for ice-age terminations whereby rapid reorganisation of the ocean and atmospheric circulation serves to link millennial-scale cooling in the North Atlantic with rising atmospheric CO₂ levels and global warming. A key part of the proposed climatic chain-of-events involves southward displacement of the global monsoon system and Southern Hemisphere westerly wind belt in response to Northern Hemisphere cooling, which in turn drives upwelling and CO₂ ventilation from the Southern Ocean, and thus deglacial warming. The vast Australasian monsoon, with the Indo-Pacific Warm Pool, could have played a key role in deglacial warming, but direct evidence for the “southern half” of the system has yet to emerge.

Here we summarise 230Th-dated stalagmite 18O/16O records of millennial-scale changes in Australian-Indonesian monsoon rainfall spanning the last 31,000 years. We exploited the palaeomonsoon signal preserved in the 18O/16O of stalagmites from Liang Luar cave on the island of Flores, Indonesia, in the Southern Hemisphere sector of the Australasian monsoon system. The 18O/16O of stalagmite calcium carbonate is set by the amount of rainfall at the site, which is controlled primarily by north-south displacements of the monsoon. Superb age-control for the 31,000-year-long record was provided by 86 uranium-thorium dates with an average precision of 0.9%.

The record revealed a clear interhemispheric “rainfall seesaw” pattern across Australasia during the last deglaciation (Figure 2). A key finding was that Flores was wet when China (on the northern end of the monsoon system) was dry during well-known millennial-scale cold intervals in the North Atlantic from 17,600 to 11,500 years ago. The most prominent southward shift of the monsoon occurred in lock-step with Heinrich Stadial 1 (17,600 to 14,600 years ago), and a rapid rise in atmospheric CO₂. Our findings show that millennial-scale climate change was transmitted rapidly across Australasia and lend support to the idea that the 3,000-year-long Heinrich 1 interval could have been critical in driving the last deglaciation.

The rainfall seesaw identified here is a robust signal in climate models, but this is the first time we have had detailed and precisely dated records showing its widespread impact across Australasia. The result is important because it contributes to a unifying hypothesis that explains how the hemispheres are coupled during ice age terminations.

This research is supported by Australian Research Council Discovery grants DP0663274 to M.G., J.-x.Z., R.D. and W.H. and DP1095673 to M.G., R.D., J.H., and W.H.



Figure 1. One of our super-cavers, Neil Anderson, up to his neck in water in Liang Luar cave, west Flores, Indonesia. Photo credit: D. Zwartz.

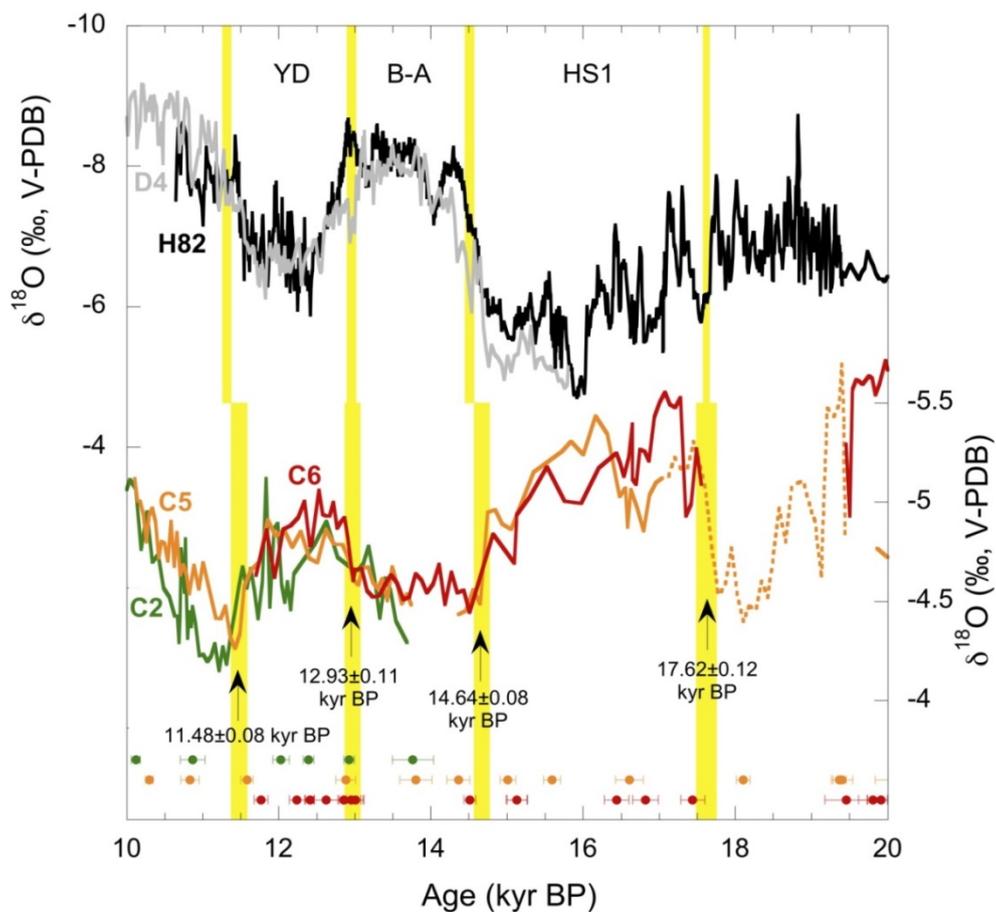


Figure 2. Comparison of stalagmite $^{18}\text{O}/^{16}\text{O}$ records for Liang Luar, Flores and Hulu/Dongge caves, China from 20 to 10 kyr BP (kyr BP, thousand years before AD 1950). Yellow bars indicate the timing and duration of the Heinrich Stadial 1 (HS1), Bølling-Allerød (B-A) and Younger Dryas (YD) climatic shifts in Flores and China. Colour-coded ^{230}Th ages (with 2σ errors indicated by bars) are shown below each of the Liang Luar stalagmite $^{18}\text{O}/^{16}\text{O}$ records.

Ayliffe, L. K., Gagan, M. K., Zhao, J.-x., Drysdale, R. N., Hellstrom, J. C., Hantoro, W. S., Griffiths, M. L., Scott-Gagan, H., St Pierre, E., Cowley, J. A. & Suwargadi, B. W. (2013), Rapid interhemispheric climate links via the Australasian monsoon during the last deglaciation. *Nature Communications* 4:2908 doi:10.1038/ncomms3908.

The first predators emerge during the Bitter Springs Stage carbon isotope anomaly, 800 million years ago

Jochen J. Brocks and Amber J. M. Jarrett

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

The Neoproterozoic, 1,000 to 541 million years (Myr) ago, was the most tumultuous period in Earth history. It saw the greatest perturbations of the carbon cycle, the most massive ice ages ("Snowball Earth" events), a rise of atmospheric oxygen, the advent of animal life followed by the rampant diversification of animals in the 'Cambrian Explosion'. The diversity of shapes and forms of single-celled eukaryotes – the ancestors of all animals, plants, protists and algae - also massively increased after 800 million years ago, and there may be links between these intriguing evolutionary events and the large carbon isotopic excursions that characterize this time. The oldest of the Neoproterozoic excursions is the enigmatic Bitter Springs Stage Anomaly (BSSA), dated to ~825 Ma. We investigated biological and environmental changes across the Anomaly by studying redox chemistry, sedimentology and molecular fossils of a particularly well preserved section in central Australia. Over ~200 meters of carbonate stratigraphy, the BSSA records a negative carbon isotope shift from +5‰ to -4‰ and back to +5‰. The isotopes recovered to positive values when the environment changed from relatively deep, partly stratified and anoxic waters to very shallow pools surrounded by exposed land. Intriguingly, molecular fossils recovered from the deep waters of the negative excursion contain the lipid remains of anaerobic predatory eukaryotes, possibly the oldest genuine biomarker signal of modern eukaryotes in the geological record. The anaerobic predator signal diminishes at the end of the carbon perturbation and is replaced by the emergence of what we interpret as the oldest known signal of modern oxygen-breathing eukaryotes. The diversification of eukaryotic fossils around 800 million years ago has been attributed to an expansion of eukaryotic algae. However, the biomarkers that emerge at the dawn of the Bitter Springs Stage Anomaly have an unusual primitive distribution, indicating that the shallow pools were not inhabited by photosynthetic algae but by heterotrophs, organisms that consume carbon and are more akin to amoebae.



Figure 1. Amber, the PhD student whose thesis is based on this work and who made the amazing discoveries, in front of a giant stromatolite (microbial mat) of the ~825 million year old Bitter Springs Formation near Alice Springs.

Ancient life, water column composition and giant lead zinc deposits

Benjamin J. Bruisten and Jochen J. Brocks

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

The Australian economy relies to a large extent on the exploitation of the country's vast mineral resources, but new deposits are increasingly difficult to find. In the framework of CSIRO's Organic Geochemistry in Mineral systems cluster we try to go new ways to better understand how and when mineral deposits form and where they can be found.

1.6 billion years ago, in a time interval called the Paleoproterozoic, giant deposits of zinc and lead sulphides formed in the restricted sea that covered the area that is now known as the McArthur Basin in the Australian Northern Territory. In the fine grained rocks of the Barney Creek Formation (BCF), almost horizontal layers of base metal ore alternate with layers of unmineralised regular sediments (see Figure 1). This kind of deposit is called a stratiform deposit and the HYC McArthur River deposit is one of the largest of its kind in the world. It is not the only one that formed at this time however: several of the world's largest zinc and lead deposits are found in rocks of this age in northern Australia. Usually such deposits and surrounding rocks have been greatly altered by time and temperature. The BCF in the McArthur Basin is comparatively little altered however, allowing a much better reconstruction of the depositional conditions. This information can help to understand how and when

these kind of deposits form, facilitating the search for new deposits. Only a few years ago, a major deposit was found only 20 km away from HYC, highlighting the great potential of the BCF to further exploration.

It is strongly debated how the HYC deposit formed: did the metals precipitate when the BCF was deposited or did the metals replace other minerals when the sediments were later traversed by hot fluids? To answer these questions, the composition of the water column at BCF times is of great importance. In collaboration with Prof. Poulton from the University of Leeds we are using a recently developed technique called Iron Speciation Analysis to assess how the water column looked like (rich in oxygen, iron or hydrogen sulfide?). We discovered that, different from what is commonly believed, the water column was rich in iron, not H₂S, so it could probably not supply the large amounts of (reduced) sulphur that are required to form vast deposits. This information has great implications for how and where such deposits form.

We are also investigating what kind of organisms inhabited the BCF water at the time of ore deposition and which role they could have played in forming the deposits. Our research therefore not only helps to understand how and where the base metals deposited but might have implications for other questions of great importance in the earth sciences: How did the ocean chemistry look like and what were the prevailing ecosystems? The thermally well preserved rocks of the BCF allow an unusual glimpse into a distant time when life on earth looked markedly different from how it looks today, a time when our early ancestors (eukaryotes) struggled to gain environmental importance.

Organic Geochemistry of Mineral Systems cluster website:
<http://wa-oigc.curtin.edu.au/ogms/>



Figure 1. Stratiform bands of Fe- and Zn/Pb sulphides in mineralised sediments of the 1.64 Ga BCF, northern Australia.

The complex mineralization of coniform microbialites in Lake Preston, Western Australia

The importance of morphogenesis for identification of microbialites

Robert V. Burne¹, Linda S. Moore†², Andrew G Christy¹ and Anna M. Carnerup³

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

² † *Deceased, formerly with Department of Microbiology, University of Western Australia, Nedlands W.A. 6009, Australia*

³ *Lithicon, Suite 2, Ground Floor, 73 Northbourne Avenue, Canberra, ACT 2600, Australia*

Here we report on progress of studies of carbonate pavements in Lake Preston that were mentioned in last year's RSES Annual Report (Burne 2013). Lake Preston, one of the Yalgorup Lakes, lies on the western edge of the 25-30 km wide Swan Coastal Plain in the south west of Western Australia between Mandurah and Bunbury. It is a linear, interdunal, saline lake 27.5 km long and a width of up to 2 km (Moore and Burne 1989). It is separated from the ocean by an unbroken dune system about 1 km wide and 25 – 52 m high. The Lake receives little runoff and is maintained by groundwater flow and direct accession of rainwater. Evaporation concentrates salts in the Lake, which remains hypersaline throughout the year with salinity ranging from 42 to 78gL⁻¹ (Moore 1987).

Ephemeral microbial mats with a pinnacle surface morphology have been observed from time to time in an embayment on the southwestern shore of the lake. (Figures 1 & 2a) When examined in 1992 the pinnacles were subcylindrical, erect. 1 to 5 cm high, 1 – 2 cm diameter, spaced about 1 – 2 cm apart, are more or less contiguous and had sub circular transverse sections. They were constructed by a benthic microbial community dominated by the cyanobacterium *Phormidium*, but also including *Spirolina*, *Aphanothece* and *Chroococcus* as well as diatoms, principally *Brachysira*.

A comprehensive survey of Lake Preston sediments has yet to be undertaken, but, in general, the lake bed consists of carbonate mud, and the lake is bordered by a lithified carbonate platform often containing shells of the bivalve *Katalesia* which are relics of an earlier marine phase of the Lake. Tepee structures occur on the platform along the eastern shore, probably related to the discharge of alkaline groundwaters in this area. Underwater examination of the lake floor at the southern end of the lake shows that here much of the lake bed is composed of indurated sediment, with small coniform, arborescent and domical lithified structures rise from this lithified platform (www.youtube.com/watch?v=ze7AoWOa9mE). These structures have been tentatively either as non-biogenic tufa deposits or as the remains of eroded microbialites (Figure 2b).

The lithified coniform structures are of comparable size to pinnacle structures found in the above-mentioned ephemeral mats. We have conducted SEM analysis of a lithified cone and have discovered that it is indeed of microbial origin, though it has subsequently undergone three distinct phases of mineralization (Figure 3). Initially a Mg silicate phase first coated and permineralized of the microbial biomass (a) and then coalesced into a uniform mass (b). Massive aragonite crystal growth then over-printed much of this initial texture (c). Following this, high magnesium calcite grew

as rims around the aragonite crystals as well as overprinting some of the remaining areas of the Mg silicate phase (d).

We conclude that syngenetic and early diagenetic carbonate mineralization of microbialites may effectively obscure all traces of the original microbial communities, leaving only morphogenetic evidence for their organosedimentary origin.



Figure 1. Cross section of pinnacle excised from living ephemeral mat from lake Preston embayment in 1992. Note laminated structure. Sample prepared and photographed at QE II Medical Centre, Perth.



Figure 2. Comparison of living pinnacle mat (a) and lithified carbonate microbialite with coniform surface structure. (a): Living microbial mat showing cross section of mat structure and surface morphology of pinnacles': (b) Surface morphology and section across lithified pinnacle mat (leiolite). Ruler scale in cm.

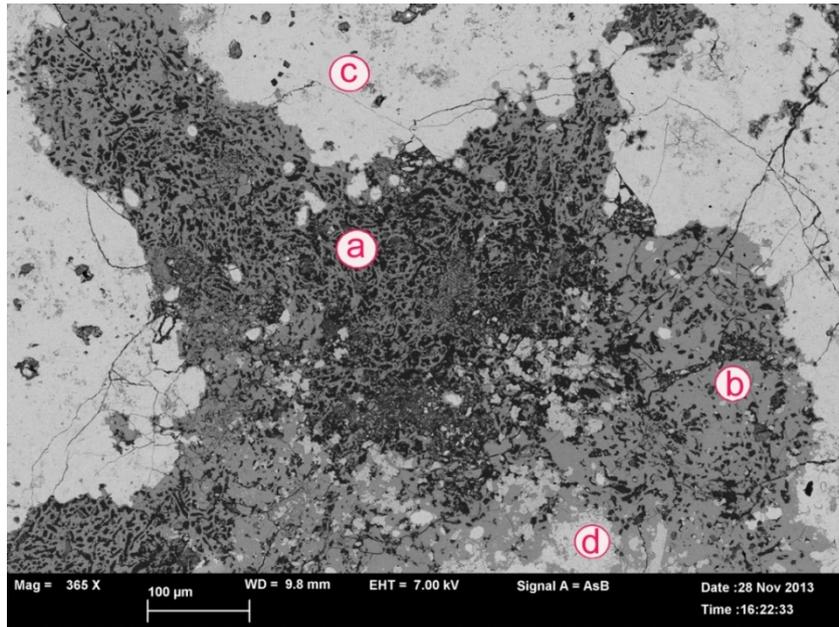


Figure 3. SEM Image of sample from lithified pinnacle similar to those shown in Figure 2b. (a) Mg silicate phase reflecting microbial filament web; (b) Massive Mg silicate phase; (c) Aragonite crystal aggregate; (d) Late high-Mg calcite crystal aggregate.

Burne, R.V., 2013, Advances in the understanding of pre-salt carbonate reservoirs of offshore Brazil and Angola from studies of Australian lakes. ANU Research School of Earth Sciences Annual Report 2012 p. 44-46.

Moore, L.S., 1987, Water chemistry of the coastal saline lakes of the Clifton-Preston Lakeland system, south-western Australia, and its influence on Stromatolite Formation: Australian Journal of Marine and Freshwater Research, v. 38, p. 647-660

Moore, L.S. and Burne, R.V., 1989, Yalgorup Lakes field excursion. Preliminary Field Guide March 1989, Geological Society of Australia (Western Australian Division), 59 pages + references.

Relict Microbialites in Lake Preston:

<https://www.youtube.com/watch?v=ze7AoWOa9mE>

Evidence of increased biomass burning AFTER the extinction of the Australian megafauna - Clues of megafaunal extinction in Australia

Raquel Lopes dos Santos¹, Patrick De Deckker², John Magee² and Stefan Schouten¹

¹ NIOZ, Royal Netherlands Institute for Marine Research, Texel, The Netherlands

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

There has been a long and heated debate in Australia about the timing and cause of the extinction of the Australian megafauna, which includes a variety of large marsupials, including the carnivorous marsupial lion (*Thylacoleo*) and the giant flightless bird (*Genyornis*). The debate has concerned whether humans are the direct cause [through hunting], or an indirect cause [through burning of the landscape]. Or

was it a shift of climate that engendered the disappearance of large animals, or a combination of any of these factors?

There is now widely accepted evidence that humans arrived in Australia between 54,000 to 45,000 years ago. The megafaunal extinction is widely considered to have occurred between 49,000 and 44,000 years ago, with no megafauna younger than that date, though some researchers dispute this chronology. This sequence suggests that the arrival of humans is the main driver for this extinction. In addition, the imposition of a human-controlled burning regime in Australia is suggested as the most likely cause of ecosystem change that affected the megafauna.

Together with a team of organic geochemists from NIOZ, we have studied a sediment core obtained from the sea floor at 865 m water depth offshore from Kangaroo Island, opposite the mouth of the River Murray. The sediments in the core originate from the Murray-Darling Basin and are mixed together with marine pelagic clays. From the core sediments we were able to reconstruct sea-surface temperature for the past 135,000 years as well as variations in the type of vegetation in the Murray Basin, estimated from changes in ratio of the carbon-13 and carbon-12 isotopes of organic compounds found in the core.

We noted the following: 1) Sea-surface temperature only varied by about 3°C during the period of megafaunal extinction and these changes are minor compared to the large changes (up to 10°C) over the full 135,000 year core record, indicating that the time of megafaunal extinction was not a time of major climate change; 2) prior to and during the megafaunal extinction, the percentage of C4 grasses averaged 70%, whereas AFTER the extinction, this value dropped to 35%, 3) the shift from C4 grass to C3 vegetation dominance coincides with an abrupt rise in the presence of Levoglucosan - an organic compound produced as a result of biomass burning. This demonstrates that increased fire coincided with the shift of vegetation (to more abundant C3 vegetation), immediately AFTER the megafaunal extinction. These findings clearly demonstrate that the megafaunal extinction event was not coincident with a major climate shift but immediately preceded a significant vegetation change.



Figure 1. The 32m long core which was used in this study is laying on the side deck of the RV *Marion Dufresne* shows proof of its penetration through sediment on the sea floor offshore Kangaroo Island with pale grey pelagic clays stuck to the outside of the coring pipe.

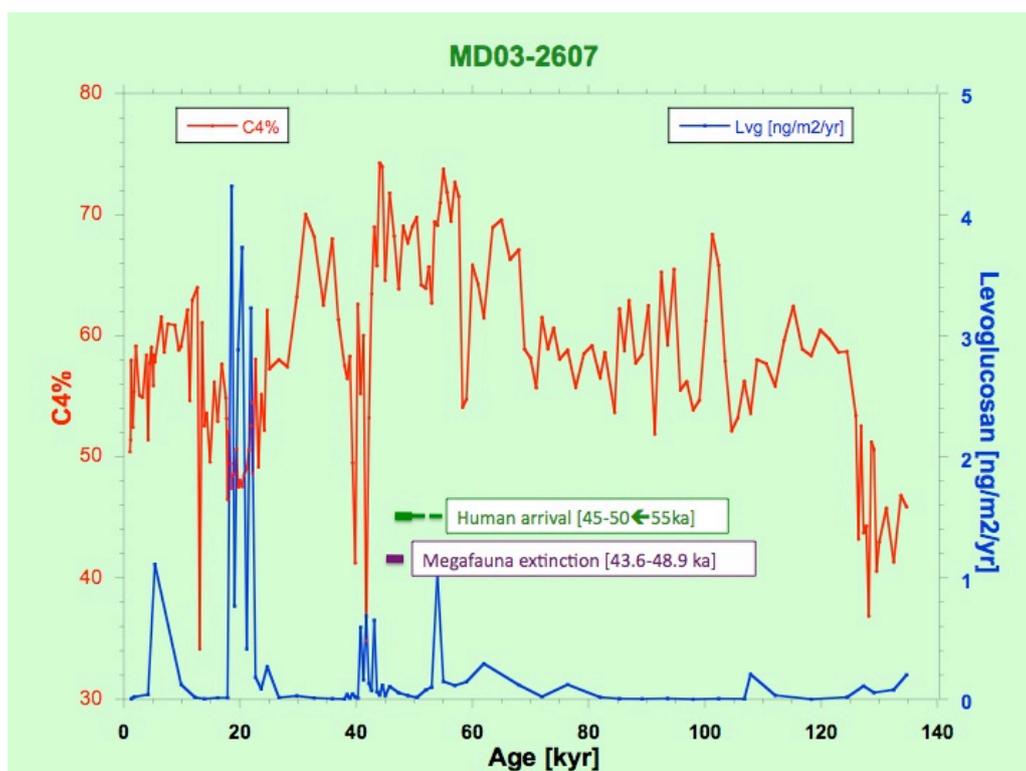


Figure 2. Plot of the percentage of C4 plants for the entire Murray-Darling Basin reconstructed from the weighted average $d^{13}C$ of C27–C33 *n*-alkanes recovered in core samples and the presence of Levoglucosan which is an indicator of biomass burning. The horizontal axis represents time in 1000 years. Note that the evidence of biomass burning occurred AFTER the megafaunal extinction and this coincided with a massive vegetation change in the basin. The high percentage of Levoglucosan at the Last Glacial Maximum is explained by the fact that Australia was very arid [hence a vegetation change] at the time and the core was close to the mouth of the River Murray.

Tracing changes in the biogeochemical cycling of iron during the annual subtropical spring bloom east of New Zealand

Michael J Ellwood¹, Philip W Boyd², Scott Nodder³, David Hutchins⁴, Steven Wilhelm⁵, Angela Milne⁶ and Maeve Lohan⁶

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

² Centre for Chemical and Physical Oceanography, NIWA, University of Otago, Dunedin, New Zealand

³ NIWA, Wellington, New Zealand

⁴ Marine Environmental Biology, University of Southern California, Los Angeles, California, USA

⁵ Department of Microbiology, The University of Tennessee, Knoxville, USA

⁶ School of Geography, Earth and Environmental Sciences, University of Plymouth, UK

The turnover time of iron in the surface ocean can vary from days to weeks and months, while within cells the turnover time can be on the order of hours to days. Accordingly, the iron isotope ($d^{56}Fe$) composition of particulate organic matter should be sensitive to changes in the cycling of iron in the surface ocean and immediately below. Here we present data showing a dynamic change in the $d^{56}Fe$

composition of particulate organic matter during the development and subsequent export of phytoplankton bloom material. Our results, obtained from two FeCycle voyages in 2008 and 2012, suggest that before the onset and development of the phytoplankton bloom iron regeneration dominates the dissolved iron signal with lighter dissolved $d^{56}\text{Fe}$ values (-0.14‰ at 100 m to 0.07‰ at 500 m) relative to particulate iron (-0.02‰ at 60 m to 0.13‰ at 300m). In contrast, during the development and export phase of the bloom, iron scavenging and/or iron consumption by heterotrophic bacteria community appears to dominate the dissolved iron isotope signal with heavier dissolved $d^{56}\text{Fe}$ values (0.15‰ at 30 m to 0.16‰ at 500 m) relative to particulate $d^{56}\text{Fe}$ values (-0.11‰ at 30 m to -0.33‰ at 300 m). A strong relationship was also observed between particulate $d^{56}\text{Fe}$ and Fe/Al ratios with lighter values as the Fe/Al ratio increased. The dissolved and particulate $d^{56}\text{Fe}$ results were modelled with Rayleigh-type functions and produced the following fractionation factors: 1.00015 prior to the onset and development of the bloom and 0.99945 during the subsequent export of the bloom material to depth. Taken together our results show that the iron isotope composition of dissolved and particulate material can be used to monitor changes in the biogeochemical cycling of iron in the marine realm.

Natural relationship between carbon dioxide concentrations and sea level

Gavin L. Foster¹ and Eelco J. Rohling²

¹ *National Oceanography Centre, Southampton, SO14 3ZH, UK*

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

By comparing reconstructions of atmospheric carbon dioxide (CO₂) concentrations and sea level over the past 40 million years, we have found that greenhouse gas concentrations similar to the present (almost 400 parts per million) were systematically associated with sea levels at least nine metres above current levels.

Our study determined the 'natural equilibrium' sea level for CO₂ concentrations ranging between ice-age values of 180 parts per million and ice-free values of more than 1,000 parts per million. It takes many centuries for such an equilibrium to be reached. Therefore, while the study does not predict any sea level value for the coming century, it does illustrate what sea level might be expected if climate were stabilized at a certain CO₂ level for several centuries. And a specific case of interest is one in which CO₂ levels are kept at 400 to 450 parts per million, because that is the requirement for the often mentioned target of a maximum of two degrees global warming.

We compiled more than two thousand pairs of CO₂ and sea level data points, spanning critical periods within the last 40 million years. Some of these had climates warmer than present, some similar, and some colder. They also included periods during which global temperatures were increasing, as well as periods during which temperatures were decreasing. This way, we cover a wide variety of climate states,

which puts us in the best position to detect systematic relationships and to have the potential for looking at future climate developments.

We found that the natural relationship displays a strong rise in sea level for CO₂ increase from 180 to 400 parts per million, peaking at CO₂ levels close to present-day values, with sea level at 24 +7/-15 metres above the present, at 68 per cent confidence limits. This strong relationship reflects the climatic sensitivity of the great ice sheets of the ice ages. It continues above the present level because of the apparently similar sensitivity of the Greenland and West Antarctic ice sheets, plus possibly some coastal parts of East Antarctica.

The study also found that sea level stays more or less constant for CO₂ changes between 400 and 650 parts per million, and it is only for CO₂ levels above 650 parts per million that we again see a strong sea level response for a given CO₂ change. This trend reflects the behaviour of the large East Antarctic ice sheet in response to climate changes at these very high CO₂ levels. An ice-free planet, with sea level 65 metres above the present, occurred in the past when CO₂ levels were around 1200 parts per million.

Sea level rises to these high values will take many centuries, or even millennia, but the implications from the geological record are clear – for a future climate with maximum warming of about two degrees Centigrade, that is with CO₂ stabilized at 400 to 450 parts per million, sea level is set to steadily rise for many centuries, towards a natural equilibrium position at around 24 +7/-15 metres (at 68 per cent confidence). This is a likely rise of at least nine metres above the present, and previous research indicates that such rises above present sea level may occur at average rates of roughly one metre per century.

Based on these results, which document how the Earth system has operated in the past, future stabilization of CO₂ at 400-450 parts per million is unlikely to be sufficient to avoid a significant steady long-term sea level rise.

Journal web page for the study:

<http://www.pnas.org/content/early/2013/01/03/1216073110>

Quantifying magnetite magnetofossil contributions to sedimentary magnetizations

David Heslop, Andrew P. Roberts, Liao Chang, Maureen Davies, Alexandra Abrajevitch and Patrick De Deckker

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

Magnetotactic bacteria grow permanent nanomagnets that, when arranged in chains, provide a means for the bacteria to orient themselves using Earth's magnetic field and locate optimal living conditions. Under suitable conditions, magnetofossils (the inorganic remains of magnetotactic bacteria) can contribute to the natural magnetization of sediments. In recent years, magnetofossils have been shown to be preserved commonly in marine sediments, which makes it essential to quantify their

importance in palaeomagnetic recording.

Testing the contribution of magnetofossils to the palaeomagnetic record has been a challenge until recently because of a lack of rock magnetic techniques that could be used to detect magnetofossils effectively. Instead, time-consuming magnetic extractions and transmission electron microscope (TEM) imaging were necessary to identify magnetofossil particles (Petersen et al. 1986; Hesse 1994), which limits the number of samples that can be investigated.

We have examined a deep-sea sediment core (MD00-2361) from offshore of northwestern Western Australia using a variety of advanced rock magnetic techniques. The magnetic mineral assemblage is dominated by continental detritus and magnetite magnetofossils (Figure 1). By separating magnetofossil and detrital components based on their different rock magnetic characteristics, it is possible to quantify their respective contributions to the sedimentary magnetization throughout the last 800 kyr. In the studied core, the contribution of magnetofossils to the sedimentary magnetization is controlled by large-scale climate changes, with their relative importance to palaeomagnetic recording increasing during glacial periods when detrital inputs were low. Our results demonstrate that magnetite magnetofossils can dominate sedimentary palaeomagnetic signals in settings where they are preserved in significant abundances.

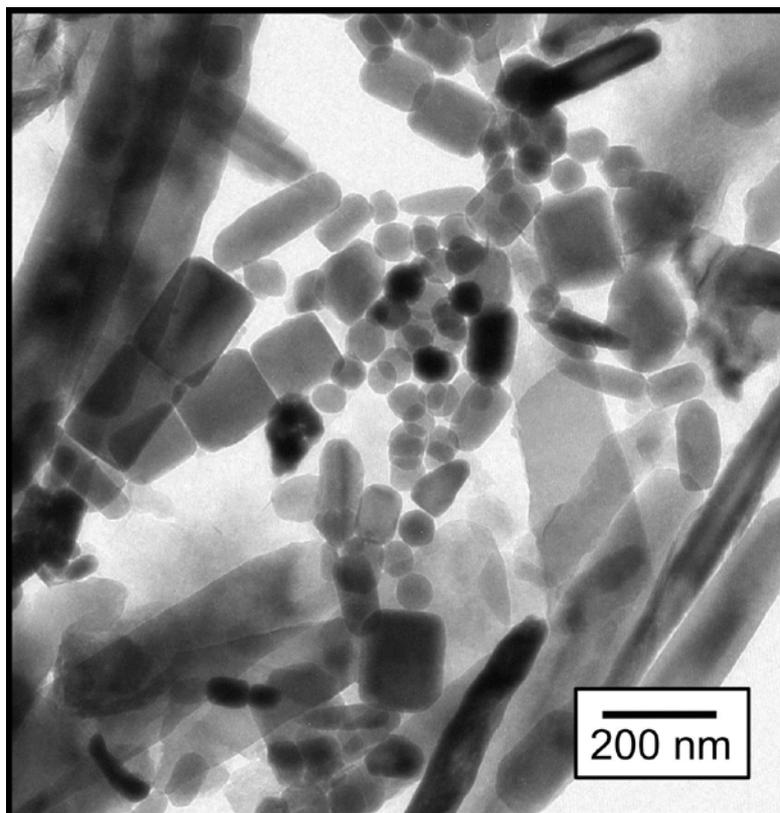


Figure 1. TEM image of a magnetic mineral extract from a glacial interval of sediment core MD00-2361. The image is dominated by magnetite magnetofossils with a variety of morphologies (the larger particles are non-magnetic contaminants, such as carbonates and clays).

P.P. Hesse, Evidence for bacterial palaeoecological origin of mineral magnetic cycles in oxic and sub-oxic Tasman Sea sediments. *Mar. Geol.*, 117 (1994), pp. 1–17.
N. Petersen, von Dobeneck T, H. Vali, Fossil bacterial magnetite in deep-sea sediments from the South Atlantic Ocean, *Nature*, 320 (1986), pp. 611–615.

D. Heslop, Roberts, A.P., Chang, L., Davies, M., Abrajevitch, A., De Deckker, P., Quantifying magnetite magnetofossil contributions to sedimentary magnetizations. *Earth Planet. Sci. Lett.*, 382 (2013), pp. 58-65.
<http://www.sciencedirect.com/science/article/pii/S0012821X1300513X>

The glacial-interglacial monsoon in Sulawesi

Alena Kimbrough¹, Mike Gagan¹, Gavin Dunbar², Wahyoe Hantoro³, Hai Cheng^{4,8}, Chuan-Chou Shen⁵, John Hellstrom⁶, Larry Edwards⁴ and Hamdi Rifai⁷

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

² *Antarctic Research Centre, Victoria University of Wellington, Wellington, New Zealand*

³ *Research Center for Geotechnology, Indonesian Institute of Sciences, Bandung, Indonesia*

⁴ *Department of Earth Sciences, University of Minnesota, Minneapolis, MN 55455, USA*

⁵ *Department of Geosciences, National Taiwan University, Taipei 10617, Taiwan ROC*

⁶ *School of Earth Sciences, University of Melbourne, Parkville, Victoria 3010, Australia*

⁷ *Department of Physics, State University of Padang, Padang, 25131, Indonesia*

⁸ *Institute of Global Environmental Change, Xi'an Jiatong University, Xi'an 710049, China*

Understanding the natural variability of climate systems throughout Earth's past is essential to assess changes in modern climate. Glacial-interglacial cycles represent some of the largest and most rapid natural climate changes over the last 800,000 years. Documenting the impacts of rapid warming events during ice-age terminations may be particularly important to understand when forecasting the behaviour of tropical monsoon systems under anthropogenic climate change.

A number of recent studies have revolutionized our understanding of past monsoon behaviour using oxygen isotope ratios ($\delta^{18}\text{O}$) in speleothems (cave calcium carbonate formations) as a proxy for monsoon rainfall. Most speleothem research has concentrated on understanding monsoon variability in the Northern Hemisphere, but few of these records extend beyond the last glacial-interglacial cycle. Much less is known about the history of the Southern Hemisphere tropics, and the Australian-Indonesian Summer Monsoon (AISM), particularly over glacial-interglacial timescales.

We present the first speleothem $\delta^{18}\text{O}$ record for southwest Sulawesi, located at 5oS in Indonesia, spanning the period ~265-165 kyr BP (kyr BP, thousand years before AD 1950). The development of this record involves a multi-proxy approach ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, Mg/Ca, Sr/Ca) to provide insight to the mechanisms controlling variability of the AISM throughout Termination III and IIIa (~248 and ~220 kyr BP). Preliminary data suggest that the near-equatorial sector of the AISM is not influenced by changes in summer insolation at the 23 kyr precession timescale, in contrast to palaeomonsoon records for China and northern Australia near the subtropical periphery of the monsoon system (Fig. 2). Instead, the most prominent decreases in the Sulawesi $\delta^{18}\text{O}$ record correlate with rapid rises in sea level during TIII and

TIIIa. The $\sim 2\text{-}3\text{‰}$ decreases in $\delta^{18}\text{O}$ at these times are much larger than the accompanying ice-volume-related changes in the $\delta^{18}\text{O}$ of seawater (and its influence on the $\delta^{18}\text{O}$ of rainfall). Therefore, the lower speleothem $\delta^{18}\text{O}$ values indicate that summer monsoon rainfall increased rapidly through TIII and TIIIa.

The speleothem $\delta^{18}\text{O}$ record for southwest Sulawesi indicates that AISM rainfall may be responding to broad-scale influences, such as changes in regional geography due to sea level rise/fall, and possibly global temperature. With further development, this new record, together with other palaeomonsoon records, will serve to unravel the ocean-atmosphere dynamics influencing tropical monsoon intensity during times when Earth's climate was warming rapidly.

We would like to acknowledge our valued collaboration with the Indonesian Institute of Sciences and their indispensable support. We are gracious to the national park staff and local residents for their knowledge of the area and assistance in fieldwork. This research is supported by Australian Research Council Discovery grant DP1095673 to Mike Gagan, John Hellstrom, Wahyoe Hantoro, Larry Edwards, and Hai Cheng.



Figure 1. National Park guide, Syaiful, shadowed by a stunning cave formation in southwest Sulawesi. (Photo credit: Garry K. Smith)

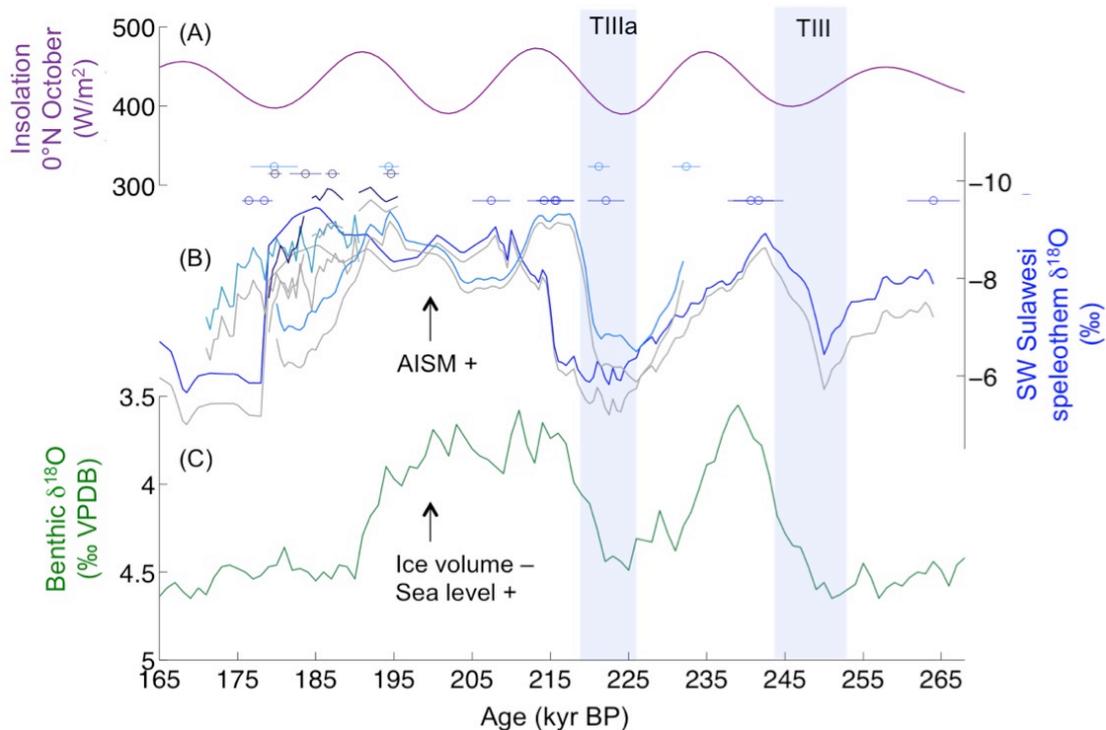


Figure 2. Comparison of southwest Sulawesi speleothem $\delta^{18}\text{O}$ records and changes in insolation and ice volume. (A) October insolation at 0°N (Laskar et al., 2004); (B) Sulawesi speleothem $\delta^{18}\text{O}$ records (grey curves) corrected for ice volume-related changes in seawater $\delta^{18}\text{O}$ (blue tones); U-series dates and error bars (2 sigma) are plotted as colour-coded circles above each record; (C) Benthic $\delta^{18}\text{O}$ stack for the Pacific Ocean (Lisiecki and Raymo, 2005).

Fish otolith geochemistry, environmental conditions and human occupation at Lake Mungo, Australia

Kelsie Long¹, Nicola Stern², Ian S. Williams¹, Les Kinsley¹, Rachel Wood¹, Katarina Sporcic^{1, 3}, Tegan Smith^{1, 4}, Stewart Fallon¹, Harri Kokkonen¹, Ian Moffat¹ and Rainer Grün¹

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

² Department of Archaeology, La Trobe University, Melbourne, VIC 3086, Australia

³ Now at: Department of Archaeology, Australian National University, Canberra, ACT, 0200, Australia

⁴ Now at: Geoscience Australia, PO Box 378, Canberra, ACT 2601, Australia

Fish otoliths from the Willandra Lakes Region World Heritage Area (south western New South Wales, Australia) have been analysed for oxygen isotopes and trace elements using in situ techniques, including the sensitive high resolution ion microprobe (SHRIMP) and dated by radiocarbon. The study focused on the lunettes of Lake Mungo, an overflow lake that only filled during flooding events and emptied by evaporation, and Lake Mulurulu which was part of the running Willandra Creek system. Samples were collected from two different contexts: from hearths directly associated with human activity, and isolated surface finds. AMS radiocarbon dating constrains the human activity documented by five different hearths to a time span of

less than 240 years around 19,350 cal. BP. These hearths were constructed in aeolian sediments with alternating clay and sand layers, indicative of fluctuating lake levels and occasional drying out. The geochemistry of the otoliths confirms this scenario, with shifts in Sr/Ca and Ba/Ca marking the entry of the fish into Lake Mungo, several years before their death, and a subsequent increase in the $\delta^{18}\text{O}$ by $\sim 4\text{‰}$ indicating increasing salinity due to evaporation of the lake. During sustained lake-full conditions, there are considerably fewer traces of human presence. It seems that the evaporating Lake Mungo attracted people to harvest fish that may have become sluggish through oxygen starvation in an increasingly saline water body (easy prey hypothesis). In contrast, surface finds have a much wider range in radiocarbon age as a result of reworking processes, and do not necessarily indicate evaporative conditions, as shown by comparison with otoliths from upstream Lake Mulurulu.

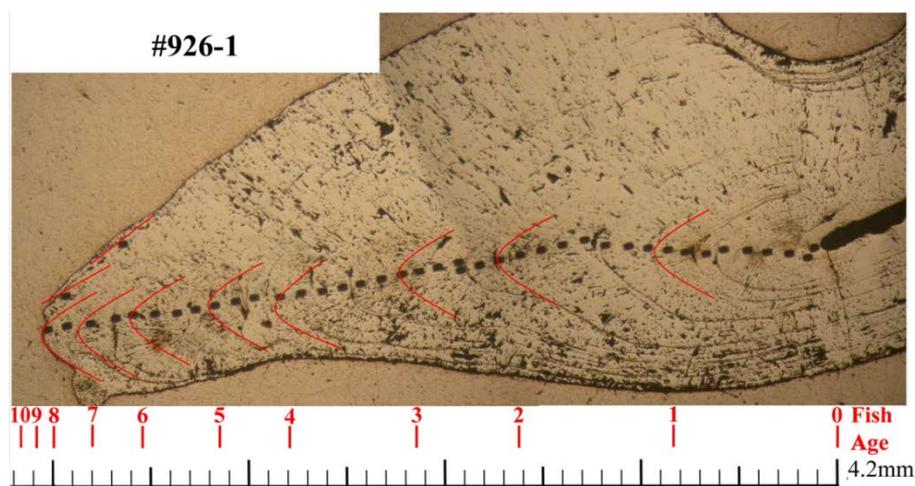


Figure 1. Sensitive high resolution ion microprobe (SHRIMP) analytical spots and age lines for otolith #926-1

Towards a mechanistic understanding of the multiplicative effects of iron and light on algal photosynthesis and iron requirements

Robert Strzepek¹, Philip Boyd² and Alessandro Tagliabue³

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

² Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS

³ Department of Earth, Ocean, and Ecological Sciences, University of Liverpool, UK

The ocean biogeochemical cycles of carbon and iron are inextricably linked at the biochemical level due to the high iron requirement for algal photosynthesis. Improved projections of the future responses of the ocean biota to changes in iron and light supply is particularly relevant to the iron-impoverished Southern Ocean, which plays a disproportionate role in carbon biogeochemistry and global climate. However, algal iron requirements vary widely with iron and light supply, and between species. Thus, we have performed iron-light manipulation

experiments on representative Southern Ocean phytoplankton. These organisms have reduced cellular iron requirements compared to model organisms, and are not subject to antagonistic iron–light co-limitation. We reveal the underlying photosynthetic architecture responsible for this decrease, and use this new information to construct a photophysiological model that encompasses the gamut of photoacclimation strategies, using only parameters that can be readily be measured in the field. Our findings may provide a clearer understanding of how low light and iron supply influences Southern Ocean phytoplankton and enable a more accurate parameterization of biogeochemical models.

Probing the response of Southern Ocean phytoplankton to changes in iron biogeochemistry, light and pH associated with climate change

Robert Strzepek¹, Michael Ellwood¹, Philip Boyd², Bill Maher³ and Brook Nunn⁴

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

² *Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS, Australia*

³ *Institute for Applied Ecology, University of Canberra, Canberra, ACT, Australia*

⁴ *Department of Genome Sciences, University of Washington, Seattle, USA*

Climate change scenarios predict that chemical and physical conditions within the Southern Ocean will vary simultaneously thereby influencing the iron requirement of phytoplankton. In this project the ability of Southern Ocean phytoplankton to respond to these climate-driven changes in iron supply and demand are being determined at a molecular level. We are probing these responses using state-of-the-art genomic, proteomic and isotope techniques in both a laboratory and field setting. The knowledge generated in this project will help elucidate the impacts and feedbacks climate change and ocean acidification will have on Southern Ocean phytoplankton in the future and their ability respond to a changing environment.

Holocene rainfall variability recorded in an aragonite speleothem from Sumatra

Jennifer B. Wurtzel¹, Nerilie J. Abram¹, Michael K. Gagan¹, Wahyoe S. Hantoro², Hamdi Rifai³ and Stephen Eggins¹

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

² *Research Center for Geotechnology, Indonesia Institute of Sciences, Bandung, Indonesia*

³ *Department of Physics, State University of Padang, Padang, Indonesia*

The region in between Asia and Australia is underrepresented by well-dated, high-resolution proxy records covering the Holocene epoch, despite the climatological significance of the area. It is the location of the Indo-Pacific Warm Pool (IPWP), the

largest body of warm water on Earth, which plays an important role in the global distribution of heat and precipitation. This region is also subject to climatic variability from the Indian Ocean Dipole (IOD), the El Niño-Southern Oscillation (ENSO), the Intertropical Convergence Zone (ITCZ) and the Australasian Monsoon (Fig. 1). Understanding how these climate modes have interacted in the past is essential to evaluating the causes of rainfall and drought across the Australasian region, and in particular how they may change in a warming climate.

Though much work has been done to generate proxy records for ENSO and the monsoon, long-term high-resolution reconstructions of the IOD have yet to be developed. A detailed history of rainfall in the tropical eastern Indian Ocean region over the last ca. 14,000 years will contribute to quantifying our understanding of changes in IOD variability at time-scales relevant to society.

To date, we have generated preliminary stable isotope data from an aragonite speleothem collected just south of the equator in western Sumatra, strategically located in the eastern sector of the IOD. This data represents the first stalagmite record of rainfall variability from Sumatra, which, in conjunction with other Indo-Pacific records, may be used to distinguish between the zonal (i.e. IOD, ENSO) and meridional (i.e. ITCZ, monsoon) controls on regional climate.

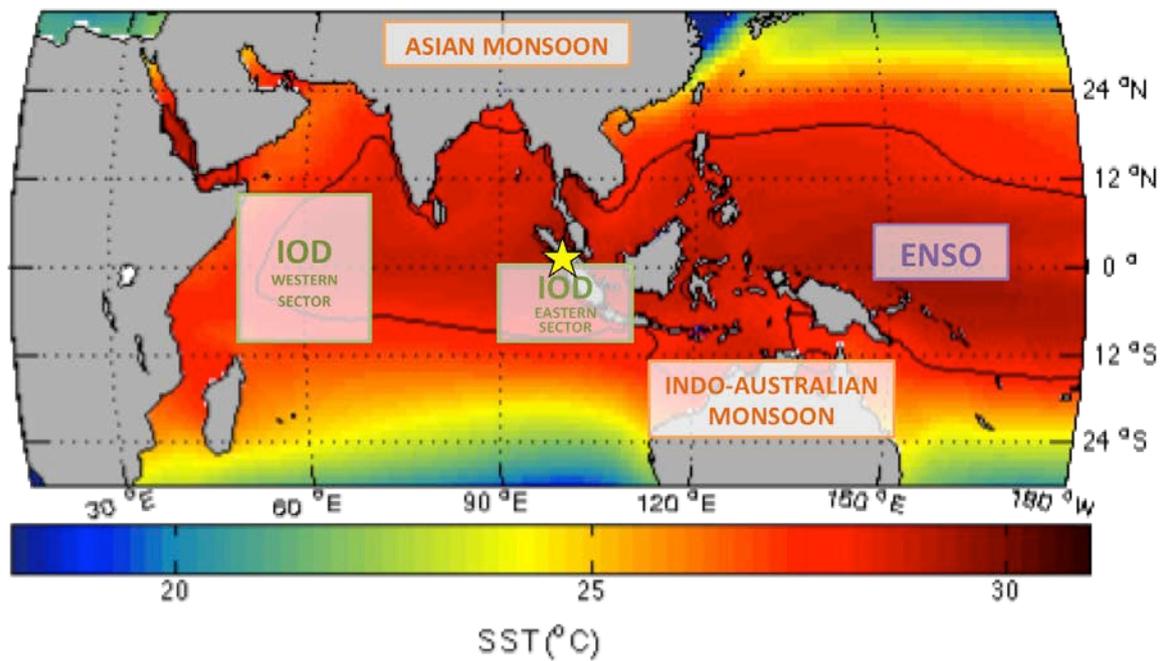


Figure 1. Map of Indo-Pacific region highlighting regional climatic influences. Yellow star indicates study site. Contour denotes 28°C isotherm, IPWP boundary.

Research interests

Jimin Yu

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

- ***Carbon cycle and oceanic carbonate system***: using trace elements and isotopic compositions of marine carbonates together with models to understand interactions between atmosphere, surface and deep oceans, and land biosphere and their roles in the global carbon cycle on various timescales;
- ***Trace elements and isotopes in inorganic and biogenic carbonates***: developing new proxies using marine carbonates to reconstruct oceanic environments such as seawater pH and carbonate ion contents; understanding mechanisms that control the incorporation and variation of trace elements and of isotopes in inorganic and biogenic carbonates;
- ***Ocean circulation changes***: using multi-proxies to reconstruct past ocean circulation changes and their impacts on climate on different timescales.

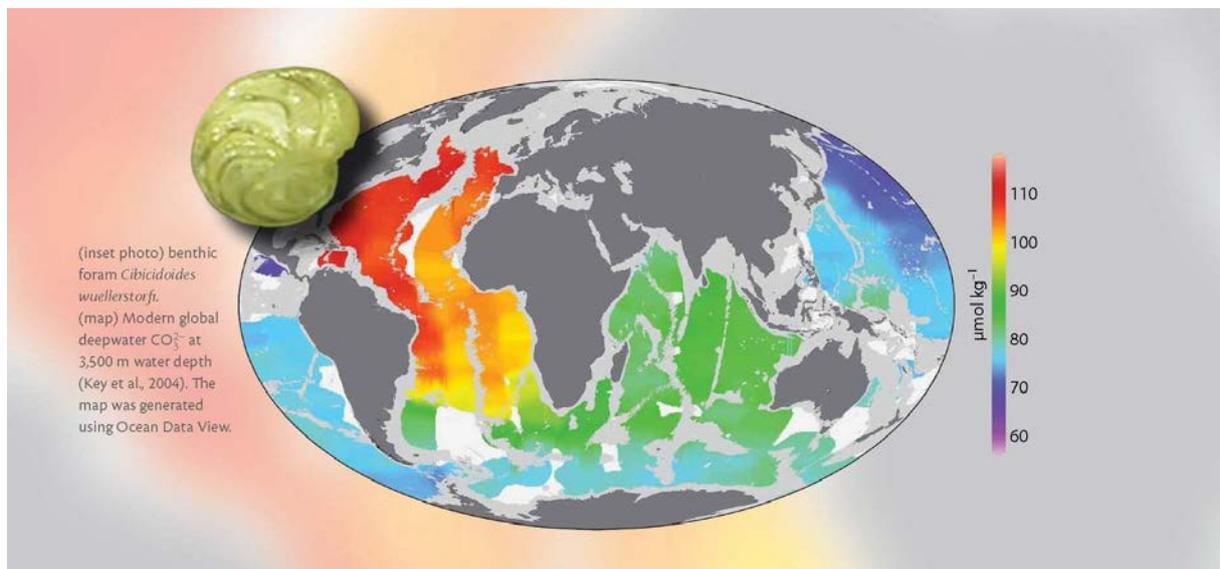


Figure 1. Deep ocean carbonate ion content is linked to ocean circulation and has critical impacts on atmospheric CO_2 on glacial-interglacial timescales. Benthic foraminiferal B/Ca serves as a useful proxy to reconstruct deep water carbonate ion, providing insights into past atmospheric CO_2 changes during Quaternary.

EARTH MATERIALS & PROCESSES

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.

Prof Hugh St C. O'Neill

Associate Director, Earth Materials & Processes

Platinum group elements in felsic rocks

Helen Cocker¹, Prof. Ian Campbell¹, Dr. Jung-Woo Park¹ and Dr. Dianne Valente²

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

² *Whaleback Hub, BHP Billiton, P.O. Box 655 Newman 6753, Western Australia*

Platinum Group Elements (PGE; Ru, Rh, Pd, Os, Ir, and Pt) have very high sulfide melt- silicate melt partition coefficients, making them sensitive indicators of sulfide saturation in magmas. PGE partition more strongly into a sulfide phase and are less affected by alteration than other chalcophile elements so make more ideal components to study to identify the timing of sulfur saturation in an evolving magmatic system. In arc-related intermediate to felsic magmatic systems, which have the potential to produce porphyry deposits, the timing and extent of sulfide saturation relative to volatile saturation may control whether these systems produce economic mineralization and, if they do, whether the deposits are Cu-Au or Cu only.

Using a NiS fire assay isotope dilution method with ICP-MS we have analysed PGE and Re abundances in felsic rocks associated with porphyry deposits. Results from analysis of samples from the El Abra-Pajonal suite and associated porphyry Cu deposit from Chile show a rapid drop in Pt and Pd abundances in samples with MgO values below 2.5 wt. % following sulfide saturation of the magmas. This suggests that although sulfide saturation occurred during magmatic evolution, the amount of sulfide that formed was enough to strip the magma of the PGE and Au but not Cu, allowing the Cu to partition into the volatile phase to form the Cu deposit. Grasberg Pd and Pt abundances are scattered but are typically much higher than in El Abra samples and the decreasing trends seen in El Abra are not visible in the Grasberg suite. Sulfide saturation did not occur at Grasberg and so all the Pd, Pt, Au, and Cu was available to partition into the volatile phase and form a Cu-Au-(Pd) type deposit.

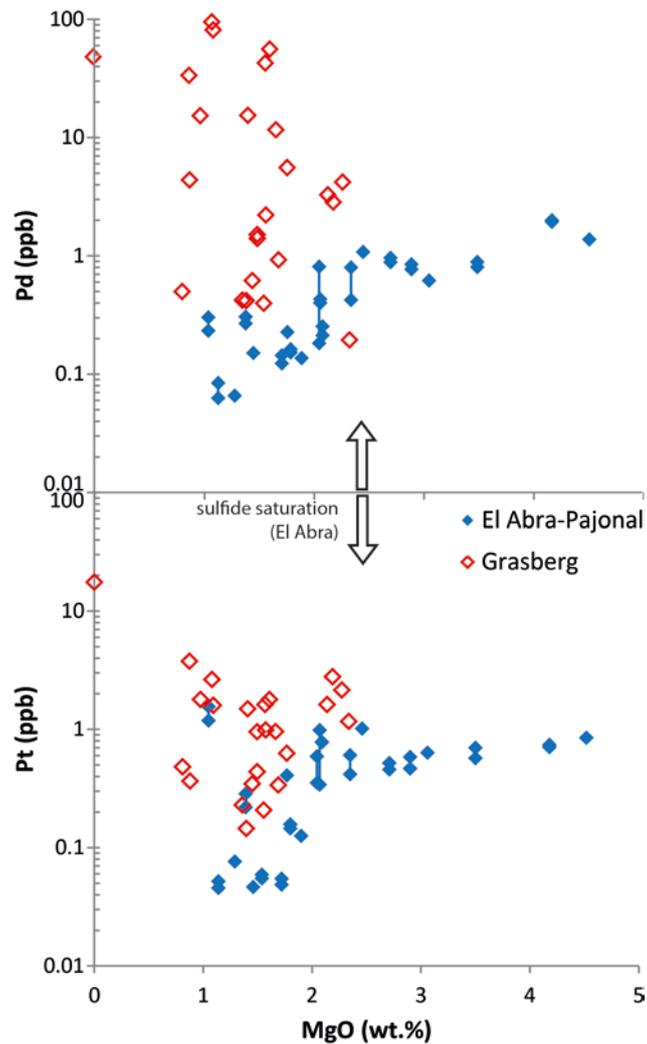


Figure 1. Pd (top) and Pt (bottom) results for El Abra (closed diamonds) and Grasberg (open diamonds) samples plotted against MgO. Vertical lines connect duplicate samples.

Injection-driven swarm seismicity: Implications for the formation of fault-hosted ore deposits

Stephen F Cox

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

Injection experiments and natural examples of swarm seismicity in hydrothermally active settings indicate that swarm seismicity is the characteristic response to injection of large volumes of overpressured fluids into intrinsically low permeability rock. Many types of hydrothermal ore deposits form in overpressured regimes during high fluid flux through active fault zones in the brittle-frictional regime. Accordingly, ore formation and fault slip in these settings is interpreted to involve swarm seismicity.

Injection-driven swarm seismicity is illustrated by injection experiments in granite in the Cooper Basin (SA) (Figure 1), Soultz-sous-Forêts (France) and Basel (Switzerland), and by natural swarm seismicity in hydrothermally active settings (Nový Kostel, Czech Republic; Hakone caldera, Japan). Injection-driven seismicity typically involves repeated sequences of up to many thousands of ruptures with moment magnitude M_w in the range $-1 < M_w < 4$. High seismicity rates are sustained over periods of days to months, and relatively quiescent inter-swarm periods have durations of years to many decades. Individual ruptures within swarms mostly have diameters less than 100 m and slip less than 1mm. Cumulative rupture areas during a swarm episode seldom exceed several km^2 ; maximum cumulative slip is usually less than several tens of millimetres.

A characteristic of injection-driven seismicity is the diffusion-like migration of a seismicity front as the injected fluid pulse, and the boundary of the associated zone of permeability enhancement, migrates away from the injection source at rates up to 100 m/day (Figure 1). Magnitude-frequency relations follow a Gutenberg-Richter law with b-values commonly, although not exclusively, greater than 1. Seismicity rates during injection can be as high as 1000s of ruptures per day, and correlate with fluid injection rate and injection pressure. Swarm termination likely is controlled by depletion of driving pressure in the hydraulically accessible parts of the fluid reservoir. The duration of inter-swarm quiescent periods is likely controlled by rates of fluid pressure recovery in the reservoir.

Relationships between net slip and ore deposit dimensions in faults, and recurrence intervals in natural, injection-driven swarm sequences, indicate that ore formation involves up to several thousand swarm episodes over periods as short as $10^4 - 10^5$ years. Relationships between injected fluid volumes and cumulative rupture areas, or moment release, indicate that individual swarms are driven by injection of $10^4 - 10^5 \text{ m}^3$ of fluid at rates of several tens of litres.s^{-1} over periods of days to weeks (Figure 2). For gold deposits, this involves deposition of up to tens of kg of gold during each swarm episode.

Injection-driven swarm behaviour provides a very dynamic environment for ore deposition involving short-lived, energetic cascades of small rupture events and intervening, much longer quiescent periods. Ruptures within cascades are coupled with sudden changes in fluid pressure and accompanying transient pulses of fast fluid flow. The flow regime involves potentially severe departures from chemical equilibrium, favouring rapid ore deposition.

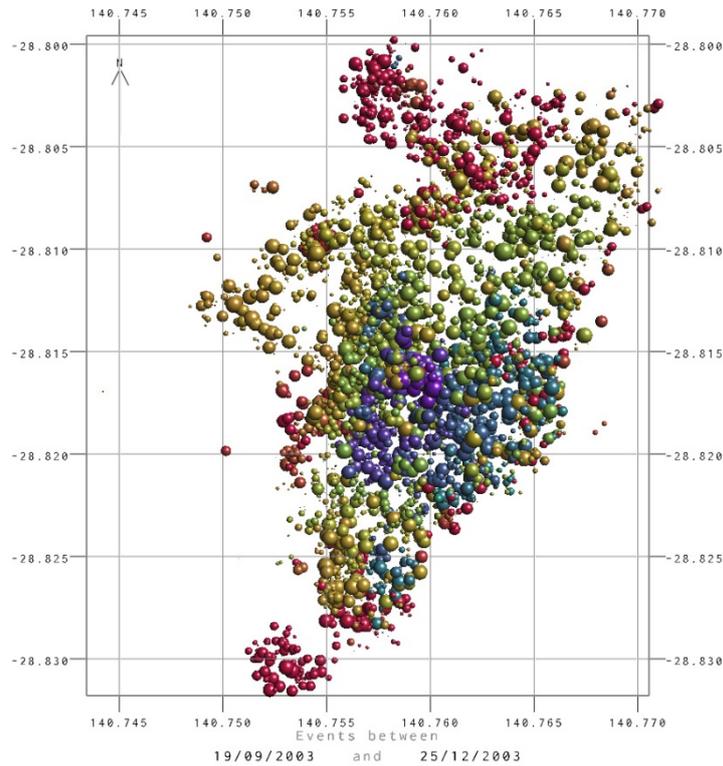


Figure 1. Plan view of microseismicity associated with fluid injection and activation of a gently west-dipping thrust fault at a depth of 4250m in the Habanero well in the Cooper Basin in 2003. Injection of 20,000m³ of water at flow rates up to 40 litres.s⁻¹ induced over 27,000 microseismic events. The main pumping test lasted 10 days. The seismicity front migrated with time away from the injection site. Hypocentres are colour-coded for time, with earliest events being purple-blue and the youngest events being red. Width of field is approximately 2 km. Data courtesy of Geodynamics Ltd.

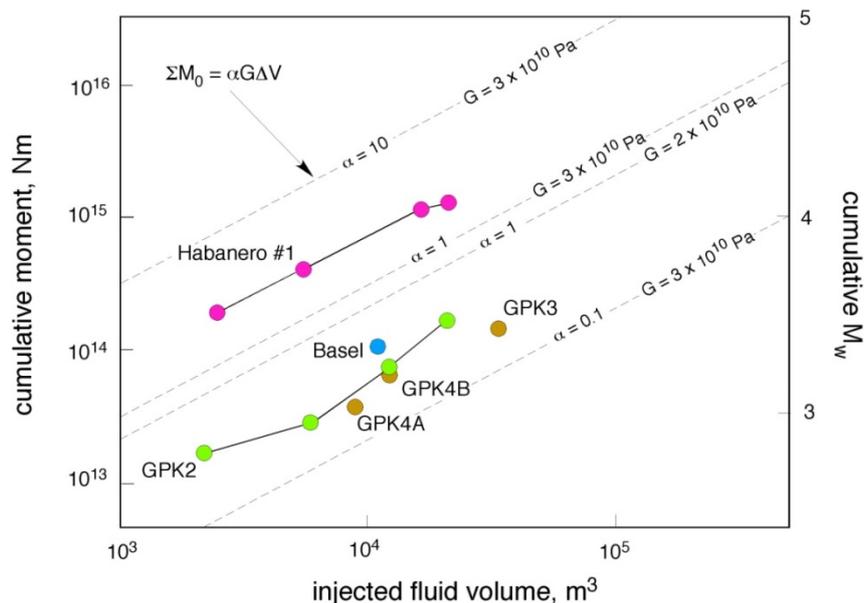


Figure 2. Relationships between injected fluid volume, cumulative seismic moment release and cumulative moment magnitude for swarm seismicity for a number of injection experiments (Habanero #1 in 2003, the Basel injection experiment in 2006, and the GPK series of experiments at Soultz sous Forêts in 2003, 2004 and 2005). The reference lines are for a theoretical relationship between cumulative moment release (ΣM_0) and injected fluid volume (ΔV) and shear modulus (G) for various proportionality constants (α) (after McGarr, 1976).

Injection-driven growth of fracture-controlled fluid pathways in intrusion-related hydrothermal systems: A modeling approach

Stephen F Cox¹, David Beck² and Arnd Flatten³

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

² *Beck Engineering, Sydney*

³ *Beck Engineering, Applied Mechanics Group, Berlin*

Porphyry Cu-Au ore systems, along with many other types of intrusion-related ore systems, form during advective flow of overpressured magmatic-hydrothermal fluids away from crystallizing magmatic bodies. Fluid migration is controlled by hydraulic gradients and permeability enhancement along fracture-controlled pathways generated by injection-driven failure processes.

Coupled hydro-mechanical modelling is being used to gain insights about the generation of fracture-controlled permeability enhancement and fluid pathways in intrusion-related hydrothermal ore systems in response to injection of overpressured fluids into a low permeability rock mass. We are investigating the effects of stress regimes, fluid pressure regimes, fluid production rates, the mechanical and fluid transport properties of host-rocks, and the presence and properties of pre-existing fault networks and lithological contacts on how the geometry and distribution of fluid pathways can evolve with time. We are also exploring how flow rates and fluid pressures evolve in the system and potentially impact on the distribution of ore grades and locations.

We adopt an approach using large-scale, explicit 3D continuum/discontinuum finite element simulations in which a brittle-frictional mechanical code is fully coupled with a hydrology simulation code. The strain softening, dilatant continuum medium contains both large- and intermediate-scale faults with complex 3D shapes and assigned mechanical and fluid transport properties. The models allow tracking of fluid streamlines, evolution of fluid pressures, damage intensity (as a dilation component of the plastic strain tensor) and permeability, as well as measurement of flow rates, flow vectors, displacements and changes in stress magnitudes and stress orientations in response to fluid pressure changes and related deformation. Conventional equations for Darcian flow are solved simultaneously with the equations for deformation and damage. Material and fluid properties can be adjusted to explore sensitivity of simulations to these parameters. Solution of the stress, strain and energy distribution uses an Abaqus solver and the LR constitutive model (Reusch & Levkovich, 2009).

The basic model involves fluid migrating out of a deep level, crystallizing magma body via a permeable (10^{-16}m^2), 500m diameter cupola whose top is at a depth of 5km. The top 3km of crust is a high permeability (10^{-14}m^2), near-hydrostatic pressured medium. At deeper levels, the initial crustal permeability is 10^{-18}m^2 . The initial relaxed fluid pressure is at hydrostatic, but evolves rapidly to an overpressured state when fluid injection starts. The position of the vertical boundaries of the model (>10km from the cupola) remains constant, and the fluid pressure is hydrostatic at this boundary. We have explored fluid production rates of 1 - 100 $\text{m}^3\text{m}^{-2}\text{yr}^{-1}$.

Although the major fracture damage and permeability enhancement is localised around the top of the cupola, a major outcome of the first phase of this project is that it highlights the important role of re-activation of pre-existing faults and lithological contacts as pathways for fluid migration away from the immediate volume of the cupola (Figures 1 & 2). Fault-related fluid pathways can be particularly important for localising the distribution of some high sulphidation epithermal Cu-Au systems, as well as more distal base metal deposits and some skarn-related deposits. Where magmatic-hydrothermal fluids are injected into relatively low permeability rocks (permeability = 10^{-18}m^2) at fluid production rates $> 1\text{m}^3\text{m}^{-2}\text{yr}^{-1}$, outward migration of overpressured magmatic-hydrothermal fluids from their source area inhibits significant downflow of meteoric fluids and subsequent interaction with the magmatic-hydrothermal fluids. The models also indicate that fluid injection leads to substantial surface deformations; in some cases inflation of fluid pressures leads to surface uplift above the cupola, whereas in others, complex displacement fields develop. The kinematics of activated faults plays a key role in governing surface deformations in response to fluid injection.

Ongoing work will investigate effects of host-rock permeability and depth of injection of fluids on flow regimes, as well as interactions between magmatic-hydrothermal fluids and meteoric fluids at shallow levels in these systems.

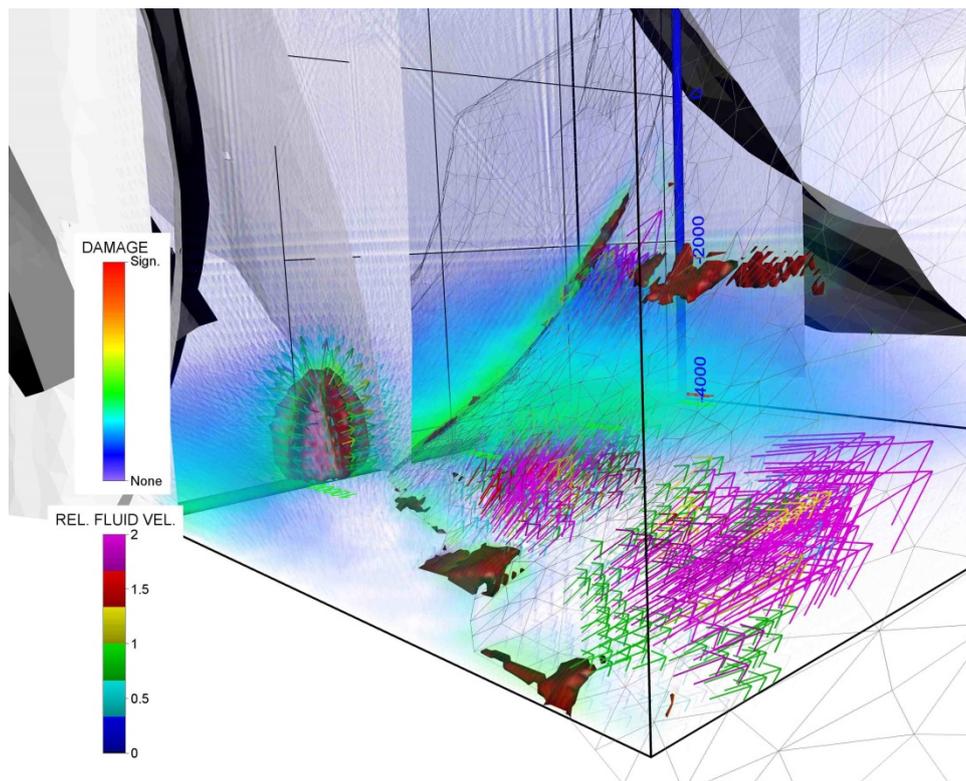


Figure 1. Snapshot of a simulation showing fluid velocity vectors around the source cupola (left-hand side of image) and an adjacent, left-dipping lithological contact. Solid red surfaces outline volumes with high damage associated with slip along the lithological contact. Note the high and very localised fluid flux associated with the damage zones.

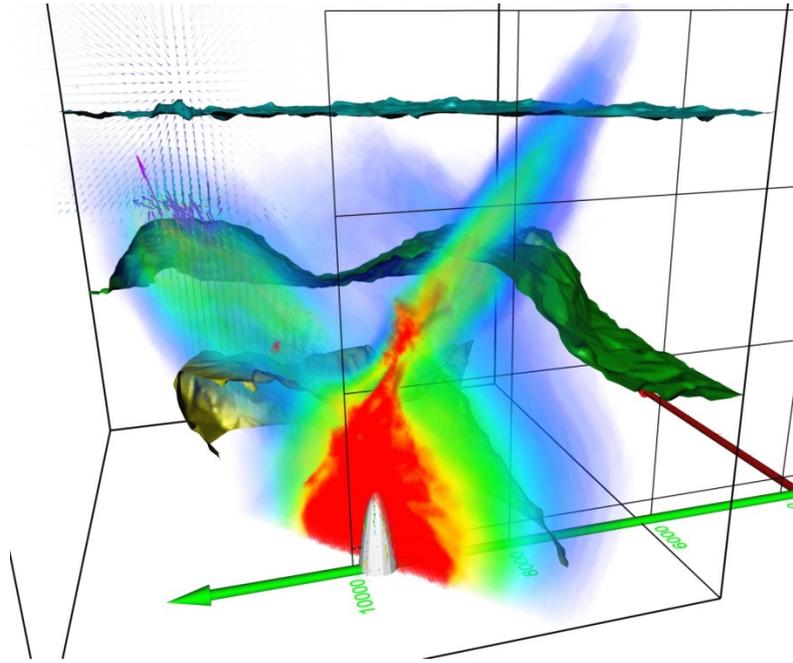


Figure 2. Another simulation illustrating distribution of damage intensity (proxy for permeability) around a source cupola (centre front). Note that fluid pressurization has reactivated two pre-existing faults; one is left-dipping, and the other is right-dipping. Note the local increase in elevation of fluid pressure iso-surfaces (green to gold surfaces) around these faults. Very high fluid flux is associated with the right-dipping fault.

Particle fluidization in fault zones: implications for transitory, rupture-controlled flow regimes

Stephen F Cox¹ and Stuart M Munroe²

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

² *Hill End Gold Ltd*

Fault damage products within the the Roamane Fault (Enga Province, Papua New Guinea) provide insights about the dynamics of fluid flow and flow velocities when fault ruptures breach magmatic-hydrothermal fluid reservoirs. The Roamane Fault locally contains "accretionary" breccias in which rock fragments are mantled by spheroidal overgrowths of hydrothermal minerals (Figure 1). Although none of the rock fragment cores in accretionary spheroids are in contact with each other, the spheroidal, mantled overgrowths typically are in contact with each other. In most cases the mantled aggregates are well cemented together, although remnant porosity can be present locally between the spheroids. At Porgera, one type of accretionary breccia has very Au-rich arsenian pyrite overgrowths. Others have calcite or quartz overgrowths of the core particles. Overgrowth mantles typically comprise elongate crystals that radiate outwards from the surface of the core rock fragment. Concentric growth banding and oscillatory zoning are present in some

hydrothermal mantles (Figures 2 & 3) and provide insights about the dynamics of mineral precipitation.

The distinctive textures of accretionary breccias are interpreted to have formed by fluidization of fault damage products in a transitory high fluid flux regime. Hydrothermal mineral overgrowth of rock fragments occurred while clasts were in a turbulent suspended state during rapid fluid upflow through dilatant fault segments. The breccias record multiple episodes of particle fluidization and indicate that the faults repeatedly provided conduits for transiently high upward flow velocities. Particle size distributions in the Roamane Fault breccias indicate that minimum fluid velocities required for fluidization were approximately 0.1ms^{-1} ; maximum flow velocities were in the range $1\text{-}2\text{ms}^{-1}$ (Figure 4). The maximum flow rates correspond to fluid fluxes in the range $10\text{-}300\text{ l.s}^{-1}$ per metre strike length of fault through dilatant fault apertures up to several tens of centimetres wide. The volumetric fluxes are comparable to, or larger than those associated with fluid injection experiments in low permeability rocks. Flow events were likely triggered by propagation of injection-driven ruptures from an overpressured fluid reservoir. Such high flow rates characteristically induce intense swarm seismicity rather than mainshock-aftershock seismicity in faults. Episodic fast flow can drive significant advective heat transport and promote severe chemical disequilibrium. These conditions provide a very dynamic environment for ore deposition in overpressured, fault-controlled hydrothermal flow systems.



Figure 1. Texture of accretionary pyrite breccia, Roamane Fault, Porgera gold mine, PNG. Field of view is 65mm wide.

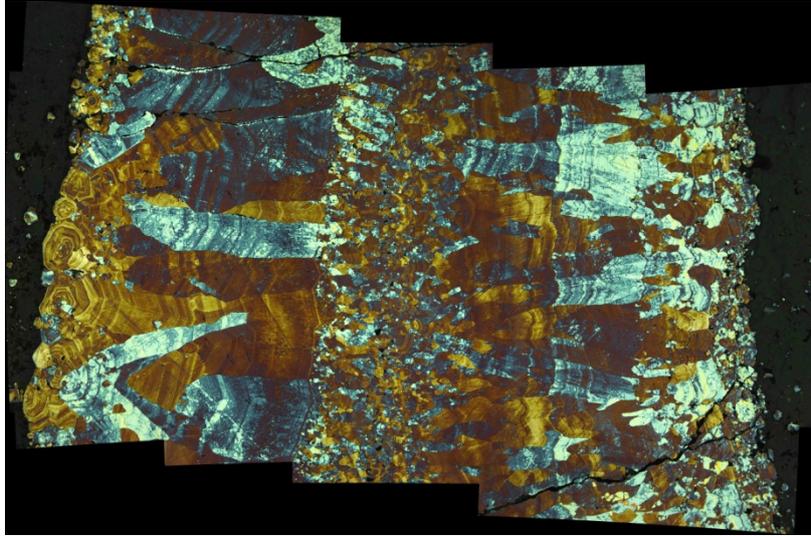


Figure 2. Internal structure of pyrite overgrowth in a pyritic accretionary breccia, Porgera. Note fine-scale oscillatory zoning revealed by etching with NaClO solution. Oldest pyrite overgrowth on core particle is at left. Rim of accretionary pyrite spheroid is at right. Field of view is 6mm wide. The microstructure reveals two main phases of pyrite growth.

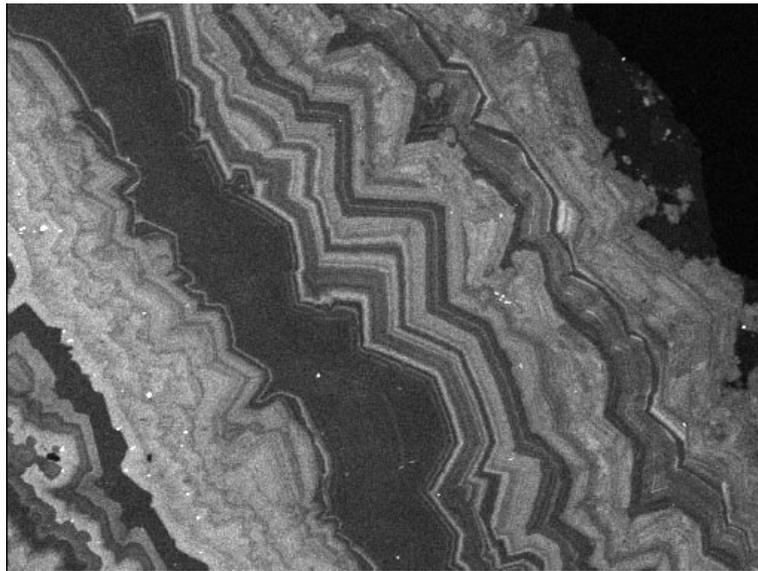


Figure 3. EPMA map of the relative concentrations of Cu within part of a pyritic overgrowth. Oscillatory zoning is well-developed. Field of view is 1mm wide.

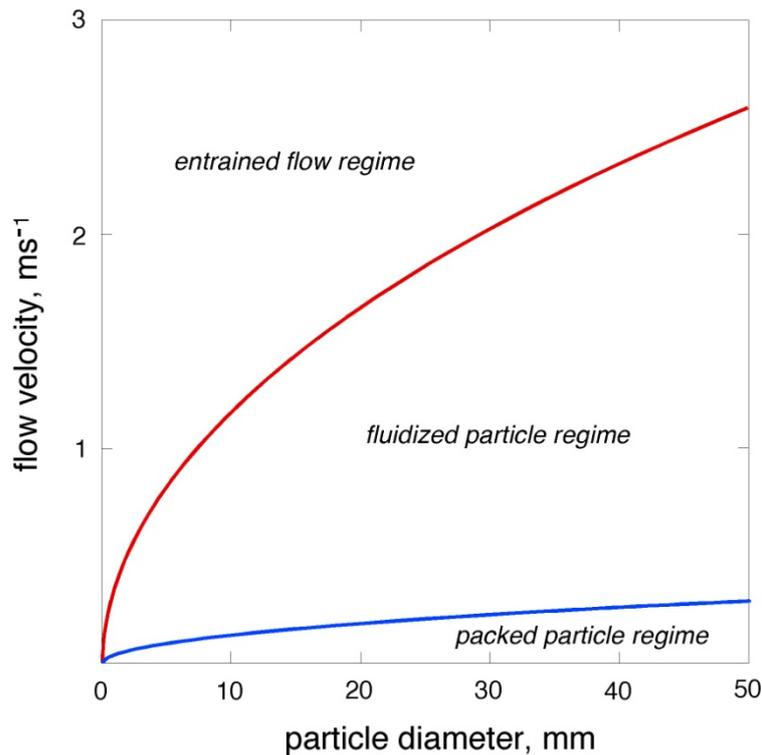


Figure 4. Calculated relationship between the diameters of accretionary pyrite spheroids and fluid velocity in the Roamane Fault zone. Particle diameters as high as 30mm indicate transitory flow velocities as high as 2 ms⁻¹.

The seismic significance of trace amounts of water in olivine

Emmanuel C. David^a, Ian Jackson^a, Ulrich Faul^b, Andrew Berry^a, Harri Kokkonen^a

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

^b Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Boston.

An extensive series of Fourier Transform Infrared Spectroscopy (FTIR) analyses was carried out at RSES, on fine-grained synthetic olivine specimens of Fo₉₀ composition, doped with 0.02-0.1 wt% TiO₂. 'Water' is incorporated into the olivine polycrystals both as hydroxyl chemically bound in the remarkably stable Ti-clinohumite defect, and as molecular water in fluid inclusions. The amount of water that is structurally retained in the defects, and the amount of molecular water that remains from specimen preparation has been estimated quantitatively over the complete history of solution-gelation samples made at RSES over the past years. Along with additional hot-pressings of such samples, the compilation of results provides clear guidelines on preparation of future Ti-doped olivine specimens. Attenuation and shear modulus dispersion (*cf. Jackson et al. research highlight*) will be measured to 1300°C in Pt-encapsulated specimens enclosed within mild-steel jackets.

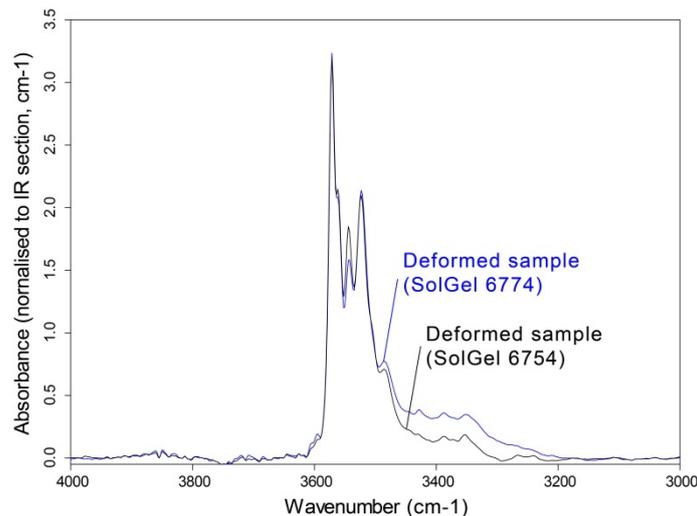


Figure 1. FTIR spectra of two olivine specimens of Fo₉₀ composition, doped with 0.02-0.1 wt% TiO₂, which were both deformed at 1200C. 'Structural Water' is retained in the stable Ti-clinohumite defect, as shown by the two main characteristic peaks observed at 3523 and 3572 cm⁻¹; in addition, the broadband absorption peak observed around 3400cm⁻¹ suggests the presence of modest amounts of 'molecular water'. Both such 'water' contents can be quantitatively calculated from the FTIR spectra.

⁴⁰Ar/³⁹Ar geochronology using Arrhenius plots to date deformation and metamorphism

Forster M.A. and Lister G.S.

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

Whereas U-Pb dates from accessory minerals are with difficulty tied to the history of fabric and microstructural evolution, the same is not true for ⁴⁰Ar/³⁹Ar data from fabric-forming minerals. Significantly, analysis of Arrhenius data from white mica diffusion experiments (i.e. managed temperature-controlled step-heating experiments) appears to allow ages from different components of complex fabrics to be distinguished. We have analysed muscovite-phengite intergrowths in fabrics from the Italian Alps, the Sesia zone (Fig. 1), and been able to distinguish exhumation ages (from the muscovite component produced during depressurization) from ages released by more retentive phengite components (providing a first estimate of the minimum age of prior early high-pressure metamorphism in this tectonic slice. The data are consistent with U-Pb geochronology.

We analysed the ⁴⁰Ar/³⁹Ar data using a program (*eArgon*) and numerically simulated mixing of gas released from multiple diffusion domains. The results suggest diffusion of ³⁹Ar in phengitic white mica involves radically different diffusion parameters in comparison with muscovite.

The merits of this approach allow structural geologists to date movement in ductile shear zones. Here we analysed phengite-muscovite intergrowths in high-pressure metamorphic rocks exhumed in and beneath extensional ductile shear zones during

continental extension. Such materials yield Arrhenius plots with a steepening of slope mid-way during the step-heating sequence. This steepening appears to correspond with steps in which release of argon from phengite components dominate. Enabling the calculation of release patterns for different white mica growth between muscovite to phengite and enables the understanding of mixing patterns in complex apparent age spectra. $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology using Arrhenius data thus appears to allow direct dating of white mica mineral growth during complex metamorphic and deformational histories.

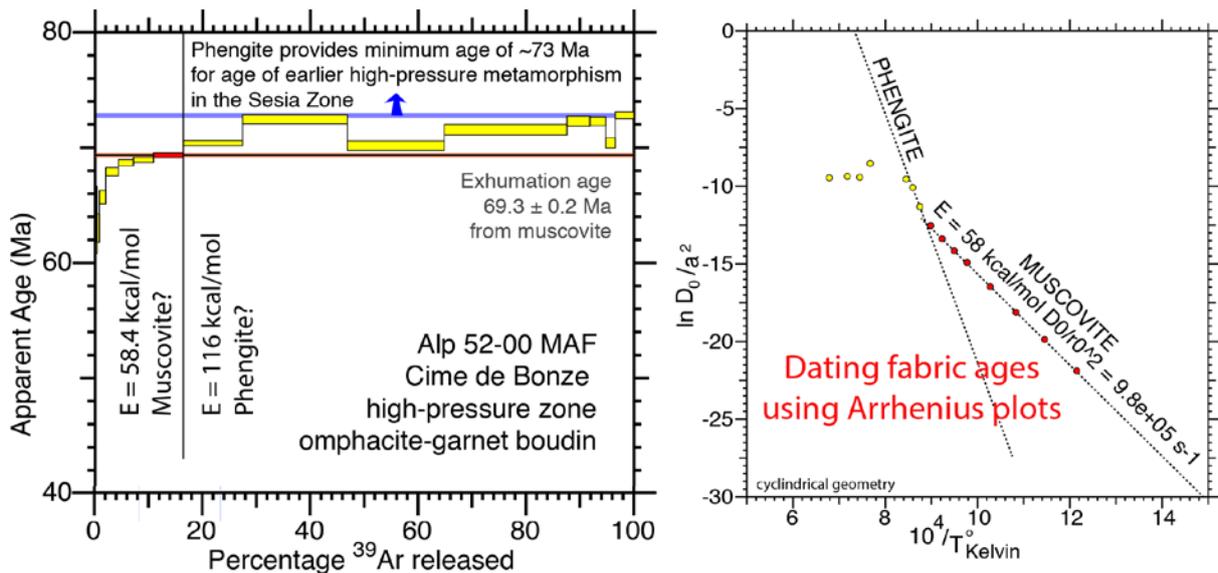


Figure 1. The age spectrum (LHS plot) shows a sequence of steps that can be separated into: i) an asymptotic rise to ~69 Ma due to degassing of the muscovite component; ii) scattered steps between two limits rising to ~73 Ma, due to degassing of the phengite component mixed with ongoing release from muscovite. This suggests exhumation from ~69 Ma with fabric superimposed on phengite grown in an earlier period of high-pressure metamorphism at >73 Ma. The microchemical components of the age spectrum can be distinguished only on the basis of Arrhenius data (RHS plot).

Metasomatism, redox state and diffusion processes in the cratonic mantle

In-situ studies of garnet peridotite xenoliths from the Wesselton and Kimberley pipes, South Africa

Brendan J. Hanger¹, Gregory M. Yaxley¹, Andrew J. Berry¹, Michael C. Jollands¹ and Vadim S. Kamenetsky²

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

² ARC Centre of Excellence in Ore Deposits, University of Tasmania, Hobart, TAS 7001, Australia

Our understanding of how metasomatism occurs in the Earth's mantle can be deepened by investigating mantle peridotite xenoliths to determine the conditions under which their constituent minerals, particularly garnet, formed. Analysis of the

chemical compositions of individual mineral phases is used to determine both the pressure and temperature at which the assemblage formed. The redox conditions of the mantle when the minerals were formed can be determined if the oxygen fugacity (fO_2) is known, which can be calculated based upon the amount of Fe^{3+} relative to Fe^{2+} in the garnet.

We have examined two suites of garnet peridotite xenoliths from the South African Wesselton and Kimberley kimberlite pipes, using electron probe microanalysis (EPMA) and laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) at RSES. EPMA revealed strong major element zonation in two garnet crystals from Wesselton. The distribution of $Fe^{3+}/\Sigma Fe$ in the crystals was mapped using Fe K-edge XANES spectroscopy at the Australian synchrotron (Geology, v. 41, pp 683-686). Diffusion profiles on the same crystals were measured at high resolution using NanoSIMS at the University of Western Australia and it was found that the rims formed in extremely fast (<10 years). Samples from the Kimberley pipe were studied with two different populations of clinopyroxene identified, along with evidence of multiple metasomatic events. The redox state of these samples was determined Fe K-edge XANES spectroscopy at the Australian synchrotron in February 2013 and it was found that the suite samples a very restricted range in pressure and oxygen fugacity that falls within the range expected for the cratonic mantle.

Berry A.J., Yaxley G.M., Hanger B.J., Woodland A.B., de Jong, M.D., Howard D.L., Paterson D., Kamenetsky V.S. (2013) Quantitative mapping of the oxidative effects of mantle metasomatism, *Geology*, 41, 683-686.

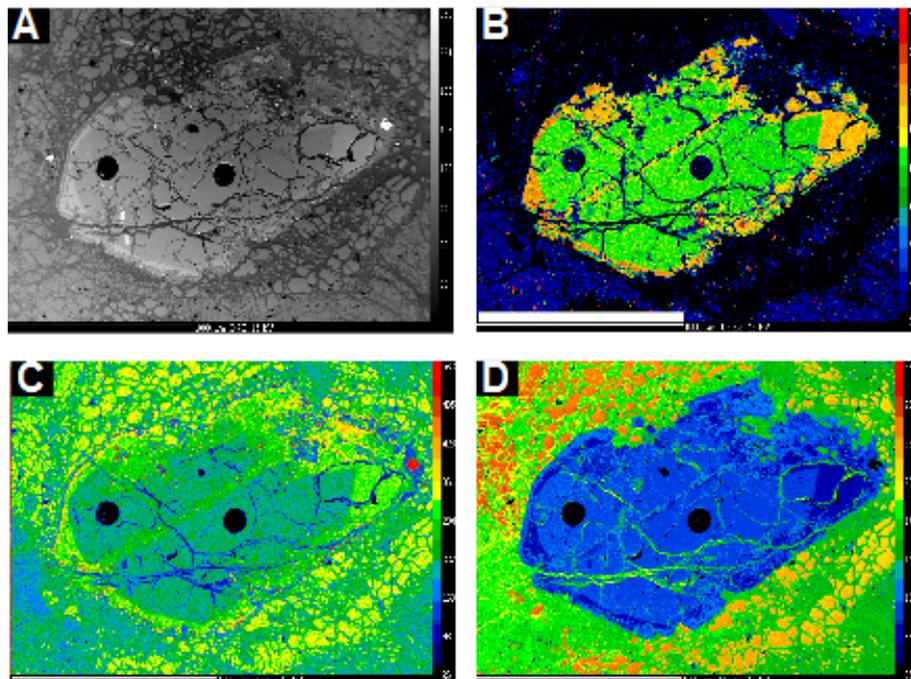


Figure 1. Compositional zonation in garnet from the Wesselton kimberlite. A - backscattered electron image, B - Ca elemental map, C - Fe elemental map, D - Mg elemental map. All images obtained using the Cameca SX100 electron microprobe at RSES.

Correlating fault behaviour with the evolution of microstructure on experimental bare interface faults at conditions simulating increasing depth in the continental crust

K. S. Hayward and S. F. Cox

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

Despite evidence on natural faults that indicate the presence of a narrow slip zone or the occurrence of bare interface sliding, much of the experimental research to date has concentrated on the properties and mechanics of fault gouge at fault interfaces. A study has commenced which aims to address some of the knowledge gaps concerning both the behavior and microstructural development of bare interface faults and the effect that increasing temperature, pressure and the addition of chemically-reactive fluids has on these fault surfaces.

Triaxial experiments are being undertaken using an internally heated, high-pressure gas medium deformation apparatus over a range of experimental conditions. Early results indicate that samples deformed under conditions simulating the upper brittle seismogenic crust, at low temperatures and at effective confining pressures up to 200MPa, show extensive brittle fracturing along the fault surfaces with the development of a distinct damage zone and the formation of fault gouge (Figure 1). With increasing temperatures, however, the extent of the brittle damage zone and gouge production is significantly reduced.

The mechanical behavior of these faults also reveals a greater level of complexity than previously thought with a transition in behaviour with both increasing temperature and also with the addition of a chemically-reactive pore fluid. Although maintaining an essentially brittle, high friction ($\mu \approx 0.7$) sliding behavior under 'dry' or unreactive conditions, multiple distinct transitions from strain hardening to strain weakening have been observed with increasing temperature. Upon the addition of reactive pore fluids at high temperatures, a process that can best be described as 'dissolution-mediated frictional sliding' is activated which involves large post-yield stress drop (via slow slip processes) and subsequent low friction ($\mu \approx 0.3$) sliding.

Over the next 12 months, the observed phenomena described above will be explored further. It is anticipated that results of this research will provide insights into the behaviour of faults at depth and the role that reactive pore fluids play in modifying fault interface properties and stability. On a larger scale, these observations may provide insights about slip mechanisms associated with such phenomena as slow earthquakes and episodic tremor and slip on faults down-dip from the base of the seismogenic regime.

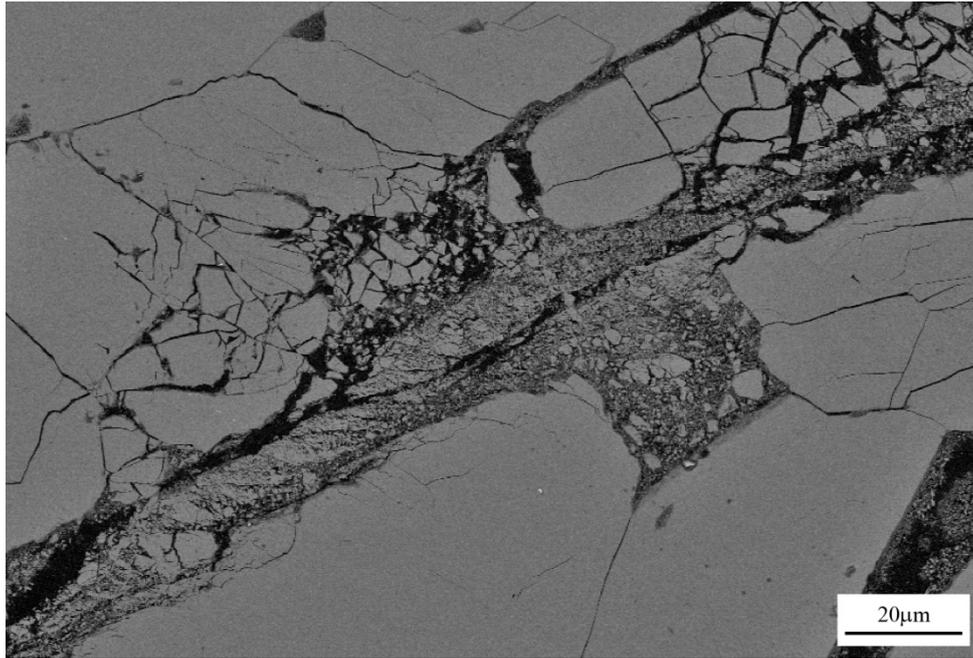


Figure 1. BSE SEM image of a bare interface fault deformed under conditions simulating the upper seismogenic crust. A clear damage zone is evident including the formation of a gouge layer. The ultrafine particles within this gouge layer have diameters of less than 50nm – far smaller than previously suggested ‘grinding limits’. These ultra-fine particles may have significant implications for fault behaviour, especially if subsequently exposed to reactive fluids and dissolution-precipitation processes.

Assessing aftershock risk in a complex earthquake sequence: an evaluation of static Coulomb stress modeling for the Canterbury earthquake sequence

K. S. Hayward, S. F. Cox and M. Salmon

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

When earthquakes occur there is a redistribution of the stresses within the crust. The idea that the stress changes surrounding a ruptured fault trigger subsequent earthquakes provides an appealingly tangible explanation for why earthquake sequences occur and the seemingly irregular location of many of the aftershocks. To those seeking to develop hazard probability and prediction information, static Coulomb stress modeling has, for a number of decades, been used as a method of improving the understanding of the distribution of aftershock activity - although few studies have considered its effectiveness in a rupture sequence where there is significant variation in fault geometry and slip regime.

The complex rupture sequence that occurred during the 2010-2011 Canterbury earthquake sequence was used to assess the effectiveness of static Coulomb stress change modeling for providing useful predictive information for earthquake risk analysis. Modeling was undertaken to gauge the extent to which changes in the

localised stress fields from the 2010 Darfield earthquake contributed to the rupture of the three large ($M_w > 6.0$) subsequent events in the Canterbury sequence and their associated aftershocks. A number of different fault models were used to assess model robustness and sensitivity to changes in input parameters that would influence the timeliness and accuracy of potential risk information. The potential loading of subsequent fault rupture planes from the previous main shocks was also tested for both the modeled large events and smaller aftershocks using the moment tensor solutions for all events $M_w \geq 4.0$.

Results indicate a positive visual correlation between the location of $M_w \geq 3.0$ aftershocks and areas of positive Coulomb stress change (Figure 1). The positive Coulomb stress change on the fault planes of the major earthquakes prior to their rupture suggests the possibility that previous seismicity within the sequence resulted in the advancement of their failure, although rupture cannot be attributed to Coulomb stress change alone.

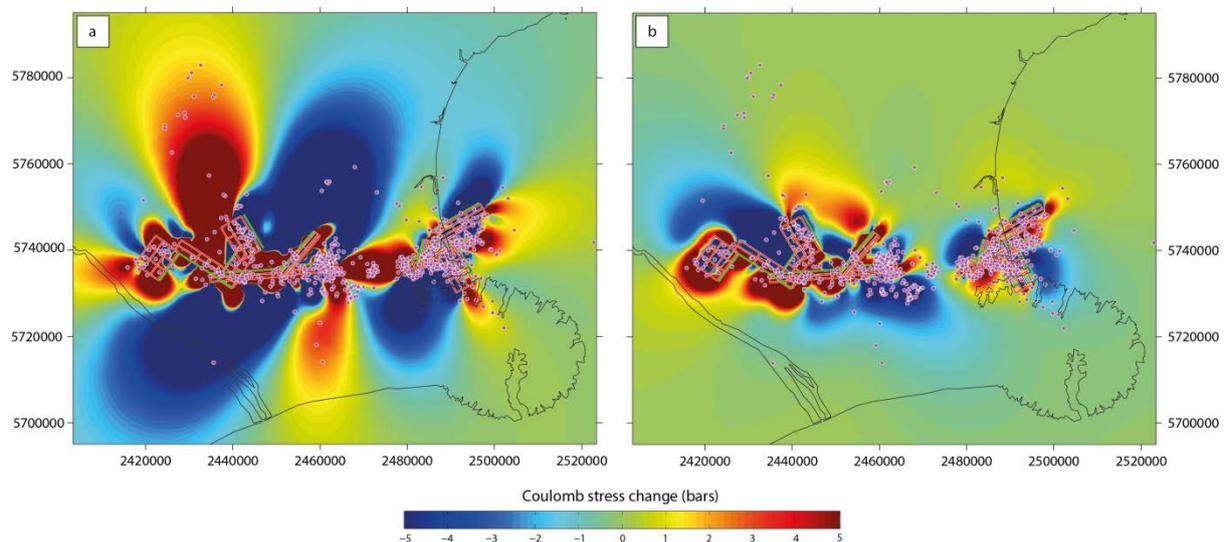


Figure 1. Modeled Coulomb stress change distributions for all major ruptures ($M_w \geq 6.0$) in the Canterbury earthquake sequence for optimally oriented (a) strike slip and (b) thrust receiver faults. The images have been overlaid with the hypocenters of $M_w \geq 3.0$ aftershocks. Areas of increased stress loading, and thus potential rupture, are shown in red and have a reasonably high (>70%) correlation with the observed aftershock distributions.

The onset of anelastic behaviour in fine-grained olivine at high temperature

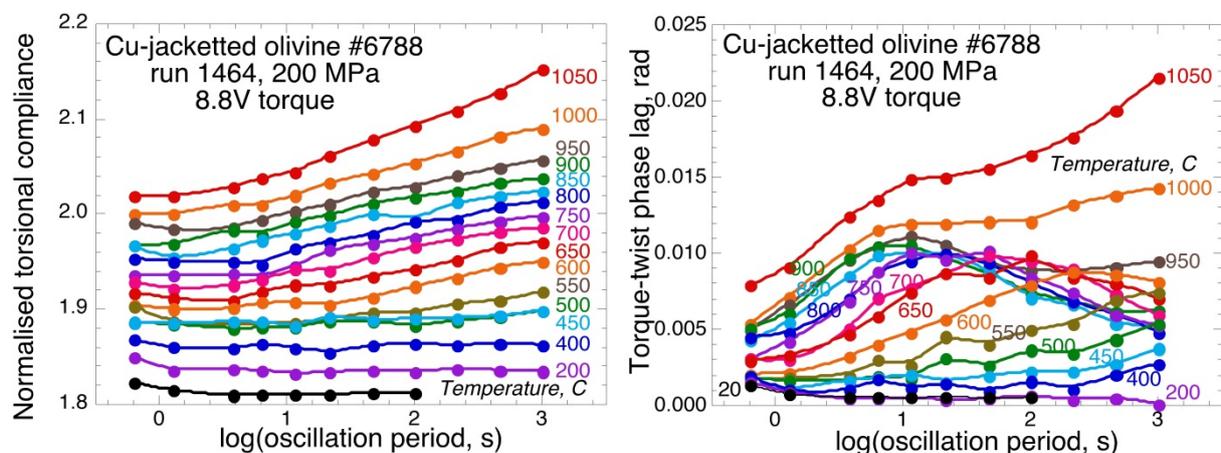
Ian Jackson^a, Emmanuel C. David^a, Ulrich Faul^b, Hayden Miller^a

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

^b Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Boston

A new series of torsional measurements have been performed on fine-grained synthetic olivine polycrystals enclosed within a copper jacket on the Jackson-

Paterson attenuation apparatus, in order to extend the exploratory work of Richard Skelton to higher temperatures. The new data, plotted in the attached figures, provide a very valuable dataset for attenuation and shear modulus dispersion between mHz and Hz frequencies, at high pressure (200 MPa), over the complete temperature range 20-1050°C. The normalised torsional compliance (left) and phase lag (right) are direct analogues for the shear modulus and attenuation of the jacketed olivine specimen, respectively. In addition to a broad, diffusively-assisted grain-boundary sliding regime with mild monotonic variation of attenuation, such experiments reveal a dissipation peak moving systematically to longer periods below 900°C. Such a dissipation peak is plausibly the signature of elastically accommodated grain-boundary sliding. Complementary microcreep tests document the fraction of the viscoelastic strain that is recoverable.



Seismic wave velocity dispersion of cracked and fluid-saturated sintered glass beads

Yang Li¹, Ian Jackson¹, Emmanuel David¹, Doug Schmitt², Harri Kokkonen¹ and Hayden Miller¹

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

² Department of Physics, University of Alberta, Edmonton, Canada

Adopting the same sample fabrication protocol in 2012, new sintered glass-bead specimens with thermal cracks were made. Following a major upgrade, the data acquisition protocols have been thoroughly tested and refined and are now delivering much higher precision - especially in the calibration of the displacement transducers. The forced oscillation experiments have been performed with the upgraded data acquisition system on the attenuation apparatus at low frequencies at the ANU (mHz to Hz). The samples were tested dry, argon- and water- saturated in sequence, revealing a significantly increased shear modulus, especially for water saturation (Fig. Left). The high-frequency test was conducted with the ultrasonic pulse transmission technique at the University of Alberta, using the same

combination of pore fluids and pressures as used at the ANU. The results at MHz frequencies also reveal systematic stiffening of samples due to pore-fluid saturation (Fig. Right). The helium pycnometry was used to determine the grain volume of samples and less than 1% porosity (connected pores) were found for these samples. The mercury porosimetry was conducted by injecting mercury into pore space to determine the pore throat size for these samples at between 0.1 and 1 μm , consistent with microscopic examination. Future collaboration with Lawrence Berkeley Lab by using resonant bar technique promises to provide critical data at intermediate (kHz) frequencies. Together, the three techniques will constrain the frequency dependency of seismic wave speeds from mHz, through kHz, to MHz. The new data will allow a comprehensive assessment of seismic-wave dispersion and dissipation resulting from stress-induced redistribution of pore-fluids within cracked media.

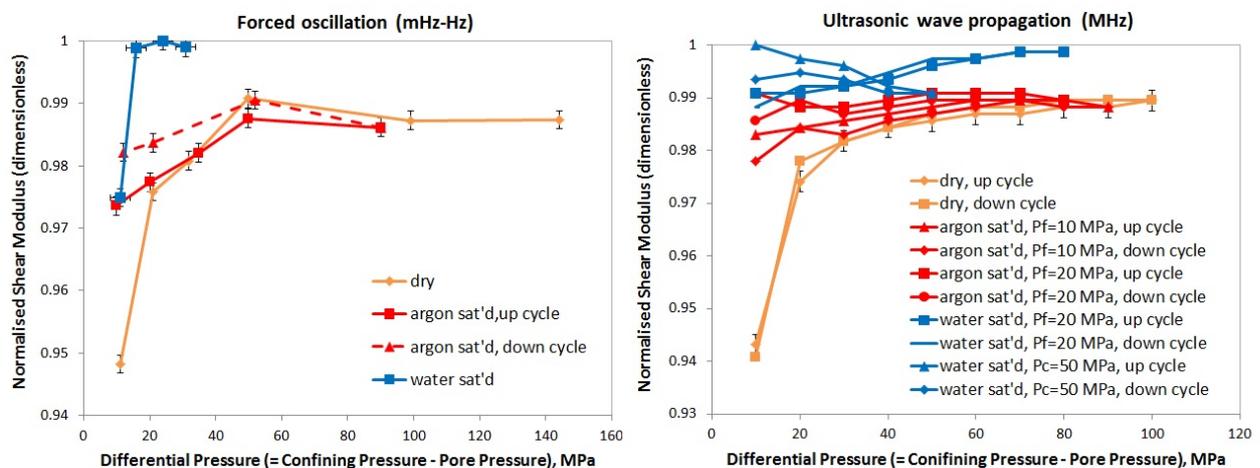


Figure 1. The differential-pressure dependent shear moduli measured at low frequencies (mHz-Hz) with forced oscillation technique and high frequencies (MHz) with ultrasonic pulse propagation technique. The moduli have been normalised to the highest value measured with water saturation.

3D geometry has 4D (3D + time) implications

Gordon Lister

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

Structural geology is that discipline in the Earth Sciences that is concerned with the shape of geological bodies, specifically their 3D geometry and the kinematic evolution that leads to that shape. Along the way the discipline has become interested in fabrics and microstructures, the nature and cause of the actual physical and chemical processes that allow rock deformation to take place, as well as the mechanics involved. To understand deformed and metamorphosed rocks one essential element is to understand when fabric and microstructure forming processes took place, how fast specific things happen, and how long specific events endured.

But what of tectonic processes at a larger scale? Are not subducting lithospheric slabs 3D geological bodies? Can they not be analysed with the same rigour as structural geologists utilise to examine regions, or individual fold and thrust belts?

Here we attempt to apply structural geology to the very large scale, examining the 3D geometry of subducting lithosphere, and showing that this 3D geometry itself may have 4D (i.e. 3D + time) implications in terms of how shapes have evolved, and how these shapes will evolve in the future.

We began by asking a simple question. Are the shapes that we infer at depth capable of being restored to the planet surface without extreme deformation being required to allow these distorted shapes to once again achieve a spherical geometry? To answer this we have written and modified computer code: the Orpheus routines in the Pplates program to manipulate tessellated 2D sheets embedded in 3D space. This allows slabs to be floated back towards the surface using a process we term 'reverse engineering' - a computational process whereby a starting model is obtained that obeys simple constraints, but which process has an indeterminate path by which it can be achieved. The next three paragraphs are from [1] "Ripping and tearing the rolling-back New Hebrides slab" Lister et al. (2012) in Australian Journal of Earth Sciences 59, 899-911.

Consider a wrinkled and crumpled bed sheet. We can reasonably surmise that the sheet once lay flat on the mattress, and that it was relatively undistorted (i.e. not strained by more than a few percent at any one location). Individuals can devise myriad ways to "reverse engineer" the initial geometry of the bed sheet, none of them unique, but all of which obey simple rules as to the end configuration that must be achieved. The same logic applies to the ways we can 'float' a subducted slab from the depths of the asthenosphere, back to the surface of the Earth. On its return journey back to the surface we do not care what path the mesh follows through space and time, so we are able to use whatever computational process we like to achieve this outcome. However we do require that the 'floated' slab be as free from distortion as possible, and that eventually it finds itself once again on the surface of the planet.

To accomplish this the Pplates program utilises some simple geometrical aspects of a distorted mesh, in particular noting that the 2D strain tensor for each mesh face allows two properties to be monitored: a) a scalar mean stress; and b) the deviatoric stress intensity based on the force balance at the mesh-face centroid. If it is possible for a particular 3D geometry for a subducted slab to be floated back to the surface in an undistorted form, a necessary and sufficient condition is that relaxation of accumulated stresses should allow each of the above quantities to become insignificant for each mesh face. It follows that if this condition cannot be achieved, the slab must have stretched and torn or otherwise distorted during its descent. Different hypotheses as to how stretching and tearing could have been accomplished can then be tested by introducing such defects into the slab geometry, and watching how these affect the overall relaxation of stress and distortion.

In-plane relative motion of the mesh nodes also takes place during this process, but these become significant when the slab has been entirely refloated. At this stage we

iteratively relax accumulated strains by considering force balance, summing several spring forces at each node. We then allow viscous drag to attempt to relax the strains in each mesh face, preserving the local conformal structure, minimising local strain buildup while at the same time redistributing strain throughout the mesh. This procedure can be repeated until the balance of forces at each node has been reduced to a negligible value. The resulting strain distribution of the floated slab will indicate the plausibility of a subducted slab geometry, including any postulated rips and tears. To float a subducted slab to the surface we use a 2D triangulated mesh embedded in 3D with each mesh face capable of arbitrary distortions and able to be torn apart from adjacent mesh faces. Elastic springs attach each mesh face centroid to the triangle nodes. The edge nodes are also connected by elastic springs. On the ascent path the slab is persuaded to 'unbend' by defining an average pole for mesh faces clustered around a particular mesh face. A 'force' is imposed on that node, parallel to that direction, and displacement is allowed proportional to curvature, depth, and reduced as the surface becomes proximal, eventually reducing to zero. The direction of motion is always towards the surface. This simple computational device simulates flexural rigidity and although intricate, as illustrated in the movie included as a supplemental file, it works amazingly well. These out-of-plane motions are key to the Orpheus routines in Pplates.

During 2013 code development proceeded, in order to allow more complex shapes to be analysed. As part of the "Banda to Burma" project we are examining the 3D shape of the subducting slab as inferred by previous and current researchers, and assessing the 4D implications of those shapes.

[1] Lister et al. 2012. Ripping and tearing the rolling-back New Hebrides slab. Australian Journal of Earth Sciences 59, 899-911.

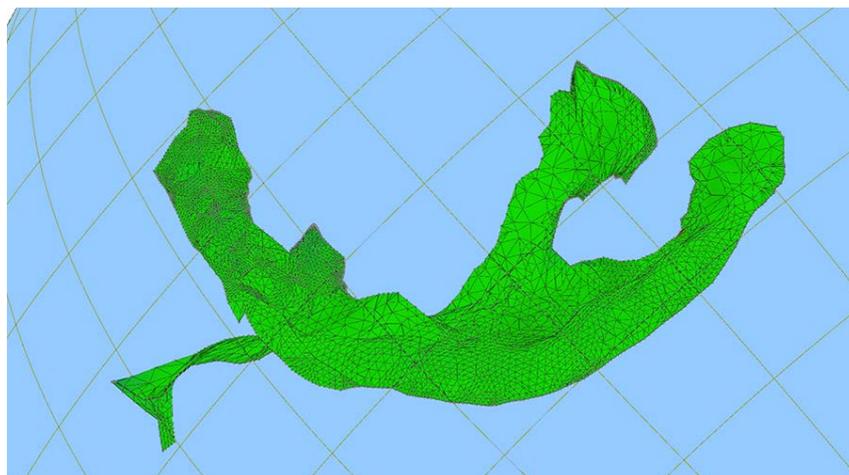


Figure 1. The Burma-to-Banda slab refloat early in the computation, with unconstrained boundary conditions. Green denotes zero areal change, red is under areal compression, while blue is dilational. The side slab tore from India during its northward migration. The 3D shape extends to ~1200 km.

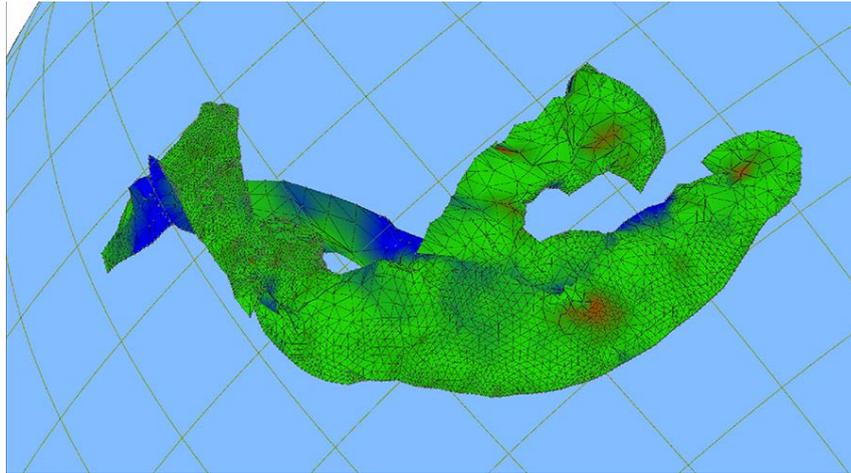


Figure 2. The Burma-to-Banda slab refloat at a later stage in the computation. A major overfold has developed that is a consequence of the starting geometry.

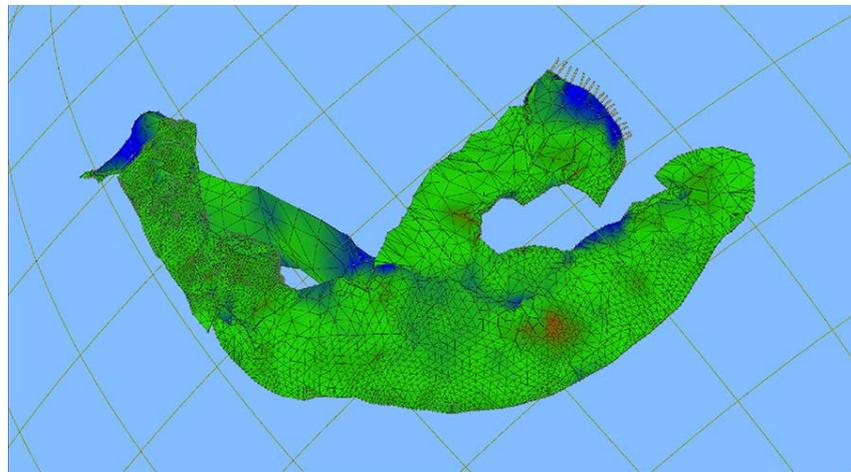


Figure 3. Forces have been applied to the Molucca slab segment to drag it free, to remove the overfold. In plane stresses will then relax to yield the starting geometry.

Complex hydrogen diffusion in forsterite

When diffusion is not as fast as expected

José Alberto Padrón-Navarta ^{1, 2}, Joerg Hermann ¹ and Hugh St. C. O'Neill ¹

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

² Géosciences Montpellier, Univ. Montpellier 2 & CNRS, 34095 Montpellier, France

The singular geodynamic and chemical evolution of the Earth seems to be dictated by the influence of “water” (more specifically hydrogen) on the physical properties of the nominally minerals of the Earth’s mantle. In the most abundant upper mantle phase, olivine, the presence of hydrogen has been shown to significantly modify the timescale of chemical diffusion, plastic deformation, electrical conductivity and the attenuation of seismic waves. Hydrogen is structurally bonded to oxygen forming hydroxyl groups. In olivine there are four different hydrogen substitution

mechanisms, associated with Mg vacancies, Si vacancies, trivalent cations and Titanium substitution, thereafter referred simply as H[Mg], H[Si], H[triv] and H[Ti] respectively. For iron-free olivine (i.e. forsterite) hydrogen diffusion is compensated by a parallel flux of vacancies. The possibility that hydrogen diffusion depends on the associated defect has not yet been considered. We addressed this issue by an experimental investigation of the dehydroxylation of synthetic forsterite with two contrasting hydrous defects: (1) Ti⁴⁺-doped forsterite with H[Si], and H[Ti] as dominant defects and H[Mg] and H[triv] as subsidiary hydrous defects and (2) MgO-buffered forsterite with only H[Si] hydrous defects. For the Ti⁴⁺-doped forsterite. Four features were observed: firstly, the small amount of H[Mg] and H[triv] disappears very quickly. Secondly, Ti is removed from the forsterite lattice by precipitation of a new phase; thirdly, the dehydroxylation of H[Ti] as monitored by the 3525 cm⁻¹ peak proceeds at the same rate as H[Si] monitored by the 3613 cm⁻¹ peak; and fourthly, once H[Ti] reaches zero, the dehydroxylation of H[Si] slows drastically, to rates that are unobservable in the duration of our experiments (1073-1273 K). Whereas the loss of H[Mg] and H[triv] is in agreement with previous estimation of hydrogen diffusion (e.g Demouchy and Mackwell, 2003, Phys. Chem. Minerals 33, 347–355), hydrogen diffusion associated to H[Ti] is up to 1.5 orders the magnitude slower. The dehydroxylation experiment of the MgO-buffered forsterite enables to constrain the diffusivity of H[Si] being up to 3 orders of magnitude slower (see Figure). Hydrogen extraction in forsterite and likely in other NAMs is thus far more complex than previously assumed. Unraveling these complex processes is crucial to understand the deep Earth's water cycle.

Goldschmidt 2013 (Florence)

<http://goldschmidt.info/2013/abstracts/finalPDFs/1911.pdf>

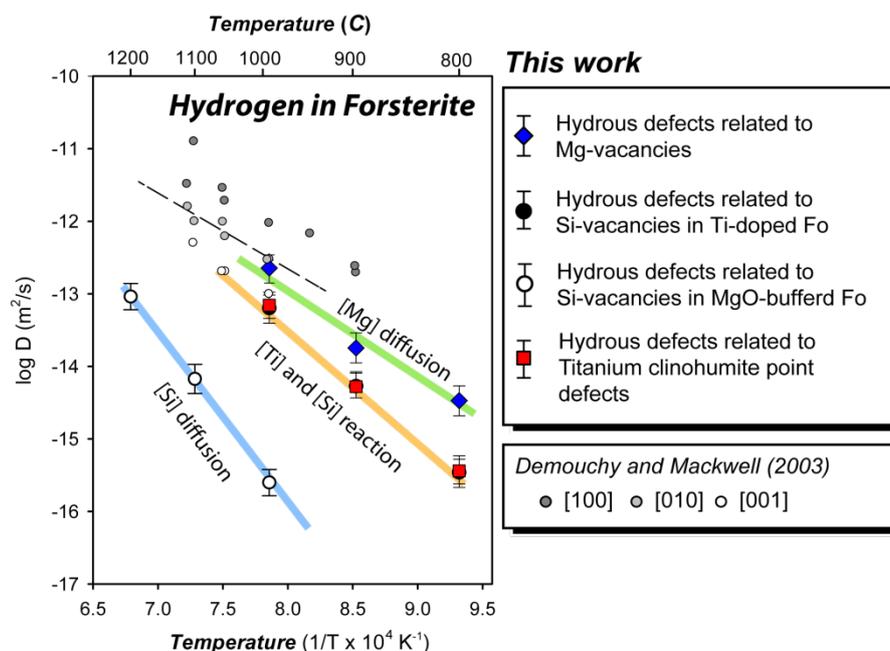


Figure 1. Arrhenius plot summarizing retrieved diffusion coefficient for the three different hydrous defects.

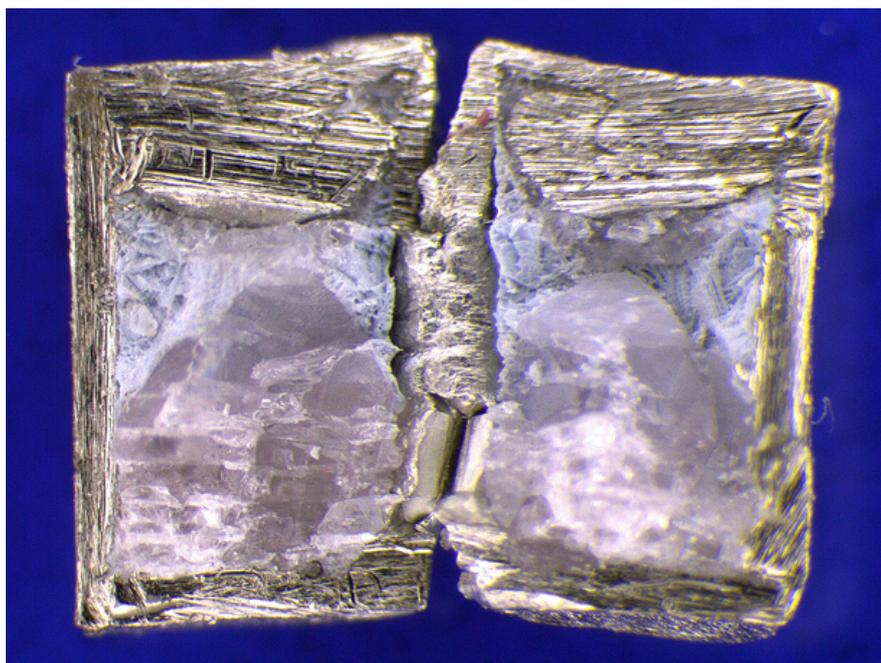


Figure 2. Ti-doped forsterite synthesized in piston-cylinder.

Systematic timing of the events within a Greater Himalayan fold-nappe

Sareh Rajabi¹, Marnie Forster¹, Trevor Ireland¹,

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

The Himalayan mountain belt represents a continent-continent collisional orogeny, which has been studied for many years. However there exist an increasing number of questions as to the formation of this belt and its orogen parallel tectonostratigraphic units, one such question being the processes associated with the formation of region-scale fold nappes. Phojal fold is one of the km-scale fold-nappes in the Greater Himalaya, located in the Kullu valley, NW India. The extreme topography of the Phojal fold region provides a natural cross-section of this structure and reveals a sequence of events within the fold. There are a number of granitoid bodies emplaced at different structural levels within this folded structure and it is these granitoids that we are using to help unravel the questions associated with the formation processes, evolution and exhumation of these significant folds of the Greater Himalaya.

The strategy we are applying to unravel the history of the rocks is to deduce 'Tectonic Sequence Diagrams' in different scales and constrain the timing of the events using different geochronology methods. Complex $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology on white micas, biotites and feldspars and $^{238}\text{U}/^{208}\text{Pb}$ ages on different growth zones in zircons are yielding information on multiple tectonic and thermal events recorded in

the rocks during their complicated tectonic history. Results so far are revealing protolith ages as well as overprinting deformation and metamorphic events from both the $^{40}\text{Ar}/^{39}\text{Ar}$ and $^{238}\text{U}/^{208}\text{Pb}$ techniques (Fig. 1). Mylonitization ages from the structurally highest zone in this fold range between 26 Ma and 37 Ma from $^{40}\text{Ar}/^{39}\text{Ar}$ ages. Whereas $^{40}\text{Ar}/^{39}\text{Ar}$ on the K-feldspars are preserving younger stages of the exhumation at 7Ma while retaining minimum ages for either older metamorphic events or protolith ages at 205Ma and 413Ma. $^{238}\text{U}/^{208}\text{Pb}$ SHRIMP dating on zircon cores and rims have so far given cores ages that range between 2Ga and 230Ma while the rims range between 30Ma and 47Ma. The conclusion has been made that the older ages are from a detrital pre-collision source but the younger ages represent different Himalayan events. The zircon age data using the $^{238}\text{U}/^{208}\text{Pb}$ geochronology have begun to show a correlation with $^{40}\text{Ar}/^{39}\text{Ar}$ ages on different fabric forming minerals from the same zones.

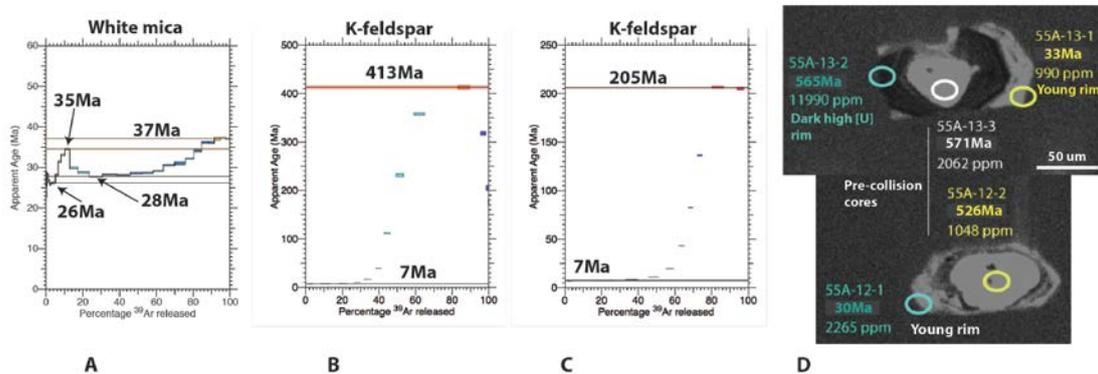


Figure 1: Geochronology results from the structurally highest granitoid body of the Phojal fold. A) $^{40}\text{Ar}/^{39}\text{Ar}$ complex age spectrum from white mica defining a shear fabric ranges between 26.2Ma and 37.1Ma. B) and C) $^{40}\text{Ar}/^{39}\text{Ar}$ age spectra from K-feldspars reveal younger stages of deformation and evidences of per-Himalayan events. D) Example of $^{238}\text{U}/^{208}\text{Pb}$ SHRIMP analysis on pre-Himalayan zircon cores and Himalayan rims.

Experimental investigation of phase relations of carbonate eclogite during subduction: the effects of redox conditions on diamond – carbonate reactions

Prokopy Vasilyev, Greg Yaxley, Joerg Hermann, Andrew Berry and Hugh O'Neill

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

Recycling of carbon during the subduction process is a critical step in the global deep carbon cycle in our planet. Annually around $2.3\text{-}2.7 \times 10^{12}$ mol of carbon are carried by subducting oceanic crust to the deep interior of the Earth (Alt 1998). Part of this carbon is believed to return to the surface during arc volcanism above the subduction zone (Sano & Williams 2012). However thermodynamic models suggest that processes of decarbonation and following formation of diamonds occur at much deeper levels than areas below arc zones (Connolly 2005; Kerrick & Connolly 2006). Also mass balance between subducted carbon in various slab areas and the outcome

carbon-bearing flux of the supra-arc volcanics indicates deep recycling of carbon. (Dasgupta & Hirschmann, 2010). Thus a significant amount of carbon should be retained in the slab and transported to great depths in the mantle, rather than to supply arc volcanoes.

Experimental investigations showed that carbonate in the subducting slab crystallizes as part of carbonate eclogite at $2.0 \text{ GPa} < P < 17 \text{ GPa}$ or carbonate peridotite at $P > 17 \text{ GPa}$ (Dasgupta et al. 2004; Dasgupta et al. 2005; Hammouda 2003; Kiseeva et al. 2013; Yaxley & Brey 2004). The studies on carbonate eclogites reported a variety of solidus temperatures and shapes, due to bulk compositional differences, such as Mg#, Ca# and Na_2O , K_2O , and presence of the water. These phase relations are reasonably well-constrained according PT-parameters, but so far the effects of oxygen fugacity have not been investigated.

My experimental study aims to clarify this effect by investigating the reaction $\text{CaMg}(\text{CO}_3)_2 + 2\text{SiO}_2 = \text{CaMgSi}_2\text{O}_6 + 2\text{C} + 2\text{O}_2$ (dolomite + coesite = diopside + diamond + oxygen) which defines the stability limit of carbonate relative to diamond in carbonate coesite eclogite assemblages (Luth 1993).

Determination of this reaction may be critical to understanding redox state of the Earth's mantle through geological time. Subduction of relatively oxidized carbonate eclogite into the deep upper mantle may cause redox heterogeneity in the mantle, as a result of juxtapositioning of oxidized subducted domains and relatively reduced ambient mantle (Frost & McCammon 2008).

The technical aspects of my research are mainly based on high pressure experiments with variable carbonate eclogite compositions and oxygen fugacity measurements. Development of new technical approaches for oxygen fugacity determination in carbonate eclogite experiments such as PGE based redox sensors and quantitative *in situ* XANES and flank method measurements of $\text{Fe}^{3+}/\Sigma\text{Fe}$ in garnet are among the principal aims of my research.

Recent series of experiments with compositionally variable carbonate eclogites were conducted to constrain the investigated reaction at $P=3.5\text{-}6 \text{ GPa}$ and $T=900\text{-}1300^\circ\text{C}$. The solidus for $\text{EA1}+10\%\text{Ca,MgCO}_3$ at $P=35 \text{ kbar}$ was determined at temperatures between 900 and 950°C . Subsolidus runs at $T=900^\circ\text{C}$ and $P=35 \text{ kbar}$ estimated the coesite + Ca-Mg carbonate = diopside-rich clinopyroxene + C + O_2 reaction position on P-T space.

The relative oxidation state of carbonate eclogites in these experiments was determined using Fe-Pd alloys as a $f\text{O}_2$ sensors. Use of redox sensors (Ir, Pd metals) allows determination of the $f\text{O}_2$ in the eclogite assemblage due to the reaction



(Hedenbergite + Kyanite = Grossular + Fe in Fe-Pd (Fe-Ir) alloy + coesite + O_2).

At given temperature and pressure, the oxygen fugacity correlates with the activity of iron in Fe-Pd (Fe-Ir) alloy. The accurate estimation of iron activity depends on the

value of activity coefficient of iron. As results of these experiments the pressure effect on the value of activity coefficient was discovered.

At this moment experiments with controlled fO_2 and Fe-doped alloy reversing technique, which is used for the first time, shows promising results on estimation of Fe activity coefficient in alloys at high pressures and determination of redox state equilibrium in experimental runs.

However determination directly from the experimental run products of the Fe^{3+} content of garnet (most likely present as the component andradite $Ca_3Fe^{3+}2Si_3O_{12}$) will allow to development of a novel oxybarometer for the whole range of natural eclogites.

This is analytically non-trivial as calculation of garnet Fe^{3+} content based on stoichiometry from electronprobe analyses has been shown to yield large errors (Canil and O'Neill, 1994). The only available microbeam techniques suitable for this application are (1) the synchrotron based Fe K-edge XANES method (Berry et al. 2010) and (2) the electron microprobe based flank method (Höfer and Brey 2007).

Synchrotron based Fe K-edge XANES method depends on the establishment of an empirical calibration curve, which relates the ratio of the intensity of post-edge features in the Fe K-edge XANES spectra of a series of standard garnets (Berry et al. 2010). Use of XANES for determination of Fe^{3+} content of experimental eclogite garnets has not yet been established but will require eclogite garnet standards with well known $Fe^{3+}/\Sigma Fe$ ratios (with the wide range of ratios) determined independently by other techniques. At this stage I have chosen 15 natural eclogite garnets as potential standards and these are being analyzed by Mössbauer spectroscopy in Frankfurt, Germany by Alan Woodland. High dependence of XANES technique for eclogite garnets on the composition of natural garnet standards requires the cross-checking of my experimental samples with over small resolution techniques, such as the flank method

Flank method is based on FeL X-ray emission lines and was developed for garnets using numbers of well-characterized synthetic and natural garnet standards. This way, $Fe^{3+}/\Sigma Fe$ can be determined on microprobe with micron-scale beam size and high precision.

Alt, J. C. (1998). Very Low-Grade Hydrothermal Metamorphism of Basic Igneous Rocks. In *Low-grade metamorphism* (pp. 169–201). Oxford, UK: Blackwell Publishing Ltd

Berry, A.J., Yaxley, G.M., Woodland, A.B., Foran, G.J., (2010) A XANES calibration for determining the oxidation state of iron in mantle garnet. *Chemical Geology* 278, 31–37.

Canil, D., O'Neill, H.S., Pearson, D.G., Rudnick, R.L., McDonough, W.F., Carswell, D.A., (1994) Ferric iron in peridotites and mantle oxidation-states. *Earth and Planetary Science Letters* 123, 205–220.

- Connolly, J. (2005). Computation of phase equilibria by linear programming: A tool for geodynamic modeling and its application to subduction zone decarbonation. *Earth and Planetary Science Letters*.
- Dasgupta, R., & Hirschmann, M. M. (2010). Earth and Planetary Science Letters. *Earth and Planetary Science Letters*, 298(1-2), 1–13.
- Dasgupta, R., Hirschmann, M. M., & Dellas, N. (2005). The effect of bulk composition on the solidus of carbonated eclogite from partial melting experiments at 3 GPa. *Contributions to Mineralogy and Petrology*, 149(3), 288–305
- Dasgupta, R., Hirschmann, M. M., & Withers, A. C. (2004). Deep global cycling of carbon constrained by the solidus of anhydrous, carbonated eclogite under upper mantle conditions. *Earth and Planetary Science*
- Frost, D.J., McCammon, C.A. (2008) The redox state of earth's mantle. Annual Review of Earth and Planetary Sciences 36:389-420
- Hammouda, T. (2003). High-pressure melting of carbonated eclogite and experimental constraints on carbon recycling and storage in the mantle. *Earth and Planetary Science Letters*.
- Höfer, H.E., Brey, G.P. (2007) The iron oxidation state of garnet by electron microprobe: its determination with the flank method combined with major element analysis. *American Mineralogist*, 92, 873-885.
- Kerrick, D. M., & Connolly, J. (2006). Modeling open system metamorphic decarbonation of subducting slabs - Gorman - 2006 - Geochemistry, Geophysics, Geosystems - Wiley Online Library. ... *Geophysics*.
- Kiseeva, E. S. (2012) Experimental study of carbonated mid ocean ridge basalt at 3.5-21 GPa - implications for the Earth's deep carbon cycle. PhD thesis. Canberra, Australia.
- Luth, R.W., 1993, Diamonds, eclogites, and the oxidation state of the Earth's mantle: *Science*, v. 261p. 66-68
- Sano, Y., & Williams, S. N. (2012). Fluxes of mantle and subducted carbon along convergent plate boundaries. *Geophysical Research Letters*, 23(20), 2749–2752.
- Yaxley, Gregory M, & Brey, G. P. (2004). Phase relations of carbonate-bearing eclogite assemblages from 2.5 to 5.5 GPa: implications for petrogenesis of carbonatites. *Contributions to Mineralogy and Petrology*, 146(5), 606–619.

Xenoliths, XANES and redox-related processes in the cratonic lithosphere

GM Yaxley¹, AJ Berry¹, AB Woodland², BJ Hanger¹ and VS Kamenetsky³

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

² *Institut für Geowissenschaft, Universität Frankfurt, Germany*

³ *ARC Centre of Excellence in Ore Deposits, University of Tasmania, Hobart TAS 7001, Australia*

The oxygen fugacity (fO_2) of peridotite upper mantle is predicted to decrease with increasing pressure because of molar volume changes of redox buffering reactions in peridotitic assemblages [1].

Fe K-edge XANES spectroscopy can now be routinely used to measure $Fe^{3+}/\Sigma Fe$ (where $\Sigma Fe = Fe^{2+} + Fe^{3+}$) in garnet from peridotite xenoliths [2]. Combined with conventional thermobarometry and experimentally calibrated oxybarometers [1] this enables rapid (30 min. acquisition), precise ($\pm 0.1 \log_{10}$ units) fO_2 determinations at micron-scale spatial resolution, as well as quantitative mapping of the distribution of Fe^{3+} in garnet crystals [3].

We have used the XANES technique [2] at the X-ray Fluorescence Microscopy beamline of the Australian Synchrotron to investigate fO_2 -depth variation in the Siberian Craton (Udachnaya East and Obnazhennaya kimberlites), the Slave Craton (Panda kimberlites) and the Kaapvaal Craton (Kimberley and Wesselton kimberlites).

In the Siberian and Slave cratonic lithosphere the fO_2 of peridotite xenoliths decreases with depth to $D \log_{10} fO_2^{[FMQ]}$ of ≈ -4 to -5 at ≈ 200 - 220 km [1,4]. Such values approach the limiting Fe-Ni precipitation curve. Metasomatic events however, have locally perturbed this trend, and lead to oxidation by 1-2 \log_{10} units [3,4]. In the case of Wesselton, we mapped the Fe^{3+} distribution in compositionally zoned garnets, demonstrating that metasomatic overgrowth rims grew at $fO_2 > 2 \log_{10}$ units higher than the cores [3] only a very short time before eruption.

Redox conditions in the deep lithosphere are in general too reduced for carbonate melt stability [1,5], unless carbonate activity is substantially reduced by other components (silicates, halides etc).

[1] Stagno et al. (2013) Nature doi:10.1038/nature11679;

[2] Berry *et al.* (2010) Chem Geol 278, 31-37;

[3] Berry *et al.* (2013) Geology, 41, 683-686;

[4] Yaxley *et al.* (2013) Lithos 140-141 (142-151);

[5] Woodland & Koch (2003) EPSL 214, 295-310.

EARTH PHYSICS

Introduction

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

This year saw the completion of the second full year of the ARC Centre of Excellence in Climate System Science, with one of its 5 university nodes in the Earth Physics area of RSES, focusing largely on ocean modeling. Academic staff joining Earth Physics in 2013 are Dr S. Allgeyer (Natural Hazards), Dr D. R. Davies (Mantle dynamics), Dr J. Dettmer (Mathematical Geophysics), Dr Y. Dossman (Geophysical Fluid Dynamics), Dr J. Stipcevic (seismology), Dr C. Stippl (Seismology) and Dr B. Gayen (Geophysical Fluid dynamics). Staff departing during the year were Mr Geoff Luton, Dr N. Darbeheshti, Dr S. Pozgay and Dr N. Rawlinson, the latter of whom took up a position as Chair of Geophysics at the Univ. of Aberdeen, UK. Three EP staff also accepted offers under the ANU early retirement incentive scheme and will retire at the end of 2013 or early 2014. Professional staff Mr. A. Beazley will retire after 27 years service and Ms. S. Kluver after more than 5 years service. Prof R. Griffiths will formally retire in early 2014 after an academic career spanning more than three decades at RSES, including more than 15 years as head of the GFD group, 4 years as Associate Director for EP, and six months as Interim RSES Director. We wish all departing staff well in their future endeavours and look forward to a continued associated as school visitors.

Dr Gayen was awarded an ARC DECRA Fellowship during the year and an AIP award for outstanding Ph.D thesis. Dr Yossman was awarded the thesis prize for physics (Prix Paul Sabatier Physique) by L'Académie des Sciences de Toulouse. Ph.D. student A. Morrison submitted her thesis and moved to a post-doctoral research position at Princeton University, USA. Earth Physics staff were successful in applications for several new ARC Discovery and Linkage projects, during the year.

In **Seismology** a series of field experiments have been completed in the last year arising out of various projects including ARC Discovery AuScope. During the year Staff in Seismology and Mathematical Geophysics and Geodesy continued with contributions to building national infrastructure through various programs supported through AuScope, a national effort in constructing Earth Science Infrastructure. During the year efforts were renewed in the areas of Geodynamics and Mantle Dynamics through new projects led by Drs. Iaffaldano and Davies respectively. In other seismological studies of the deep interior Dr Tkalcic, Prof Sambridge and students published a study containing the first seismological evidence supporting time dependent differential rotation of the Earths inner core with respect to the mantle. As part of an outreach program led by Drs. Balfour and Salmon, 40 seismometers were installed in High schools around the nation, with data flowing via ANU to an international data centre in real time. During the year this program

received national recognition by way of 1st place in Education category of the Australian Innovation award.

In **Geophysical Fluid Dynamics** the energetics and dynamics of convection continues to be a major focal point. Two different modes of convection have been investigated: classical Rayleigh-Bernard convection and horizontal convection. In Rayleigh-Bernard convection, new insights into an age-old problem have been obtained through a full understanding of energetic pathways. Horizontal convection continues to be of interest for geophysical fluids (such as the ocean) and the transient energetics and dynamics of this mode of convection have been used to clarify the role of nonlinear mixing in partially driving the circulation of the ocean. Numerical ocean models have been used to transfer this knowledge into understanding the ocean's response to climate change.

Circulation in the Southern Ocean and its likely response to future change has been investigated using a hierarchy of numerical models. A major focus of this research has been to understand the role of eddies, jets and other fine scale processes in the Southern Ocean. Under changing forcing, these fine scale features are the primary mode of response of the system, and help to stabilize the large-scale currents. The interactions of jets with topography at the bottom of the ocean has revealed new modes of oceanic variability, and the extension to coupled ocean-atmosphere models extends fundamental understanding into the predictive regime. A major goal of this program is to continue to develop high-resolution global ocean-climate models with collaborators via the ARC Centre of Excellence for Climate System Science.

In **Mathematical Geophysics** research has been ongoing in the area of nonlinear inverse problems and development of Computational Earth imaging and more general inference problems. In 2013 the focus has been on computational statistical approach to various data inference problems. The AuScope inversion laboratory continued development of open source computer software for data inference and seismic imaging. Release of these codes to the community is scheduled for late 2013 through a dedicated web portal. The inversion laboratory is an AuScope supported venture whereby scientific computer software is developed for the geoscience community implementing advance algorithms for nonlinear inversion applied to a range of Earth science areas.

In **Geodesy and Geodynamics** research has been ongoing in areas of glacial isostatic adjustment, mass balance change in polar regions, sea level studies and the use of satellite observations to study changes on Earth. GPS fieldwork was undertaken in eastern Indonesia by Drs McClusky and Koulali as part of an ARC Linkage project to quantify present-day crustal deformation occurring, and hence likely seismic hazards, and a study on the global deformation pattern caused by Great earthquakes was published, including co- and post-seismic deformation across the Australian continent. Dr Lescarmonier and PhD. student Bianca Kallenberg went to Antarctica for 2 months as part of a multi-year project using GPS to quantify present-day uplift rates in Enderby Land. Work continued on the development of the in-house GRACE space gravity observations, including several improvements in the orbit modelling and efficiency of the software. Progress has been made on PhD projects focusing on developing a firn compaction model for Antarctica, extracting high-accuracy ice height changes in Antarctica from satellite altimetry observations,

a new ice history model for eastern Canada and how to define the global coordinate system on a temporally evolving Earth.

Prof Malcolm Sambridge

Associate Director, Earth Physics

When tsunami physics meets the solid Earth

Toward better tsunami numerical simulations

Sébastien Allgeyer and Phil Cummins

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

A tsunami is a set of long-period waves generated by a large-scale displacement of the sea surface, which can be caused by phenomena such as earthquakes, landslides, volcanic events, extreme meteorological conditions and asteroid impacts. The very large scale of this initial water displacement compared to the ocean depth allows us to make some major simplifications to the hydrodynamical theory, resulting in the Saint Venant equations (or Shallow water theory). These equations allow us to model shallow water waves, in a non-dispersive theory, over a non-deformable rigid Earth. These approximations often result in a reasonable ability to model observed data. However, the adequacy of this approximation has been called into questions by recent well-recorded tsunami observations, using various sensors such as bottom pressure sensors and GPS buoys, for two major tsunami events: the 2010 Maule, Chile and 2011 Tohoku, Japan, earthquake-generated tsunamis. These observations have shown that there are some discrepancies which are clearly evident in tsunami waveforms that have propagated over large distances that can be attributed to the compressibility of seawater, the elasticity of the solid earth and the gravitational potential change associated with the sea water mass motion during the tsunami propagation. These discrepancies, of up to 2% in tsunami arrival time, can explain the fact that the reconstruction of the seismological sources using tsunami data (data inversion) differ from inversion results using other data types.

We are developing a new modification to the Saint Venant equations that allows the inclusion of the loading and other effects normally ignored in conventional tsunami simulations, in order to determine whether they have a significant influence on tsunami propagation and source inversion. These new equations have been implemented in a new finite difference code for tsunami propagation. Because some of these effects require the introduction of a spatial convolution at each time step, the computational demands are greatly increased, but with parallelization we find that simulations can be performed on a high-performance cluster. Our preliminary results show that the effect of tsunami loading is significant and failure to include this effect will likely bias source inversions using far-field tsunami data.

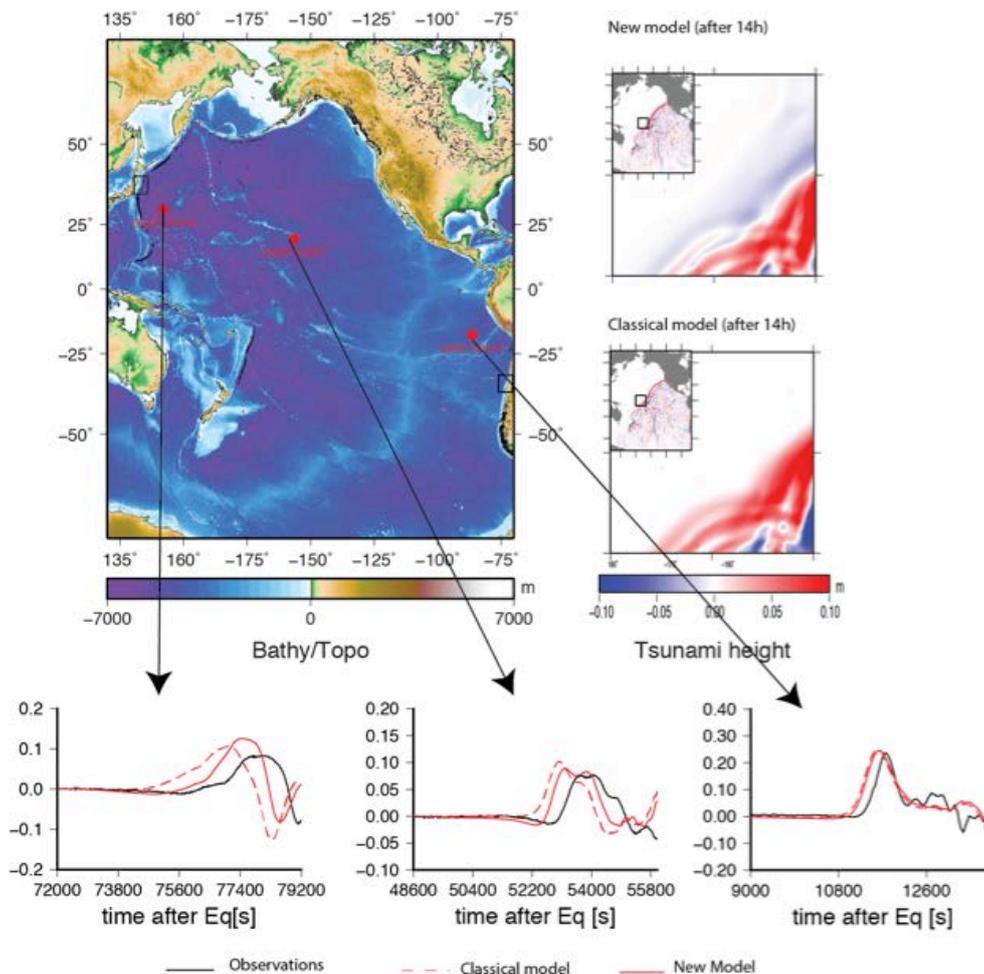


Figure 1. Results of numerical simulations with observations for the tsunami generated by the 2010 earthquake ($M_w=8.8$) off Maule, Chile. The upper left panel shows the position of the earthquake (lower right rectangle) w.r.t. three observations points across the Pacific at which comparisons are made. For the tsunami waveforms in the lower panel, observations are given by the black curve, tsunami computations for a rigid seafloor by the dashed red curve, and computations including the loading effect by the solid red curve. Note that the loading calculations provide a much better result for the tsunami waveform shape. At right are snapshots of the tsunami height computed at 14 hours propagation time, including (upper) and not including (lower) the loading effect account.

Rapid finite fault solutions for large earthquakes

Roberto Benavente and Phil Cummins

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

Our research aims to characterize the rupture process using seismic records. Particularly, we are using a seismic wave called the W-phase to constrain the distribution of the rupture. Owing to the fact that the W-phase is especially suited to work in real time context, an important application of our research is the construction of a fully automated algorithm to perform finite source inversion soon after an earthquake. Working in that direction, throughout the course of the present

academic year we have created scripts to do finite fault inversion and analyzed two important megathrust earthquakes: Maule (Mw=8.8, 2010) and Tohoku (Mw = 9.0, 2011). Our results are compatible with most of the solutions we are aware of and they are good first order characterization of the respective seismic sources.

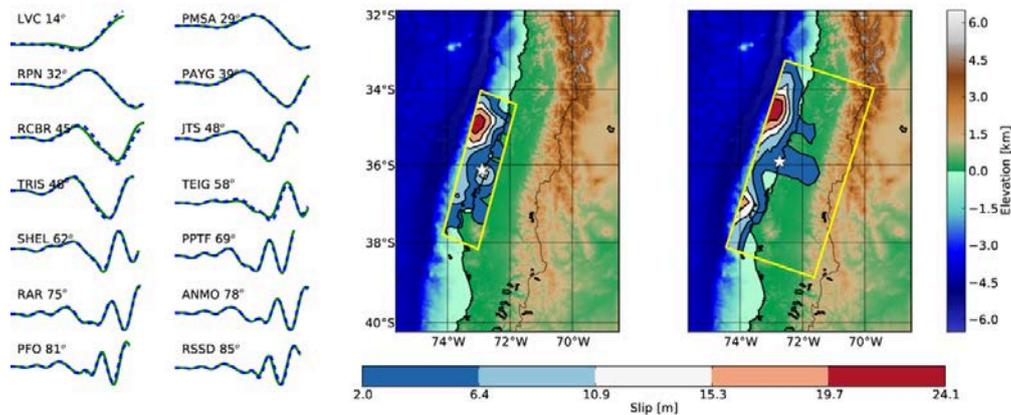


Figure 1. Results of our approach applied to the the Maule (Mw = 8.8) event. (left) Waveform fits are shown for selected stations. Observed displacements and their respective synthetics are indicated by a continuous green line and a dashed blue line, respectively. (middle) A reference model is plotted from Koper et al. [2012]. Different slip regions are indicated by contours, the yellow rectangle marks the faulting area considered, and the hypocenter is indicated by a white star. (right) The achieved solution plotted in the same way as the reference model in Figure 1 (middle).

Characterizing sea level variations around the Australian coastline

Reed Burgette², Christopher Watson², John Church³, Neil White³, Paul Tregoning¹ and Richard Coleman²

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

² Surveying and Spatial Science Group, School of Geography and Environmental Studies, University of Tasmania

³ Centre for Australian Weather and Climate Research, CSIRO

Sea level rise around the Australian continent was quantified from a study of tide gauge and GPS observations. A spatially coherent pattern of sea level variation is found, with a weighted average rate of 1.4 +/- 0.6 mm/yr over the period 1900-2012, increasing to 4.6 +/- 0.8 mm/yr over the shorter 1993-2012 period and the rate of increase is greater in the northern regions of Australia. The apparent acceleration in sea level rise may not be significant because a range of short-term temporal variations may dominate the longer-term trend. Vertical motion of the tide gauges was accounted for using vertical velocities estimated at nearby GPS sites. We found that the majority of sites had vertical velocities that were statistically insignificant from zero, with the exception of Hillarys in the Perth area where crustal subsidence of > 3 mm/yr is occurring as a result of groundwater extraction. This highlights the need for continued monitoring of vertical ground motion at tide gauges, and for the ongoing monitoring

The article published in Geophysical Journal International can be found at <http://gji.oxfordjournals.org/content/194/2/719.full>

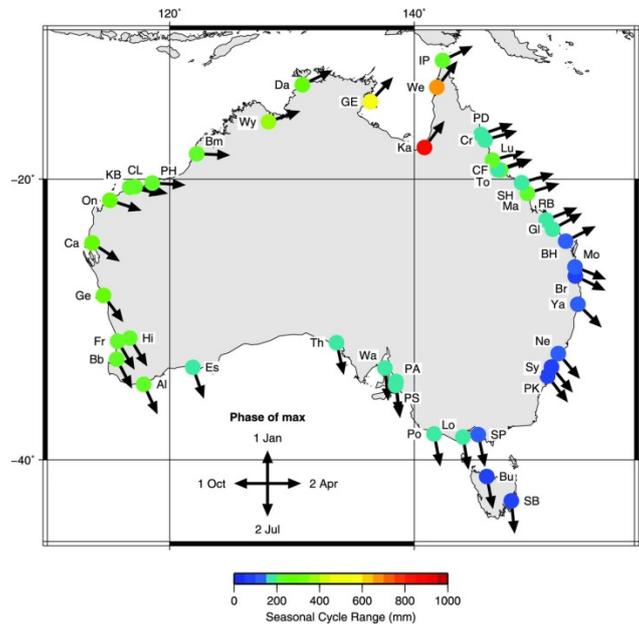


Figure 1. Amplitude and phase of seasonal variations in sea level at tide gauges around the Australian coastline (Burgette et al., 2013)

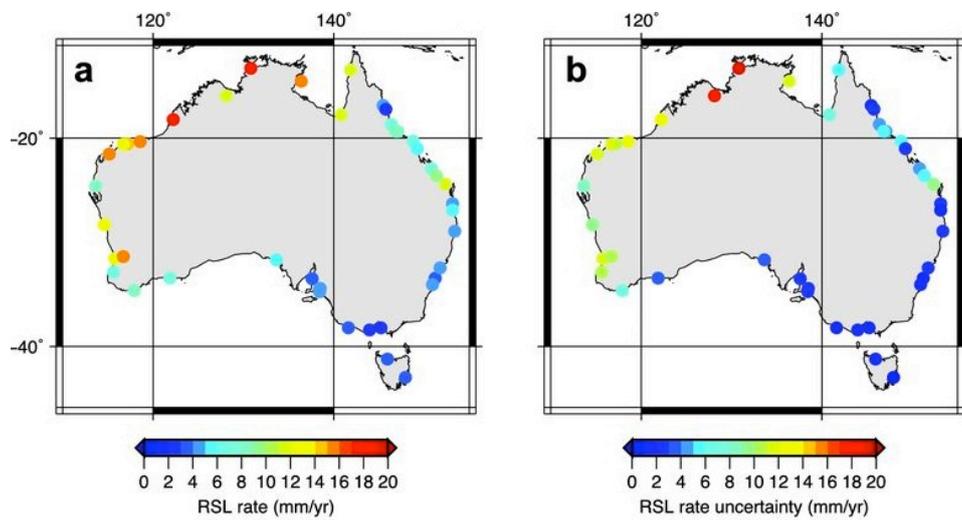


Figure 2. Rate of relative sea level (RSL) rise at tide gauges around the Australian coastline

The 2011 Tohoku earthquake and tsunami

Lessons for Australia and Indonesia

Phil R. Cummins¹, Widjo Kongko² and Hamzah Latief³

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

² *Indonesian Agency for the Assessment and Application of Technology, Yogyakarta, Indonesia*

³ *Bandung Institute of Technology, Bandung, Indonesia*

The earthquake and tsunami that struck northeastern Japan in March 2011 was a terrible human tragedy that should serve as a wake-up call to earth scientists and disaster managers everywhere. Like the northeast Japan subduction zone prior to the 2011 earthquake, the subduction zone south of Java has no historical experience of an earthquake larger than magnitude 8. The two subduction zones are similar in other respects, so we have to question whether a large event similar to the 2011 Tohoku earthquake could occur off Java. The lesson from Japan is that the lack of historical experience of such an event does not guarantee it will not happen in the future.

In this work we review the features of the 2011 Tohoku event that made it so dangerous, and attempt to draw some conclusions about what the impact on Australia and Indonesia would be if a similar event occurred in the Java Trench. We consider two scenarios, one in which an earthquake like the Tohoku event occurs off West Java, and one in which it occurs off Bali. In both cases we consider the possible impact of both the ground motion and the tsunami generated by the earthquake.

Our analysis of the impact of the ground motions shows that many more people would be exposed to potentially damaging ground motions than was the case for the 2011 Tohoku event. While northeast Japan has less than 150 people per km², Java is one of the most densely populated regions of Indonesia, with almost 1,400 people per km². Were such an event to occur off Java, a much larger number of people would be exposed to strong ground shaking, and many of them live in buildings far less resilient than those in Japan. We note also that even in Jakarta, about 400 km from the hypothetical epicenter off West Java, ground motions would exceed the design requirements of the Indonesian building code, so even large, engineered buildings may experience damage.

The tsunami generated by such an earthquake would similarly impact a much more densely populated coastline along the southern coast of Java. We show that the tsunami could completely inundate the city of Cilacap in West Java and Kuta in Bali, respectively. Australia would not be immune to the effects of such an earthquake. Although Australians would be spared the experience of strong ground motion in densely populated areas, the tsunami would almost certainly impact ports along Australia's northwest coast that are a key link for the generation of much of Australia's export income.

All indications are that an event similar to the 2011 Tohoku earthquake occurring off the coast of Java would result in a disaster rivalling the 2004 Indian Ocean tsunami, and would perhaps present even greater challenges for disaster response. While

such an event may be extremely unlikely to occur any time soon, we would be remiss not to consider it as a low-probability, worst-case event.

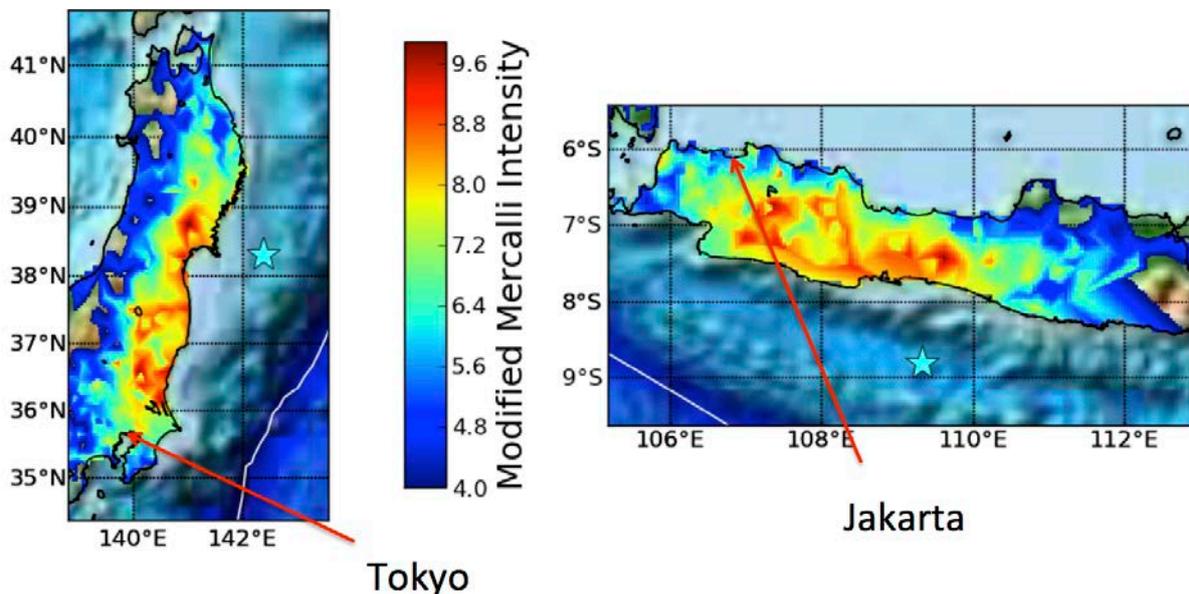


Figure 1. Earthquake ground motion (in units of Modified Mercalli Intensity) observed during the 2011 Tohoku earthquake and translated to a similar earthquake scenario south of west Java. The cyan stars indicate the positions of the respective hypocentres. Note the similar positions Tokyo and Jakarta occupy with respect to the rupture pattern.

Energy budgets and dynamics of turbulent convection

Bishakhdatta Gayen, Ross Griffiths, Graham Hughes and Juan Saenz

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

Convection is the flow that arises in response to buoyancy forcing applied at the boundaries of a box. This year we have studied two canonical types of thermal convection: Rayleigh-Benard convection, in which cooling and heating is applied at the upper and lower horizontal boundaries, respectively, and horizontal convection, in which the thermal forcing is applied at the same horizontal boundary.

One focus of this work has been to understand the energy budget – in both types of convection the buoyancy forcing maintains a (statistically stationary) density field in the flow that is not at equilibrium. We have demonstrated that the rate at which the buoyancy forcing acts to disequilibrate the flow (through generation of available potential energy) balances the rate of irreversible mixing in the fluid. Convection is not usually viewed in these terms, but our approach demonstrates that both types of convection correspond to highly efficient mechanisms of stratified mixing. In Rayleigh-Benard and horizontal convection, the proportion of the energy supply that is consumed by mixing is about 50% and almost 100%, respectively. The remainder

is lost to heat – through viscous dissipation. These proportions compare with values of less than 20% that generally characterise other mixing processes.

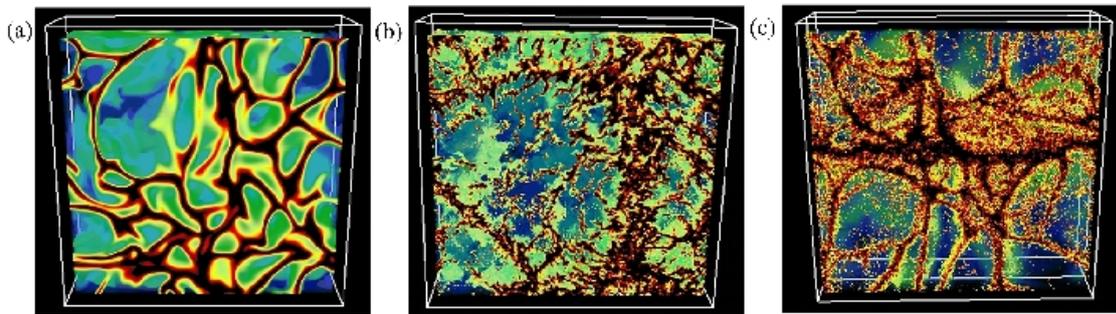


Figure 1: Visualization of the thermal structures in Rayleigh-Benard convection by colour contours of the 3D temperature field inside thermal boundary layer viewed from the bottom, at (a) $Ra=6 \times 10^6$, (b) $Ra=6 \times 10^8$ and (c) $Ra=6 \times 10^{12}$. Dark red indicates the warmest fluid.

We have also understood the dynamics of transient adjustment towards a statistically stationary state in horizontal convection. The timescales governing such adjustment can be surprisingly rapid under certain circumstances, but approach that for diffusion through the depth of the box in others. These findings have helped clarify the mechanisms responsible for buoyancy transport in horizontal convection - in general, transport by diffusive-like processes (i.e. owing to molecular diffusion or small-scale turbulence) is significant only in the thin strongly stratified boundary layer adjacent to the boundary at which the thermal forcing is applied.

Numerical simulations of the convection have been conducted at some of the highest Rayleigh numbers achieved to date, and evidence for new flow regimes has emerged. Large scale convective flows are observed to develop that interact strongly with the boundary layer structure. As the Rayleigh number is increased, the figures show how strong large motions develop to sweep gravitationally unstable fluid in the boundary layer into “mega-plumes”, or sites of concentrated upwelling (and downwelling), which are relatively long-lived and in turn reinforce the large-scale motions.

Hughes, G.O., Gayen, B. & Griffiths, R.W. 2013 Available potential energy in Rayleigh-Bénard convection. *J. Fluid Mech.* 729, R3, doi:10.1017/jfm.2013.353.

Gayen, B., Griffiths, R.W., Hughes, G.O. & Saenz, J.A. 2013 Energetics of horizontal convection. *J. Fluid Mech.* 716, R10, doi:10.1017/jfm.2012.592.

Griffiths, R.W., Hughes, G.O. & Gayen, B. 2013 Horizontal convection dynamics: insights from transient adjustment. *J. Fluid Mech.* 726, 559–595.

Gayen, B., Hughes, G.O. & Griffiths, R.W. 2013 Completing the mechanical energy pathways in turbulent Rayleigh-Bénard convection. *Phys. Rev. Lett.* 111, 124301.

An assessment of the minimum timing of ice free conditions of the western Laurentide Ice Sheet

Evan J. Gowan

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

The Laurentide ice sheet covered much of Canada and the northern United States. The nature and timing of retreat of the ice sheet is complicated by a lack of chronological constraints that indicate ice free conditions. Most reconstructions of ice sheet retreat draw isochrones of the inferred location of the ice margin using a limited amount of radiocarbon, optical and cosmogenic dates. As the distribution of these data can be very limited, there are large uncertainties on these reconstructions in many areas. Another issue is that most chronological constraints only give the minimum timing of retreat, i.e. there is an unknown period of time between deglaciation and deposition of the material dated.

In this study, I took a new approach. Instead of attempting to determine where the ice sheet margins were, I determined the area where it can be confirmed that the ice sheet was gone. Due to the large size of the Laurentide Ice Sheet, I focused only on the western part, encompassing the area east of the Cordillera and west of Hudson Bay and the Great Lakes. All radiocarbon dates from this region were checked for quality, with dates that could give anomalously old ages, such as bulk sediments, excluded from the analysis. Next, the direction of ice margin retreat for the region was determined using landforms such as moraines, drumlins, flutings and eskers. It was assumed that these features formed in a time transgressive matter, meaning that features used to determine the direction of retreat do not significantly predate deglaciation. I created a model of the minimum timing of retreat based on projecting the chronological constraints backwards from the inferred direction of retreat. The results show there are many areas where the timing of retreat is highly uncertain. For example, the region in Northwest Territories between Great Slave Lake and the Cordillera has a minimum timing of retreat of after 11,000 cal yr BP, though the inferred margin by Dyke (2004) is over 500 km from the Cordillera. The results raise questions on the availability of a drainage route of Glacial Lake Agassiz to the Arctic Ocean at the start of the Younger Dryas (fig. 1). The results also show where additional chronological constraints would be most helpful in determining the timing of retreat.

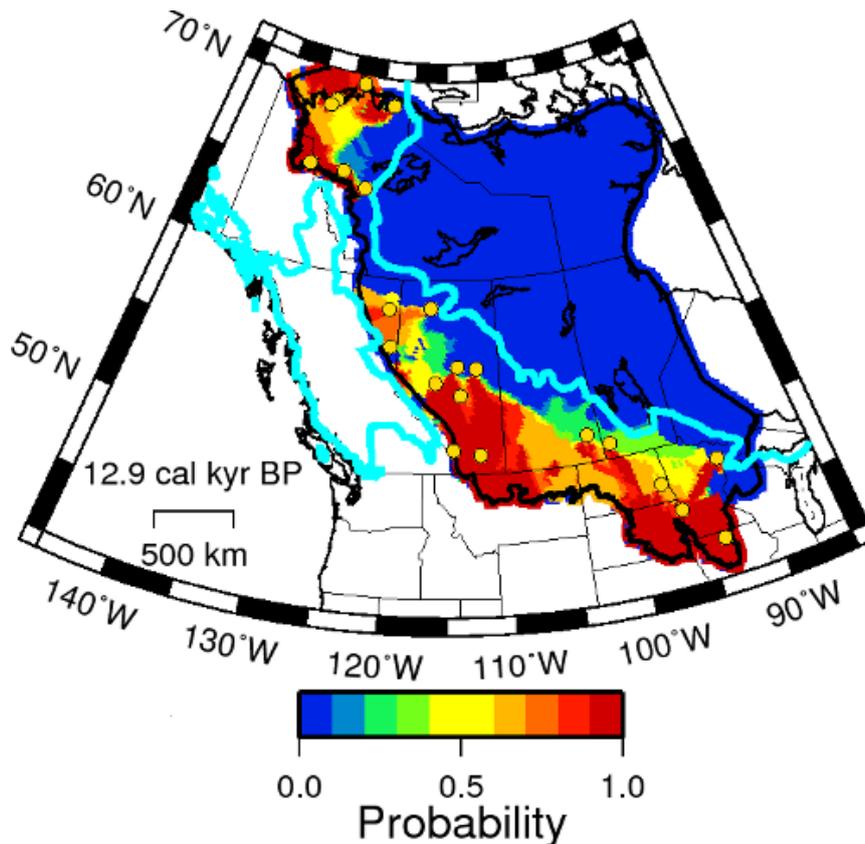


Figure 1. Minimum timing of retreat of the western Laurentide Ice Sheet at 12,900 cal yr BP. Red and yellow areas indicate that there is a high degree of confidence that the ice sheet has retreated from that region. Blue line is the margin reconstruction by Dyke (2004) for this time. Yellow dots are chronological constraints used to determine the minimum timing of retreat.

Dyke, A.S., 2004. An outline of North American Deglaciation with emphasis on central and northern Canada. *Quaternary Glaciations - extent and chronology - Part II: North America. Developments in Quaternary Science*, pp. 373-424.

Link to paper in *Quaternary Science Reviews*
<http://dx.doi.org/10.1016/j.quascirev.2013.06.001>

Does the sensitivity of Southern Ocean circulation depend upon bathymetric details?

Andrew McC. Hogg¹ and David R. Munday²

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

² *Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford, Parks Road, Oxford, OX1 3PU, United Kingdom*

The response of the Southern Ocean to changes in climate will control the global stratification, and the carbon budget of the deep ocean. However, a scarcity of observations and the inability of global ocean models to resolve important Southern Ocean processes has made progress difficult.

We have investigated the response of the major ocean currents to changes in wind stress forcing with a series of idealised, but eddy-permitting, model simulations. Previously, ostensibly similar models have shown considerable variation in the oceanic response to changing wind stress forcing. Here it is shown that a major reason for these differences in model sensitivity is subtle modification of the idealised bathymetry. The key bathymetric parameter is the extent to which the strong eddy field generated in the circumpolar current can interact with the bottom water formation process. The addition of an embayment, which insulates bottom water formation from meridional eddy fluxes, acts to stabilise the deep ocean density and enhance the sensitivity of the circumpolar current (see Fig. 1). The degree of interaction between Southern Ocean eddies and Antarctic shelf processes may thereby control the sensitivity of the Southern Ocean, and hence the global climate system, to change.

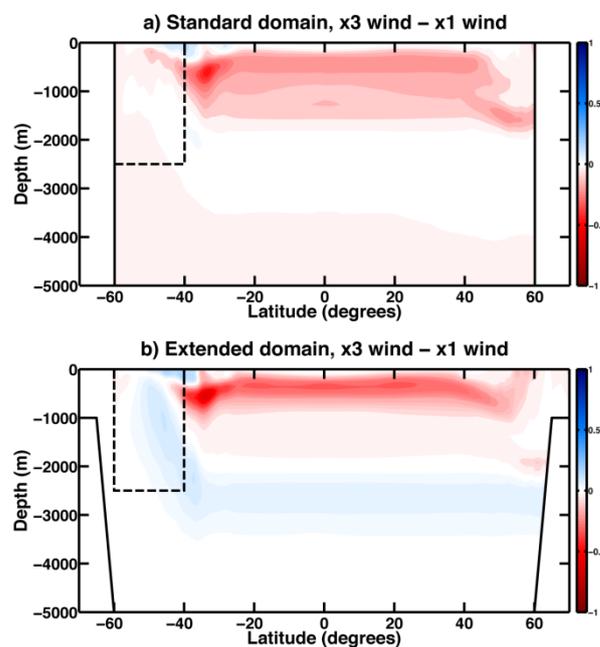


Figure 1. Differences in the zonally averaged stratification between the triple wind (with a peak wind stress of 0.6 N/m²) and the reference case (0.2 N/m²) for (a) the standard domain, and (b) the extended domain.

Slow-downs and speed-ups of India–Eurasia convergence since ~20 Ma: Data-noise, uncertainties and dynamic implications

Giampiero Iaffaldano¹, Thomas Bodin² and Malcolm Sambridge¹

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

² *Department of Earth and Planetary Sciences, University of California at Berkeley, USA*

The relative motions of India with respect to Somalia and North America with respect to Eurasia since ~20 Ma have been recently reconstructed at unprecedented temporal resolution of less than 1 Myr. These new datasets sparked renewed interest in the convergence of India relative to Eurasia, which is obtained from the

India-Somalia-Nubia-North America-Eurasia plate circuit. The reconstructed kinematics, however, appear to be surprisingly unusual over the past ~20 Myr. In fact, motions change erratically and underwent sudden increases and decreases. In other words, convergence across the Himalayan front featured significant speed-ups as well as slow-downs with almost no consistent trend. Arguably, this pattern arises from the presence of noise in the data, because the reconstructed India/Eurasia motions cannot demonstrably result from the temporal evolution of geological forces acting upon plates. In our previous work, we resorted to Bayesian inference to reduce finite-rotation noise from the inference of plate kinematics. Here we build on this advance and revise the India--Eurasia kinematics since ~20 Ma. We find that India-Eurasia kinematics are simpler and, most importantly, geologically plausible upon noise reduction. Convergence across the Himalayan front overall decreased until ~10 Ma, but then systematically increased, albeit moderately, towards the present--day. We test with global dynamic models of the coupled mantle/lithosphere system several geophysical hypotheses to explain the inferred kinematic patterns.

Link to webpage:

<http://www.sciencedirect.com/science/article/pii/S0012821X13000812>

Dissolution of an ice wall by turbulent compositional convection

Ross Kerr and Craig McConnochie

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

Over the past decade, an important component of global climate change has been the increasingly rapid decrease in the mass of the Antarctic and Greenland Ice Sheets. This mass loss occurs from the underside and fronts of ice shelves formed where glaciers reach the polar oceans (at about 1500 Gt/year) and from the icebergs that calve from the shelves (at about 1265 Gt/year).

As a first step towards a fluid dynamical understanding of this mass loss, we have examined the dissolution of an ice wall in the case where the heat and mass transfer is driven by turbulent compositional convection (Kerr & McConnochie 2013). We developed a model of the turbulent dissolution, which has no free parameters and no dependence on height. The analysis predicts the interface concentration, the interface temperature and the dissolving velocity. We compared the model with laboratory measurements of the ablation of an ice wall in contact with salty water (figure 1). We found that the model predicts the measured interface temperatures to within 0.1°C and the measured dissolving rates to within 10%, for water temperatures up to about 5°C (at which point there is a transition from turbulent dissolution to turbulent melting). When applied to the polar oceans, our model predicts dissolving velocities as a function of ocean temperature that are reasonably consistent with field estimates of the dissolving rates of Antarctic icebergs and ice shelves.

Kerr RC, McConnachie, CD (2013) Dissolution of a vertical solid surface by turbulent compositional convection. *Journal of Fluid Mechanics* (submitted).

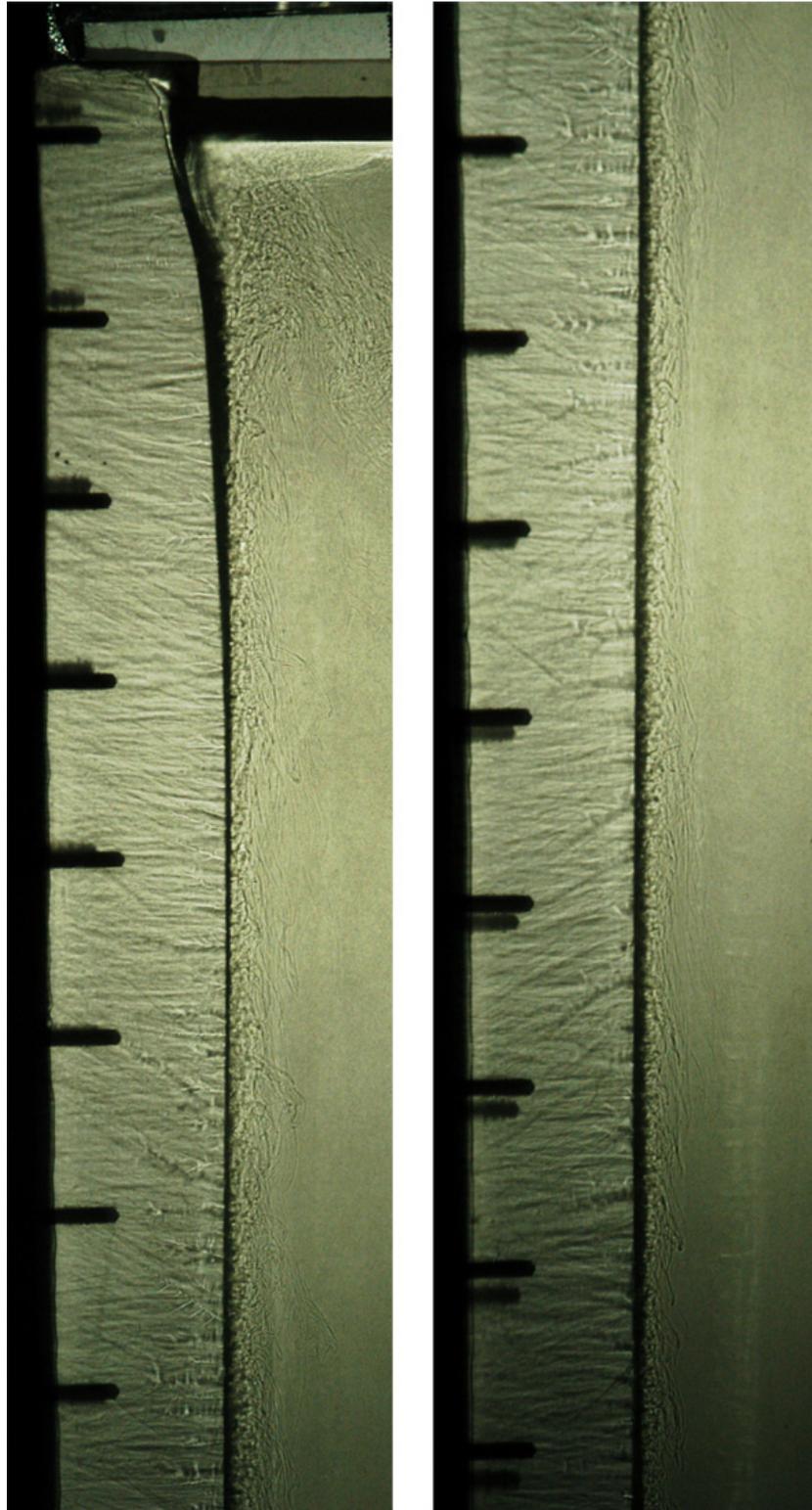


Figure 1. Shadowgraph of the rising turbulent compositional boundary layer on a dissolving ice wall. The photo on the left shows the ice from a height of 72 cm up to the free surface height at 114 cm, while the photo on right shows the ice wall at heights of 32 to 76 cm.

GPS constraints on active deformation in the Isparta Angle region of SW Turkey

Simon McClusky¹, Robert Reilinger² and Ibrahim Tiryakioğlu³

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

² Earth Atmospheric and Planetary Sciences, MIT, Cambridge, MA, 02139, USA

³ Afyon Kocatepe University, Department of Geomatics Engineering, Afyonkarahisar, Turkey

GPS satellite observations collected during the period 1997-2010 were used to investigate active deformation in the Isparta Angle region of SW Anatolia, Turkey. This region, bordered by the Fethiye Burdur Fault Zone (FBFZ) in the west and the SE extension of the Aksehir Simav Fault Zone (AKSFZ) in the east, accommodates part of the active deformation of W Turkey. These new results show that the Isparta Angle region rotates counterclockwise with respect to the Anatolian microplate. Both the FBFZ and the AKSFZ are predominantly transtensional boundaries that accommodate southward motion of the Isparta region with respect to Anatolia. The FBFZ has left-lateral strike slip behavior along its SW segment that changes to right-lateral strike slip along its NE extension. This change in the sense of strike slip motion is accommodated by extension on a NW-SE striking normal fault system that is associated with the Menderes Graben system. Transtensional fault systems along the boundaries of the Isparta Angle with Anatolia are inconsistent with extrusion models for present-day southward motion. An increase in motion rates towards the Hellenic and Cyprus arc subduction systems supports dynamic models involving active roll-back of the subducting African Plate and/or gravitational collapse of the overriding Anatolia Plate.

Published paper: <http://gji.oxfordjournals.org/content/195/3/1455.refs>

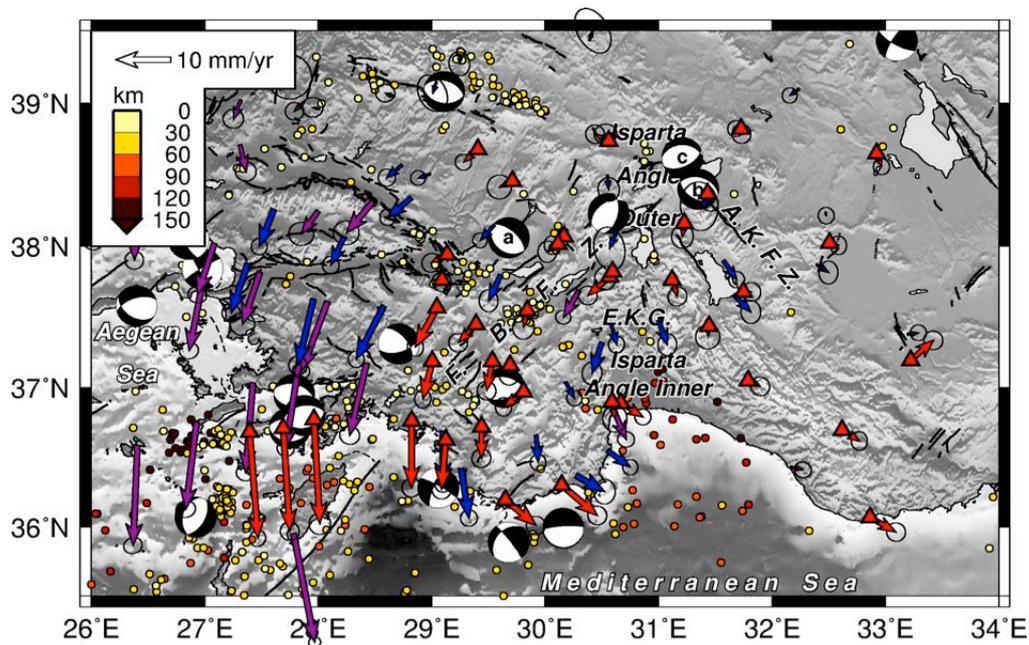


Figure 1. GPS derived crustal velocities with respect to a fixed (non rotating) Anatolia block [as defined by Reilinger et al. (2006)] and their 95% confidence ellipses in SW Turkey and SE Greece. (Red: New or updated velocities from this study; Purple: Reilinger et al., 2006; Blue: Aktug et al., 2010). Earthquake locations shown are from the International Seismological Centre (EHB) catalog

(Engdahl et al., 1998 and updates thereof), with the hypocenter depth scale shown inset. Focal mechanisms (lower hemisphere projection) are for earthquakes with magnitude greater than 5.5 in southwest Anatolia between 1976 and 2012. Abbreviations: AKFZ, Aksehir Simav Fault Zone; FBFZ, Fethiye Burdur Fault Zone; EKG, Egirdir-Kovada Graben.

Towards improved measurements and analysis of normal modes of the earth

Surya Pachhai, Marija Mustac and Hrvoje Tkalčić

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

Body wave tomographic inversion is a widely used method to image Earth's interior, however, its resolution in deeper parts of the Earth is reduced due to a limited spatial coverage by seismic waves. In contrast, the vibrating pattern of the Earth in response to large earthquakes, known as normal modes of the Earth, does not depend on the source and receiver geometry and thus represents excellent complementary tool to study Earth's interior. Pre-processing and processing methods for measuring normal modes, however, could benefit from improvements to enable us to fully harvest the available waveform data. In particular, the data quality and mode excitation are traditionally determined by visual inspection. Not all modes are well excited by a single earthquake, and source effects need to be removed from the seismograms prior to further analysis. Furthermore, there is no reliable way to determine how many earthquakes and stations should be included to compute Earth's structure. We start our analysis by collecting waveforms of large earthquakes (e.g. the 1994, Bolivia, earthquake) recorded on seismographic stations around the globe to infer deep Earth's structure (the core and the lowermost mantle). An initial goal is to calibrate our measurements and methods with already established and published results. For normal modes sensitive to the Earth's core, seismograms are cut to remove surface waves and modes sensitive to the crust and upper mantle. Their spectra are computed in frequency domain (Figure 1 shows an example for a spheroidal mode 13S2 that is sensitive to the Earth's inner core). Spectral peaks are broadened and split mainly by Earth's rotation, but also due to heterogeneity and anisotropy in the inner core. Initially, we use a standard approach of linear inversion to reduce the spectra from all the stations to 5 spectra (for 13S2 mode) known as receiver strips (Figure 2). Subsequently we visualize inner core structure through a splitting matrix (Figure 3), whose elements represent deviations in frequency due to differences of inner core 3-D structure from a 1-D Earth model. Although these results agree well with the published results, subjective choices made in data processing and selection require further attention. This subjectivity will be reduced within the Bayesian hierarchical framework, where it is possible to obtain uncertainties. The noise in the data will be relaxed as a free parameter in the inversion. Knowing the noise in the data will constrain the level of fit, and this will help accurately quantify Earth's 3-D structure. An immediate goal in conjunction with adding the improved normal modes dataset to the existing body wave travel-time data is to constrain inner core dynamics by means of comparing structure of the

inner core seen by normal modes in a chronological manner. The observed changes in normal mode splitting matrices will enable us to estimate the rotation of the inner core with respect to the mantle. Another application includes combining normal modes with body wave data to invert for inner core anisotropic structure.

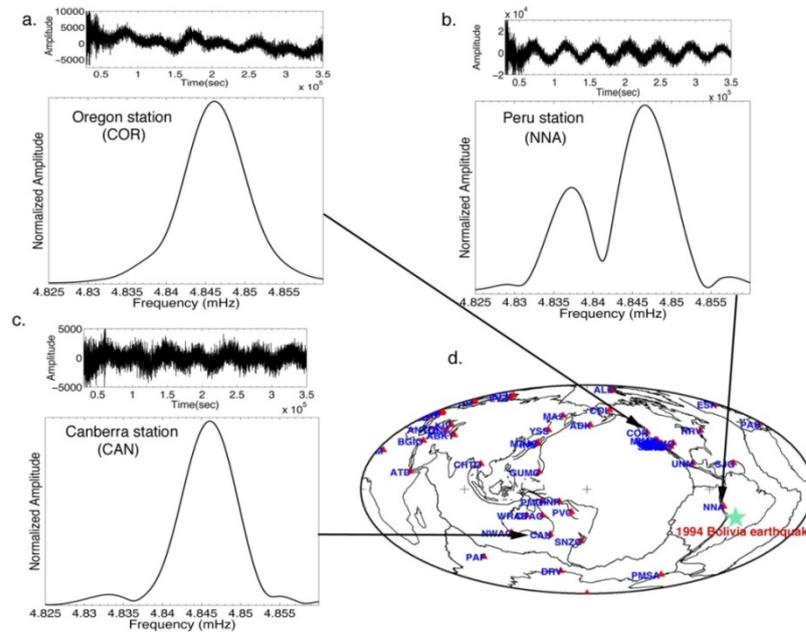


Figure 1. Seismograms (top) and amplitude spectra (bottom) for inner core sensitive mode (13S2) at COR station in Oregon (a), NNA station in Peru (b), and CAN station in Canberra (c). Seismograms in (a), (b) and (c) are cut between 10 and 97 hours after the event origin time for display purposes. (d) Station map used in this study. Triangles represent the station locations while the star represents the earthquake location.

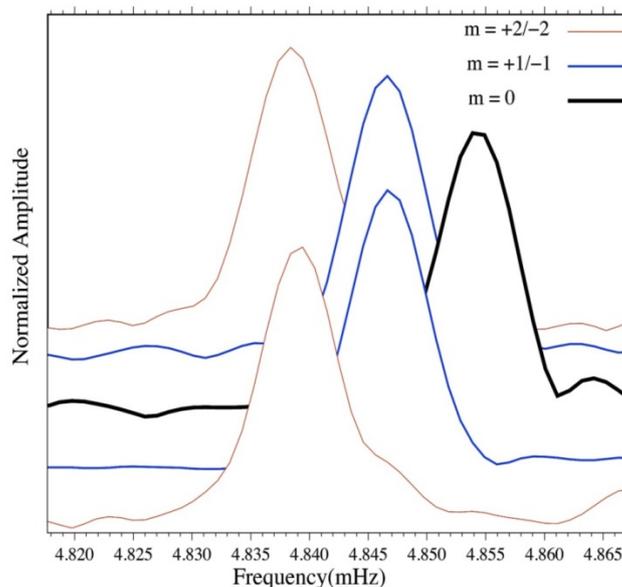


Figure 2. Receiver strips for 13S2 mode that samples the Earth's inner core. All the spectra are normalized to their maximum amplitude for visualization purpose. Horizontal axis is plotted in milliHertz (mHz).

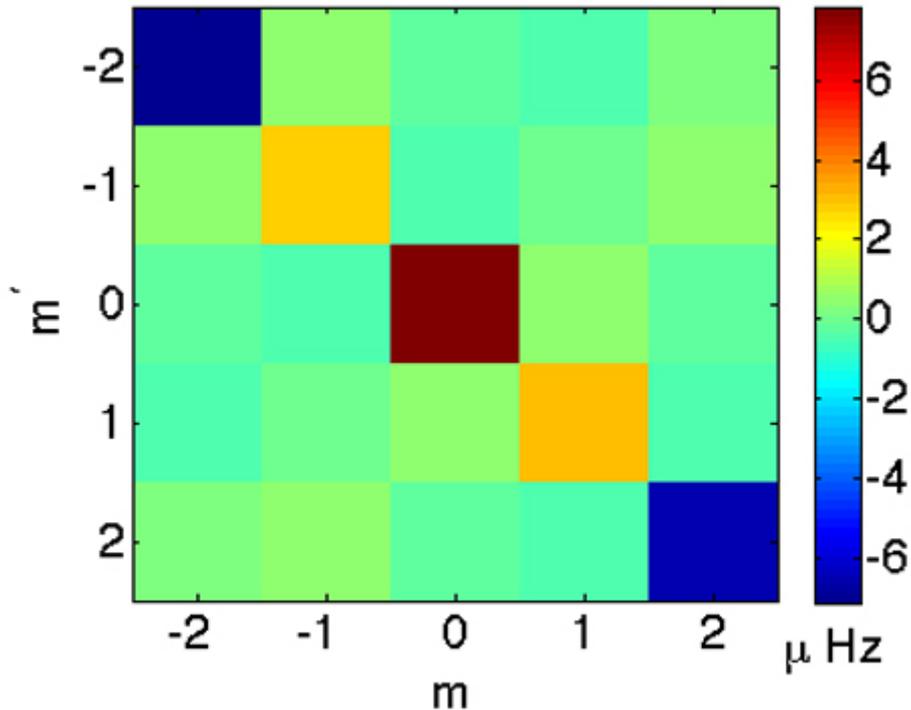


Figure 3. Splitting matrix for 13S2 mode that samples the Earth's inner core. Horizontal and vertical axes represent 5 different spectra shown in Figure 2. Individual color indicates the frequency perturbation (in microHertz unit) from the 1-D Earth model. Note: only the real part of elastic structure is considered in this matrix.

Multiple layer ultra low velocity zone in the earth's lowermost mantle under the Philippines using Bayesian inference

Surya Pachhai¹, Hrvoje Tkalčić¹ and Jan Dettmer^{1,2}

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

² University of Victoria, Victoria BC Canada V8W 3P6

Strong decrease in shear (S) wave speed by up to 30% and compressional (P) wave speed by up to 10% has been observed in some regions at the top of the core mantle boundary (CMB) and is known as the ultra low velocity zones (ULVZs). Partial melt of the lowermost mantle material and interaction between the core and mantle materials are viable candidates for these reductions, however, exact physical cause is still to be known. In addition, the ULVZ properties play an important role in the dynamics of the lowermost mantle. Traditionally ULVZ properties are estimated using the forward waveform modeling of waves sensitive to the anomalous structure either by trial and error method or a simple grid search. However, forward waveform modeling that utilizes 1-D and 2-D Earth structure models is inadequate to uniquely quantify the ULVZ properties because of their inherent trade-offs. Moreover, these methods do not provide an adequate tool to estimate the uncertainty in the ULVZ

parameters (layer thickness, P- and S- wave velocity, and density) and the noise in the data.

We thus develop a hierarchical Bayesian inversion scheme to address the aforementioned problems. In Bayesian inversion, results are expressed in terms of posterior probability distribution, which combines the prior knowledge about the structure and the information obtained from the data. We then apply this method to the S-wave converted into and reflected as the P-wave from the CMB (ScP- wave), recorded by Hi-Net array in Japan. These waveforms originate from the north east of Indonesia and sample the CMB region under the Philippines (Figure 1a). Final data used in the inversion are plotted in Figure 1b (black line). Selected group of model predictions from the posterior distribution of the ULVZ parameters is shown in Figure 1b (grey lines). The complexities in the waveforms before and after the main ScP-arrival are due to the existence of a ULVZ.

Statistical analysis of the posterior distribution of ULVZ models with a different number of layers suggests that a 2-layered ULVZ explains the data significantly better than other models. Final results for selected ULVZ model are presented in Figure 2. All the parameters (thickness, P- and S-wave velocity, and density) are well constrained within the prior range. The different strength of the velocity perturbation in bottom and top layer of ULVZ could be due to partial melting with different melt content, while the strong increase in density could be due to the core mantle interaction.

Presently, we are applying the same method for the waveforms recorded by the WOMBAT array of seismometers installed by Research School of Earth Sciences in Australian Continent. The unprecedented sampling of the lowermost mantle by the waveforms recorded in Australia will enable us to better understand structure and dynamics of the lowermost mantle beneath the east of Australia.

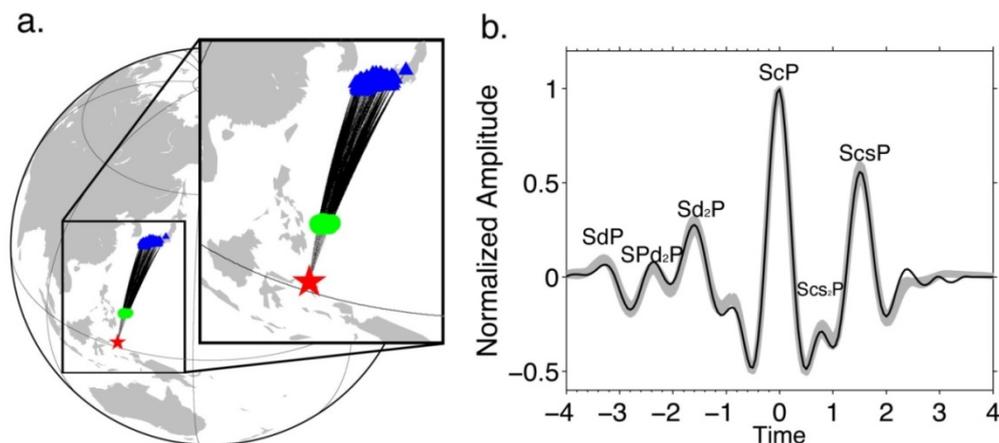


Figure 1. (a) Map of the lowermost mantle investigated in our study. The earthquake from Indonesia (event id 203050515) is shown with a red star. Superimposed on the map are surface projections of ray paths of ScP waves (black lines), their reflection points at the core-mantle boundary (green circles), and the recording stations of Japanese Hi-Net array (blue triangles). (b) Observed waveforms (thin black line) and modeled waveforms from the posterior probability distribution of the physical properties of Ultra-Low Velocity Zones (thick grey lines). Pre- and post-cursors due to the effect of ULVZs are marked as SdP, SPd₂P, Sd₂P, Scs₂P and ScsP while the main phase is marked as ScP.

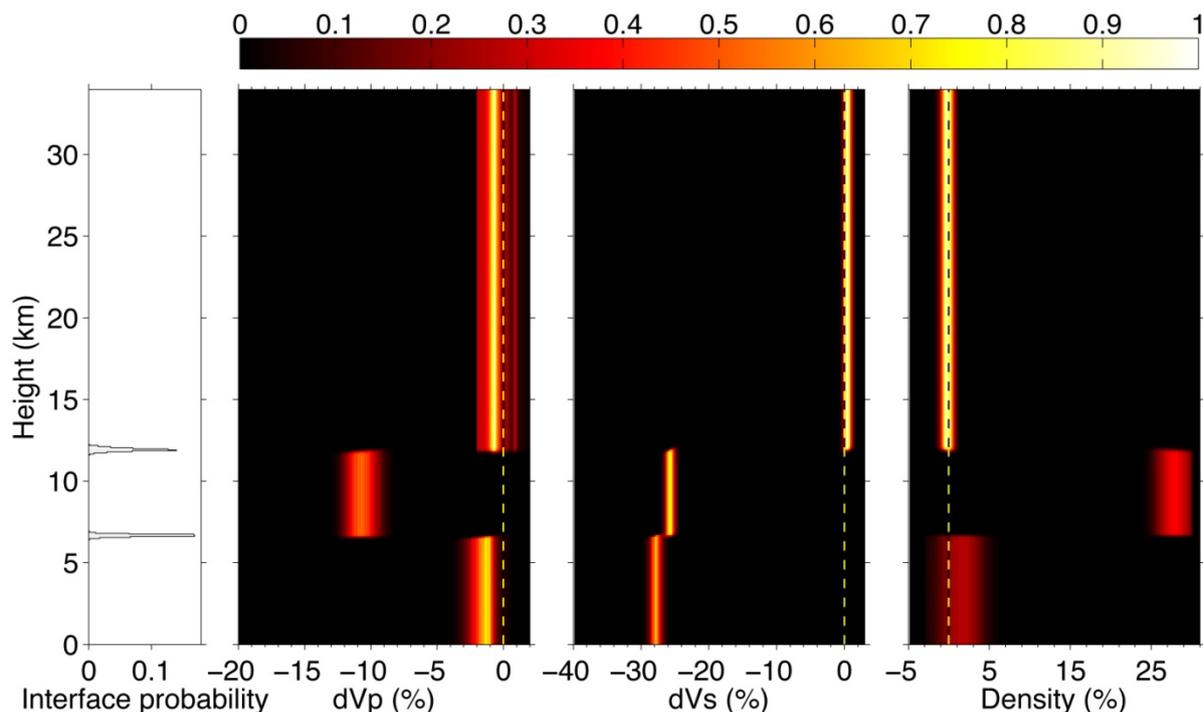


Figure 2. Posterior probability distribution of selected physical properties of a ULVZ model with 2 layers. Left panel: interface probability as a function of height above the core-mantle boundary. Right panel: posterior probability distributions of P-wave velocity perturbation (dVp), S-wave velocity perturbation (dVs), and density perturbation in percentage (horizontal axis). Dashed lines represent the 1-D reference Earth model ak135.

Pachhai, S., H. Tkalčić, J. Dettmer (2013). Towards Improved Modelling of Ultra Low Velocity Zones in the Earth's Lowermost Mantle Using Bayesian Inference: a Multiple Layer ULVZ Confirmed Under the Philippines, *J. Geophys. Res.*, submitted.

Can we trace the eastern Gondwanan margin in Australia? New perspectives from transdimensional inversion of ambient noise for 3D shear velocity structure

Simone Pilia¹, Nicholas Rawlinson¹, Nicholas Direen² and Anya Reading²

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

² *School of Earth Sciences, University of Tasmania, Hobart, Tasmania 7001, Australia*

The location and nature of the eastern continental margin of Gondwana in Australia is still poorly understood and remains one of the most hotly debated topics in Australian geology. Moreover, most post-Rodinian reconstruction models choose not to tackle the 'Tasmanian challenge', and focus only on the tectonic evolution of mainland southeast Australia, thereby conveniently ignoring the wider tectonic implications of Tasmania's complex geological history. One of the chief limitations of the tectonic reconstructions in this region is a lack of information on Palaeozoic (possibly Proterozoic) basement structures (see below schematic geological map). Vast Mesozoic-Cainozoic sedimentary and volcanic cover sequences obscure older

outcrops and limit the power of direct observational techniques. In response to these challenges, our effort is focused on ambient seismic noise for imaging 3D shear velocity structure using surface waves. The data used in this study mainly originates from oceanic disturbance recorded by the WOMBAT transportable seismic array. This has been in operation since 1998 and to date has involved 16 consecutive array movements with a cumulative total of over 700 stations deployed at spacing varying between 15-50 km.

The goal of this study is to carry out an innovative imaging experiment based on ambient seismic noise to image the crust beneath eastern Australia in high-detail by exploiting a cutting-edge inversion technique. The key significances of my project are: i) elucidate the geometry and position of key crustal features (including sedimentary basins, e.g. Murray, Otway, Bass, Gippsland Basins and partially the Sydney Basin) associated with the transition from Palaeozoic eastern Australia to Precambrian central and western Australia that were formed along the proto-Pacific margin of east Gondwana; ii) address fundamental questions regarding Tasmania's tectonic provenance and its enigmatic relationship with the mainland.

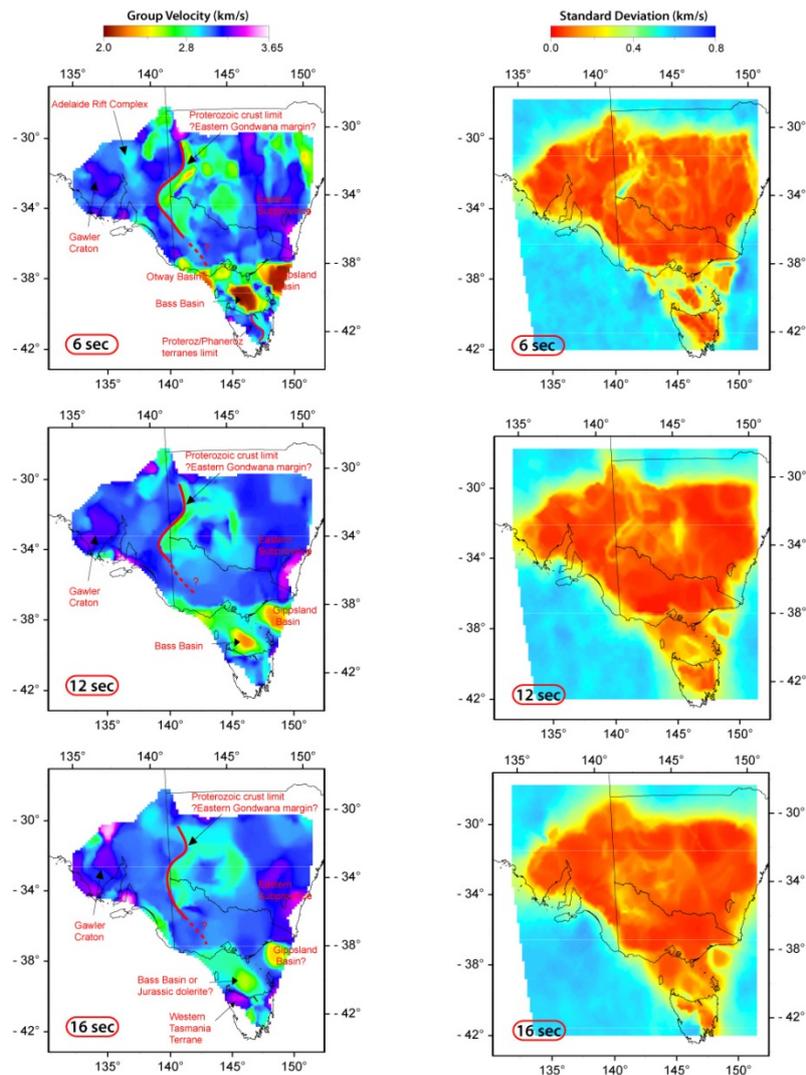


Figure 1. A series of horizontal maps at different periods is shown with the respective standard deviation maps.

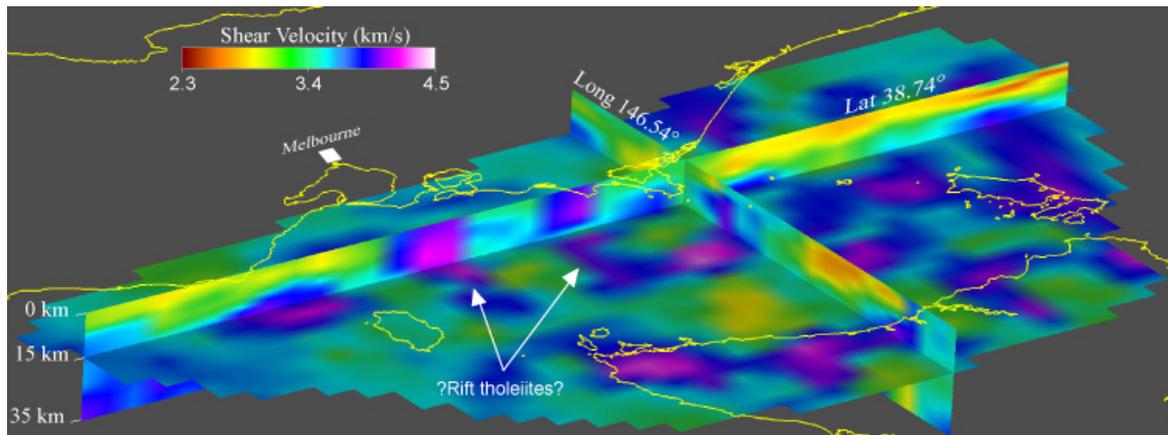


Figure 2. 3D model of Bass Strait. In the same fashion a 3D model will be obtained for the whole study area, including Tasmania, Bass Strait and SE Australia.

Noise estimation of remote sensing reflectance using a segmentation approach suitable for optically shallow waters

Stephen Sagar^{1,3}, Vittorio Brando² and Malcolm Sambridge¹

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

² CSIRO Land & Water, GPO Box 1666, Canberra, ACT, 2601, Australia

³ Geoscience Australia, GPO Box 378, Canberra ACT 2601

The ability to assess the noise characteristics of remote sensing imagery is an important step in establishing its capabilities and limitations in an operational and scientific context.

Accurate characterisation of noise is essential in inversion methods which propagate uncertainty estimates to parameter retrievals, provide confidence or reliability indicators on estimated parameters, or require a balance of the relative influence of data and prior information in Bayesian style cost functions.

In this research we develop a method to estimate the image-based environmental noise reflectance from optically shallow aquatic remote sensing imagery. Previous methods to assess the environmental noise, which encompasses the sensor signal to noise and other environmental and processing influences, have been implemented in areas of deep water of the imagery being assessed.

Through an object based segmentation of the image and homogeneity testing of the objects, we have proposed a method which can extract residuals from an optically shallow image area and produce comparable noise estimates to those made in optically deep waters. This offers potential benefit in characterising the reflectance noise in imagery with no available deep water. We have also extended the method

to characterise co-variance, and have successfully demonstrated the accurate retrieval of correlated noise in a synthetic study.

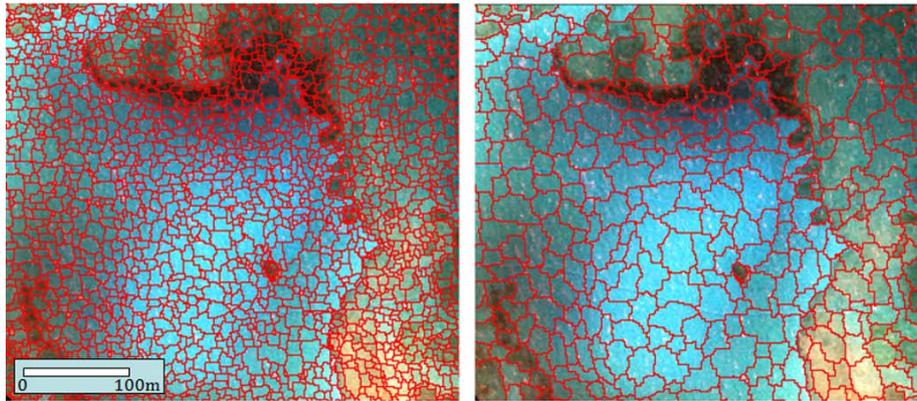


Figure 1. Influence of the segmentation scale on object homogeneity – small scale (left) to large (right).

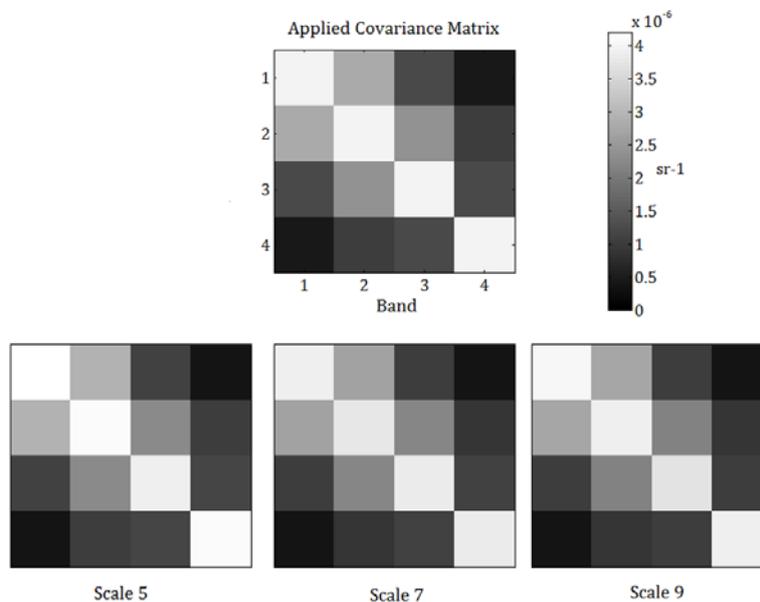


Figure 2. Retrieved covariance noise matrices from varied segmentation scales (comparison to applied noise at top).

Australian Seismometers in Schools

A network connecting students and scientists

Michelle Salmon, Natalie Balfour, Malcolm Sambridge and Herb McQueen

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

This year has seen the roll out of 39 seismometers to schools around the country as part of the Australian Seismometers in Schools program (AuSIS). This is a dual-purpose program aiming to engage students with hands on science and connect

them with scientists while providing quality data for research. Along with the installations we have engaged with the schools with seminars and tutorials, providing teachers and students with the tools to help them understand the multidisciplinary nature of Earth Science.

The seismometers used are research quality broadband instruments (Guralp CMG-6TD) with network capabilities that mean the data can be transmitted in near real time. The seismometers record local, regional and international earthquakes. Students see real-time seismic traces from their seismometer on a local computer and are able watch as waves from earthquakes as far away as Russia roll in. We keep students and teachers up to date on notable earthquake events through our Facebook page, and provide them with links to be able to look at seismographs from the other schools in the program, linking 30000 students to real-time science. Next year with the help of AuScope we will be launching a new smartphone/tablet app to make it even easier for students to connect with the seismometer. The program this year won the Education category of the Australian Innovation Challenge.

Because the instruments provide near real-time research quality data the information from them is now being integrated into Geoscience Australia for use in regional earthquake location and analysis. The distribution of the seismometers means that we have been able to fill some gaps in the National Network and the additional information will enable Geoscience Australia to obtain more accurate locations for earthquakes across Australia.

AuSIS is part of the AuScope AGOS Project.

AuSIS webpage: <http://www.asis.edu.au>

AuSIS facebook: <https://www.facebook.com/asisnetwork>

AuScope: <http://www.auscope.org.au>

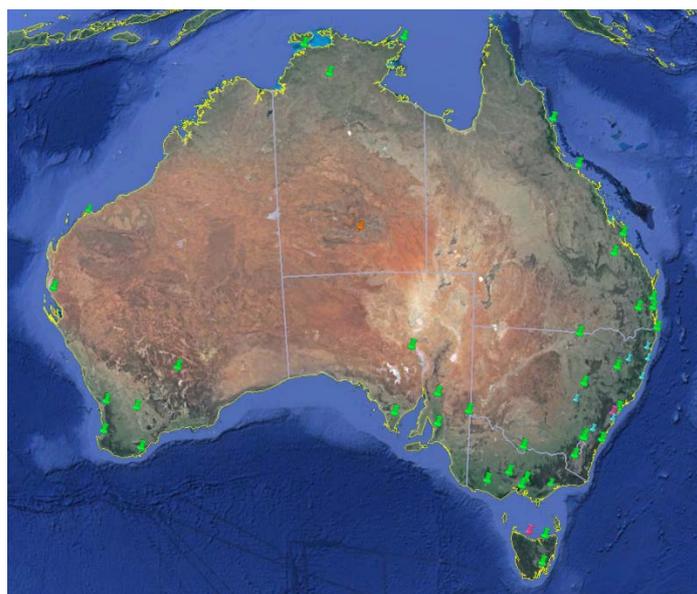


Figure 1. AuSIS seismometer installations. Green pins indicate operational stations, pink pins indicate future installations and cyan pins show our secondary seismometer locations.



Figure 2. Installation at Ayr State High School. The Seismic Vault was built by students in the construction class.

Probabilistic sampling and multi-modal optimization using Parallel Tempering

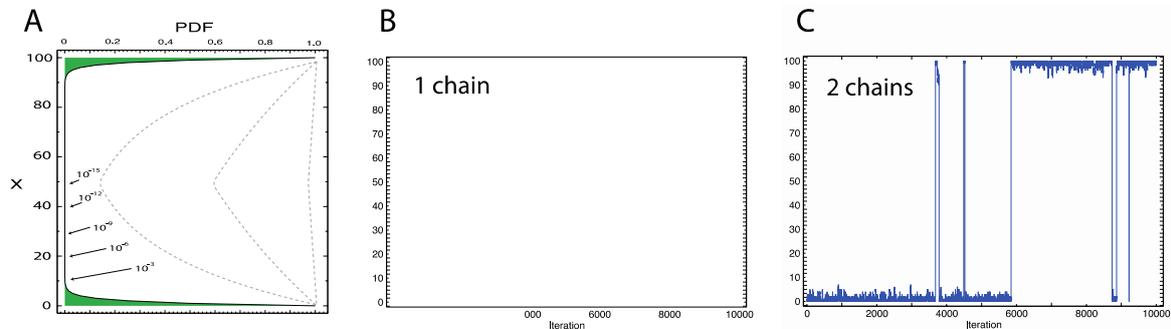
Malcolm Sambridge

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

Nonlinear inverse problems in the geosciences often involve probabilistic sampling of multi-modal density functions or global optimisation and sometimes both. Efficient algorithmic tools for carrying out sampling or optimisation in challenging cases are of major interest. A project over the past year has involved numerical experiments with a technique, known as Parallel Tempering which is able to significantly accelerate Markov chain Monte Carlo inversion algorithms. We have compared Parallel Tempering to related methods such as Simulated Annealing and Simulated Tempering for optimisation and sampling respectively. A key feature of Parallel Tempering is that it satisfies the detailed balance condition required for convergence of Markov chain Monte Carlo algorithms (MCMC) while improving the efficiency of probabilistic sampling. Numerical results have been obtained on use of Parallel Tempering for trans-dimensional inversion of synthetic seismic receiver functions and also the simultaneous fitting of multiple receiver functions using global optimisation. These suggest that its use can significantly accelerate sampling algorithms and improve exploration of parameter space in optimisation.

The figure below shows an example of our locally designed variant to Parallel Tempering applied to the probabilistic sampling of a difficult double highly peaked

probability density function dependent on a single variable X (Panel A). This PDF has high probability peaks at $X=0$ and $X=100$, and extremely low probability region between the two peaks at $X=50$ which is a barrier to Markov chains. A standard MCMC sampler which starts in the chain at $X=0$ is trapped there (see panel B) and a Tempered MCMC sampler is able to jump between peaks and explore the space more effectively.



The generality and demonstrated performance of Parallel Tempering suggests that there is significant potential for applications to both sampling and optimisation problems in the geosciences.

Three-dimensional lithospheric structure of a craton edge from passive seismic methods

A close look at the Albany-Fraser Orogen in Western Australia

Christian Sippl¹, Hrvoje Tkalčić¹, Brian L. N. Kennett¹, Catherine Spaggiari² and Klaus Gessner²

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

² *Geological Survey of Western Australia (GSWA), Perth, Australia*

The crustal and lithospheric properties of Archaean cratons, both in Australia and elsewhere, have been studied in some detail, and although many questions are still to be answered, a basic model of cratonic lithospheric structure has emerged. Archaean crust is exempt from the general trend that crustal thickness increases with continent age, instead is on average significantly thinner than in most Proterozoic regions, not deviating far from the global average thickness of continental crust (35 km). Receiver function studies at different cratons have shown an overall absence of intracrustal velocity discontinuities and a clearly defined, sharp Moho. Below that, cold and chemically depleted mantle lithosphere of an age comparable to that of the overlying crust extends to depths of about 200 km.

The margins of these cratons, usually suture zones from the collisions between different cratonic blocks, however, have not been studied very extensively, and the processes of craton reworking and accretion are currently not well understood. The sparse data that exist show thicker crust and a more diffuse Moho in these regions, which often exhibit considerable structural complexity.

In this experiment, we want to resolve the detailed 3D crustal and lithospheric structure of the Albany-Fraser orogen in Western Australia, which is situated along the southeastern rim of the Yilgarn craton (see Figure 1). Since its formation by the collision between the Western Australian Craton and the Mawson Craton about 1.3 Ga ago, there have been virtually no major tectonic events in that region that could have overprinted the old suture zone signature, i.e. the original structure of this orogen is extraordinarily well preserved.

An array of 40 seismometers has been set up in the Albany-Fraser region in November 2013, and continuous three-component waveform data will be recorded for two years, with a southward shift of the array at midterm (see Figure 1). Passive seismic methods will be employed to complement the results from two active seismic profiles that have been shot in 2012 directly to the north and south of the array, and will enable us to extend lithospheric imaging of the Albany-Fraser orogen into the third dimension.

Analysis methods will include ambient noise tomography, joint inversion of receiver function and surface wave dispersion data and possibly direct imaging of subsurface discontinuities with station autocorrelograms. Transdimensional Bayesian Inversion methods, recently developed at RSES, will be applied to this large dataset, and obtained results will be interpreted in conjunction with aeromagnetic and -gravity data and magnetotelluric sounding results.

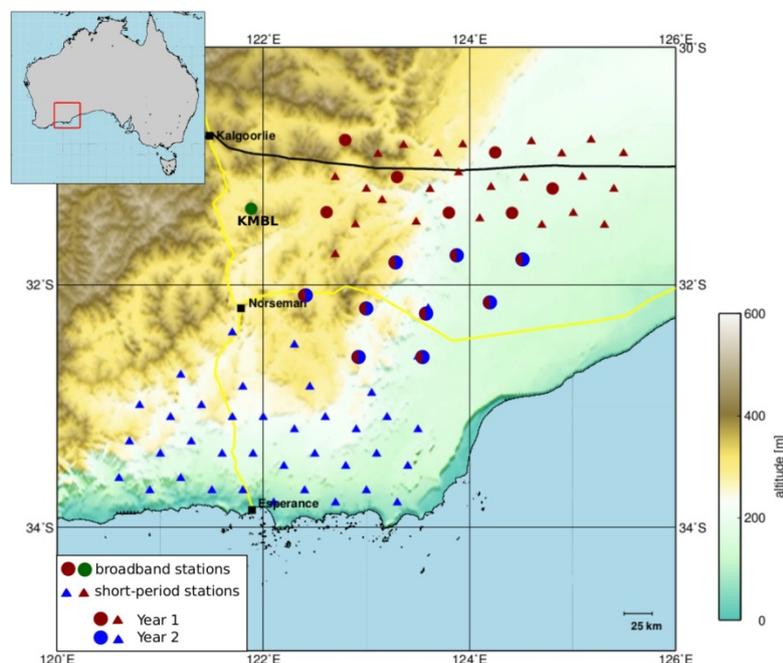


Figure 1. Map of currently deployed (brown) and planned (blue) seismic stations.

Multi-array, multi-frequency probing of the earth's heterogeneity

Josip Stipčević¹, Hrvoje Tkalčić¹, Brian L. N. Kennett¹ and Satoru Tanaka²

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

² *Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan*

Variations in elastic properties of the Earth's crust and mantle, such as those induced by changes in local chemistry, scatter seismic energy. Many of the seismic phases that need to be observed in order to infer small-scale heterogeneity, particularly at great depth, are often so attenuated that it is difficult to identify them on a single seismogram. In addition, small-scale seismic structures cannot be directly imaged by seismic tomography. The use of seismic arrays allows signals with small amplitudes to be enhanced by exploiting the coherency of waveforms at adjacent stations. The benefits of array technology have been recognised in many fields that analyse wavelike disturbances. The combination of results from many sensors allows the enhancement of coherent signals and the suppression of incoherent 'noise'.

The main goal of this recently funded ARC Discovery Proposal (DP130101374) is to extend array techniques from single to multiple, simultaneously operating networks of seismic instruments, to provide finer control on the nature of structure within the Earth. We proposed to use data from a seismic event to 'triangulate' on the source of the anomalies and refine understanding of the nature of heterogeneities. By looking at the various phases in the seismic records we can achieve multiple coverage of the mantle and hence provide additional sources of information. New methods will be developed for exploiting multiple arrays using both short-period and broad-band data together to gain improved resolution going below the resolution limit of seismic tomography. This translates to about 10 km or smaller near the surface and about 100 km near the core-mantle boundary. Such fine scale structure is likely to have stronger correlation with trace-element geochemistry than larger scale anomalies dominated by major element variations. It is at these fine scales that we hope to be able to reconcile geophysical and geochemical views on Earth development.

The backbone of this experiment will be two temporary arrays; one that we deployed in Queensland in November 2013 (Figure 1) and another, deployed in Western Australia (see the research highlight of Sippl et al.). In addition, we will exploit the fixed seismic arrays in Australia (WRA, ASAR in the Northern Territory, and the new PSAR array in the Pilbara) linked to nearby deployments of broad-band stations. This will provide a new style of seismological experiment with multiple arrays in reasonable proximity being used to study the same events and exploit Australia's unique geology and location relative to major seismogenic zones. We also aim to link the networks in Australia and Asia such as Hi-net and F-net in Japan to provide a unique tool to look deep into the Earth.

DP130101374 ARC Discovery Project Multi-Array, Multi-Frequency Probing of the Earth's Heterogeneity, Hrvoje Tkalčić, Brian L. N. Kennett and Satoru Tanaka.

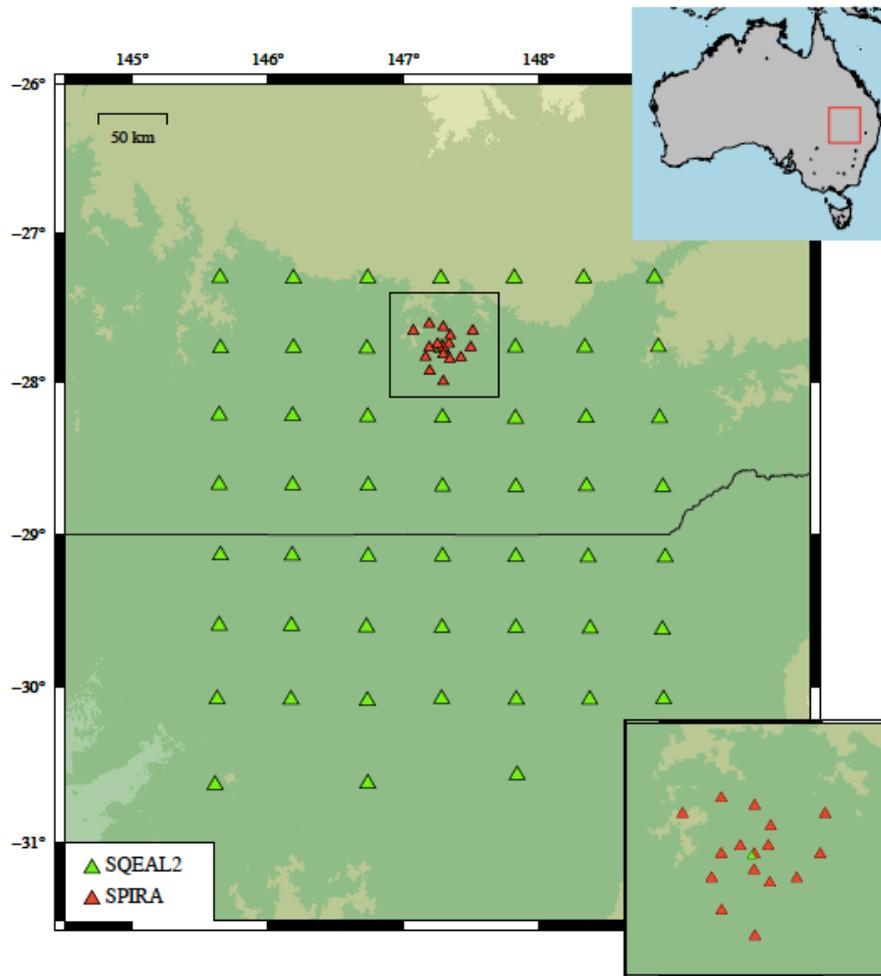


Figure 1. Map of deployed stations for large aperture array - SQEAL2 (green) and small aperture array – SPIRA (red).

A decade of horizontal deformation from great earthquakes

Paul Tregoning¹, Herb McQueen¹, Reed Burgette², Simon McClusky¹, Sandrine Lejeune³, Christopher Watson¹ and Herb McQueen¹

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

² Surveying and Spatial Science Group, School of Geography and Environmental Studies, University of Tasmania

³ Royal Meteorological Institute of Belgium

The 21st Century has seen the occurrence of 17 great earthquakes ($M_w > 8$), including some of the largest earthquakes ever recorded. Numerical modelling of the earthquakes shows that nearly half of the Earth's surface has undergone horizontal co-seismic deformation > 1 mm, with the 2004 Sumatra-Andaman earthquake dominating the global deformation field. This has important implications for both the

realisation of a terrestrial reference frame and in the interpretation of regional tectonic studies based on GPS velocities. We show that far-field co-seismic deformations from great earthquakes will, if unaccounted for, introduce errors in estimates of linear site velocities of at least 0.1-0.3 mm/yr across most of the surface of the Earth. The accumulated global deformation field shows that two regions, Australia and the north Atlantic/Arctic Ocean, have been largely undeformed by these great earthquakes, with accumulated deformations generally <0.5 mm. Using GPS estimates of surface deformation, we show that the majority of the Australian continent is deforming at <0.2 mm/yr, the northern part of New Zealand is rotating clockwise relative to the Australian Plate with relative horizontal velocities of ~2 mm/yr, while the southeastern coast of Australia is undergoing post-seismic relaxation caused by the 2004 Mw=8.1 Macquarie Ridge earthquake. The presence of ongoing post-seismic relaxation thousands of kilometres from plate margins violates the secular/linear assumption made in current terrestrial reference frame definitions. These effects have significant ramifications for regional tectonic interpretations and global studies such as sea level rise that require reference frame accuracy greater than this level.

Paper published in Journal of Geophysical Research:
<http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50154/abstract>

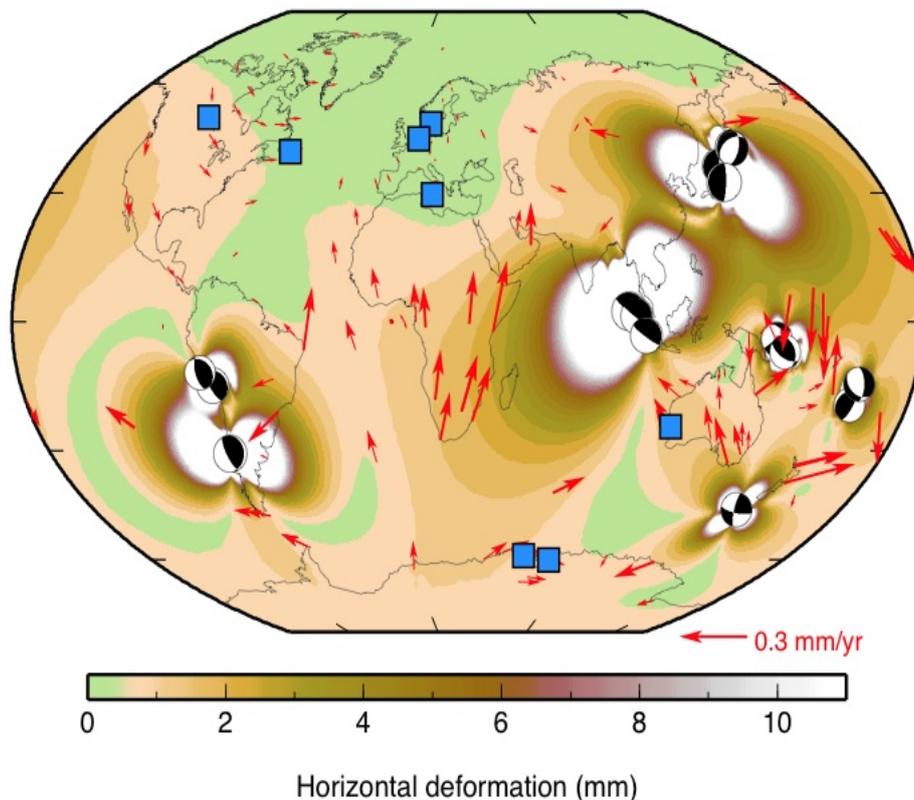


Figure 1. Accumulated co-seismic horizontal deformation field of great earthquakes (Mw>8) since 2000. Focal mechanisms are from the Global Moment Tensor catalog [Ekstrom et al., 2012]. GPS sites used to define the terrestrial reference frame are shown (blue squares), along with far-field site velocity errors (red arrows) induced by not accounting for the co-seismic horizontal deformations of the great earthquakes

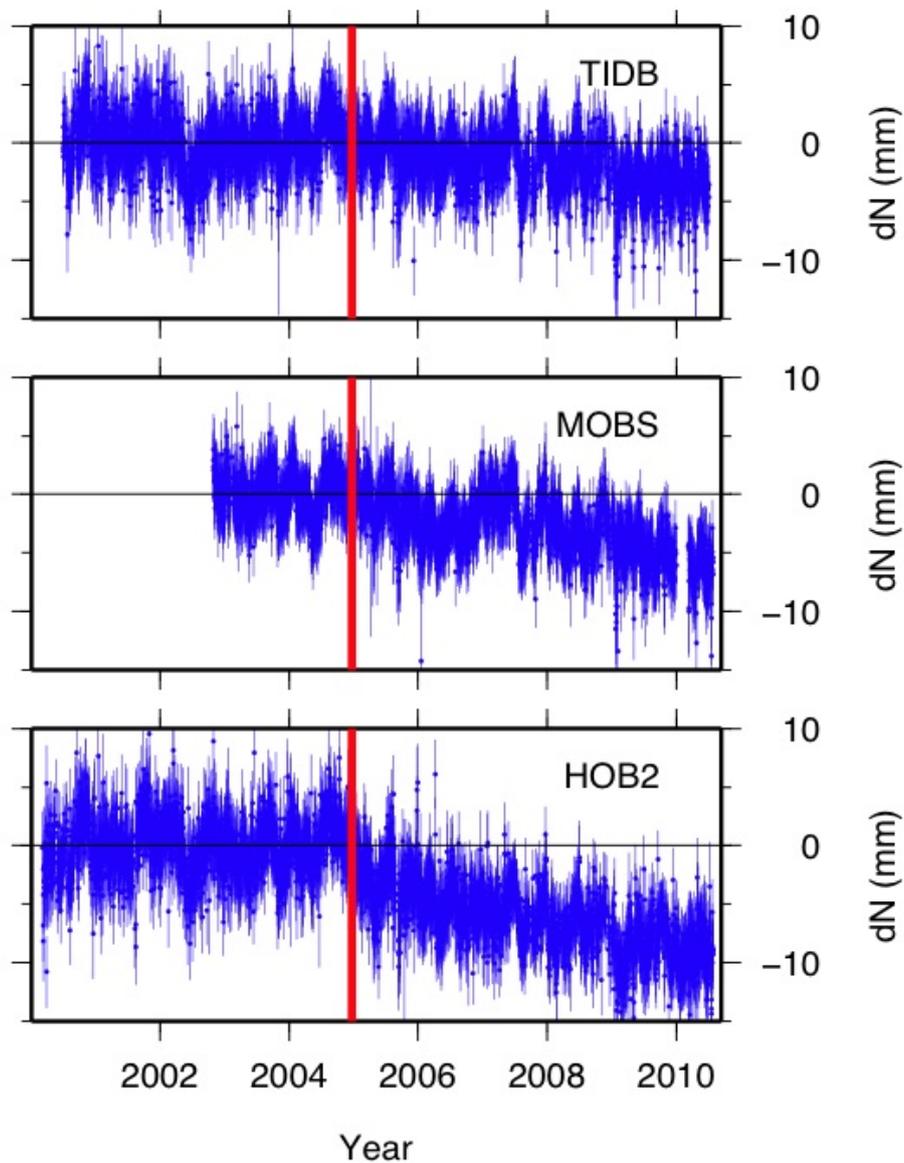


Figure 2. GPS time series of the north components at Hobart (HOB2), Melbourne (MOBS) and Canberra (TIDB), detrended over the pre-earthquake period (2000-2004.9). 100-day running mean is plotted. Vertical lines indicate the date of the Macquarie Island earthquake.

Application of hierarchical transdimensional tomography to ambient seismic noise data from a large transportable array in eastern Australia

Mallory Young¹, Nick Rawlinson¹, Ross Cayley², Mark MacLean², Pierre Arroucau³ and Michelle Salmon¹

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

² Department of Primary Industries, Geological Survey of Victoria, Melbourne, VIC, Australia

³ Center of Research Excellence in Science and Technology, North Carolina Central University, Durham, NC, United States

Seismic tomography methods which recognise the spatially variable resolving power of seismic datasets through the use of static or adaptive irregular parameterizations have become increasingly common over the last decade. A frequently used approach is to pre-set the irregularity prior to inversion based on readily quantifiable information such as path density. More sophisticated techniques allow the parameterization to vary during the course of the inversion, although a robust criteria for parameter refinement remains elusive. An alternative approach is to use a set of overlapping regular grids across a range of different scales, as is done with a wavelet parameterization. In this study, we make use of a hierarchical Bayesian transdimensional formulation which attempts to maximize the role of the data in determining the spatial distribution of information that is recovered. Key attributes of this approach include: (1) solution represented by a large ensemble of data-fitting models; (2) parameter values are unknowns in the inversion; (3) parameter distribution is an unknown in the inversion (4) number of parameters is an unknown in the inversion; (5) level of data noise is an unknown in the inversion; (6) fully non-linear stochastic search for model unknowns with natural parsimony. Although computationally expensive, this data driven approach to inversion seeks to minimize the need for arbitrary user settings that influence the inversion results.

We apply the Bayesian transdimensional tomography scheme to Rayleigh wave phase dispersion data obtained from the long-term cross-correlation of ambient seismic noise recorded by the WOMBAT transportable array in eastern Australia. WOMBAT has been in operation since 1998, and to date has involved 15 consecutive array movements with a cumulative total of over 700 stations deployed at spacings varying between 15-50 km. Here, a subset of the mainland data is used to investigate the crustal structure of the east Gondwana margin in southeast Australia. The transdimensional scheme is applied in two stages: first, to recover phase velocity maps from the dispersion data over a range of periods, then to extract a dense grid of 1-D shear wave velocity profiles that can be merged to form a pseudo 3-D shear wave velocity model. An advantage of our approach is that data uncertainty is propagated through the sequence of inversions, thus resulting in a reliable posterior probability distribution from which robust features can be inferred. The pattern of 3D velocity variations helps elucidate the geometry and position of key crustal features associated with the transition from Paleozoic eastern Australia to Precambrian central and western Australia that were formed along the proto-Pacific margin of east Gondwana.

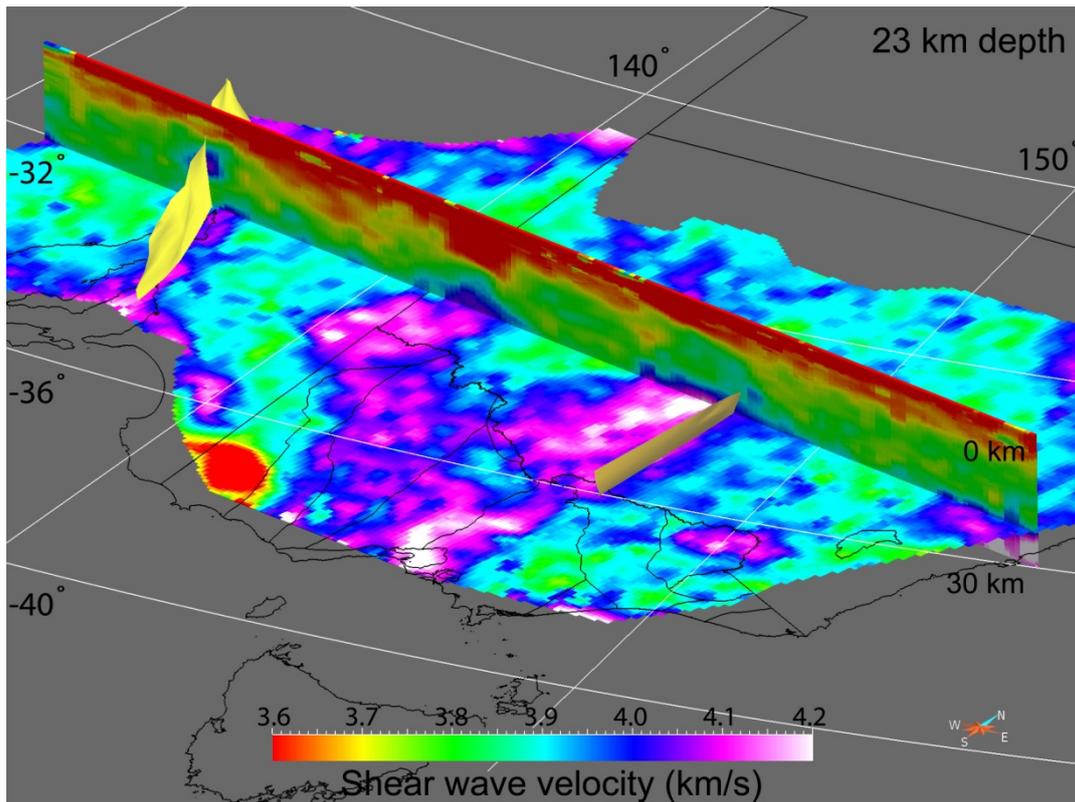


Figure 1. Vertical and horizontal section through 3-D shear wave speed model of the crust beneath southeast Australia determined by the transdimensional tomography technique.

Strong, multi-scale heterogeneity in earth's lowermost mantle

Mallory Young and Hrvoje Tkalčić

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

Approximately 2,890 km beneath the Earth's surface, the core mantle boundary separates the liquid iron core from the slowly convecting solid mantle. The ~300 km thick barrier above the boundary remains largely an enigma and has proven to be far more than a simple dividing line; rather it is a complex region with a range of proposed phenomena such as thermal and compositional heterogeneity, partial melting, anisotropy. Characterizing the heterogeneity in the lowermost mantle will prove crucial to accurately understanding key geodynamical processes within our planet.

In this project we obtain high-resolution compressional wave velocity images and uncertainty estimates for the lowermost mantle using old and newly collected travel time data sensitive to the lowermost mantle and core and collected by waveform cross-correlation. The images obtained by the inversion technique are void of explicit model parameterization and smoothing.

Subsequent spectral analyses reveal a power of heterogeneity three times larger than previous estimates and a multi-scale wavelength content in the P-wave velocity field of the lowermost mantle. The newly obtained P-wave tomographic images of the lowermost mantle are not dominated by harmonic degree 2 structure as is the case for tomographic images derived from S-wave data. Instead, the heterogeneity size is more uniformly distributed between about 500 and 6000 km. Inter alia, the resulting heterogeneity spectrum provides a bridge between the long-wavelength features of previous global models and the very short-scale dimensions of scatterers mapped in independent studies. Last but not least, our P-wave velocity images confirm that most ultra low velocity zones are found near the edges of long-wavelength features in the lowermost mantle.

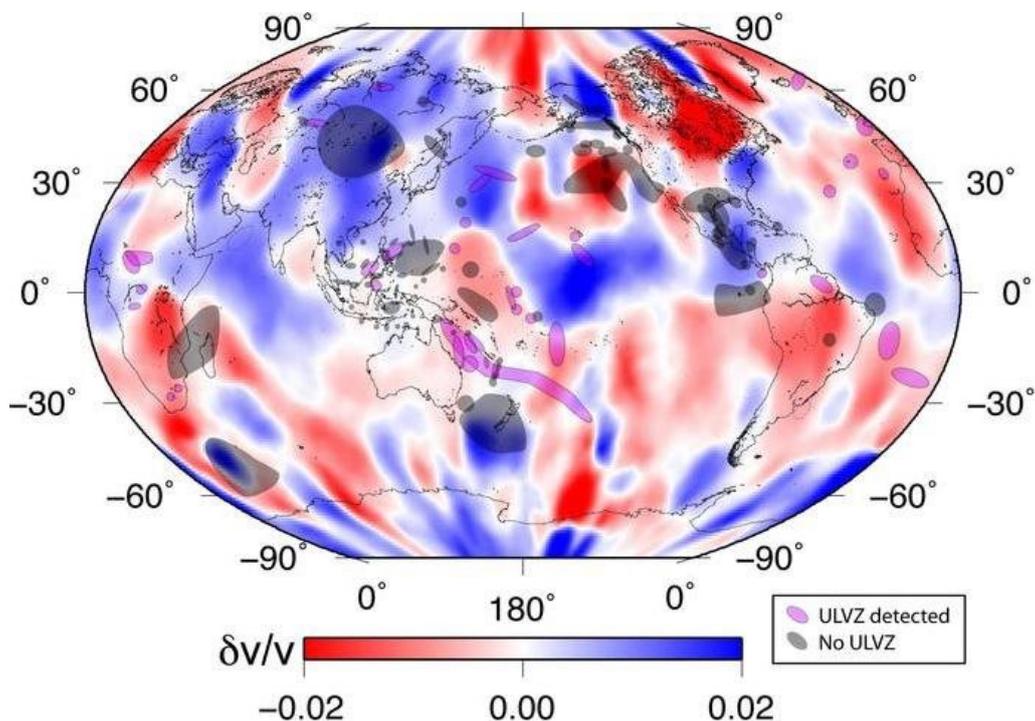


Figure 1. Detected (pink) and undetected (gray) ultra low velocity zones as reported in McNamara et al. (2010) plotted against the preferred P-wave velocity model obtained in this study.

Upper crustal structure of central Java-Indonesia from high resolution transdimensional seismic ambient noise tomography

Zulfakriza¹, Erdinc Saygin², Phil Cummins², Sri Widiyantoro¹, Andri Dian Nugraha¹, Birger-G. Luhr³ and Thomas Bodin⁴

¹ Institute of Technology Bandung, Bandung, 40132, Indonesia

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

³ GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam, Germany

⁴ Berkeley Seismological Laboratory, University of California at Berkeley, Berkeley, California 94720, USA

Delineating the crustal structure of central Java is crucial for understanding its complex tectonic setting. However, seismic imaging of the strong heterogeneity typical of such a tectonically active region can be challenging, particularly in the upper crust where velocity contrasts are strongest and steep body wave raypaths provide poor resolution. To overcome these difficulties we apply the technique of ambient noise tomography (ANT) to data collected during the Merapi Amphibious Experiment (MERAMEX), which covered central Java with a temporary deployment of 120 seismometers during May-October 2004. More than 8000 Rayleigh wave Green's functions were extracted by cross-correlating the noise simultaneously recorded at available station pairs. We applied a fully nonlinear 2D Bayesian probabilistic inversion technique to the retrieved travel times. Features in the derived tomographic images correlate well with previous studies, and some shallow structures that were not evident in previous studies are clearly imaged with ANT. The Kendeng Basin and several active volcanoes appear with very low group velocities, and anomalies with relatively high velocities can be interpreted in terms of crustal sutures and/or surface geological features.

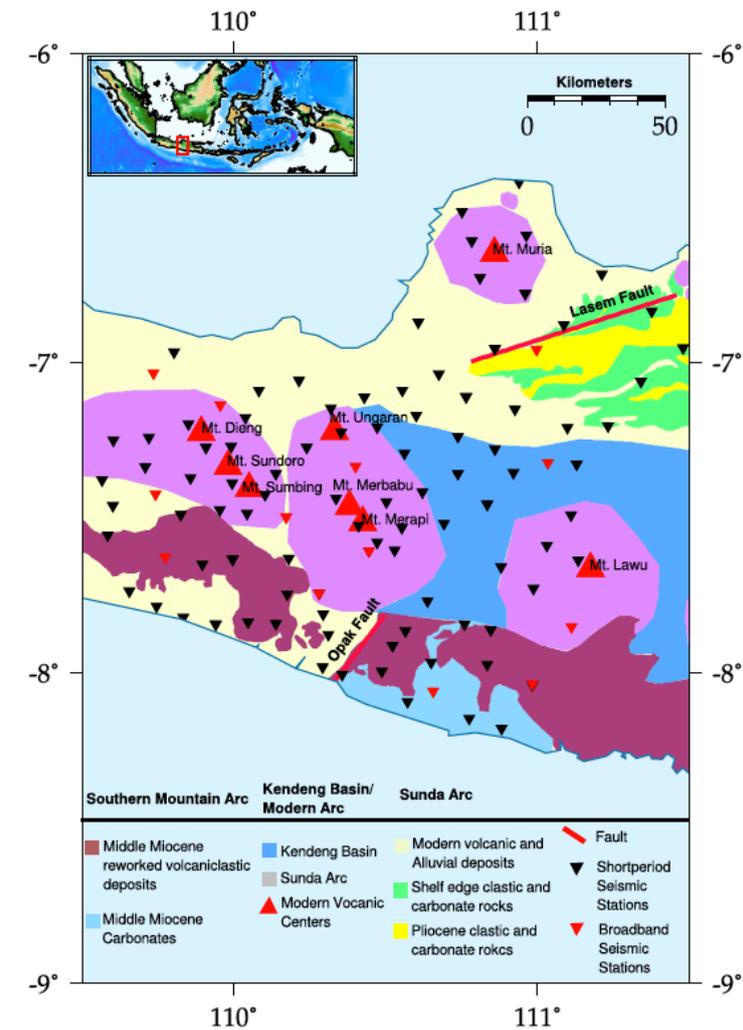


Figure 1. Map of geological features and the MERAMEX seismic stations that were operated around central Java-Indonesia, 106 short period seismometers (black triangles), 14 broadband seismometers (red triangles). Red triangles show the location of volcanoes. Studied area (red box) is showing the index map.

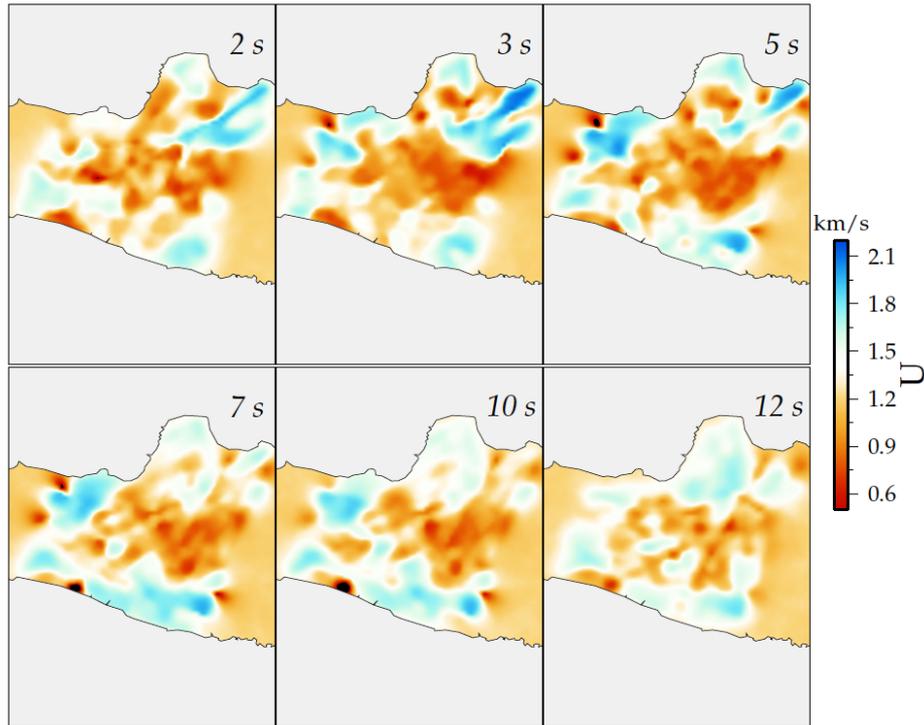


Figure 2. Tomographic inversion results for Rayleigh wave group velocities between 2 s and 12 s shown in map view.

PRISE

Introduction

The PRISE group operates as an externally funded unit within the Research School of Earth Sciences, providing analytical and research expertise to clients and collaborators in the areas of geochronology, geochemistry and archaeology. While the emphasis is necessarily on commercial projects, PRISE staff also continued their involvement in research projects supported by successful grant applications, both domestic and international. As in previous years, projects have been primarily SHRIMP-based and focussed mainly in South America, Africa and Southeast Asia.

During the year, PRISE was pleased to host fourteen local and international visitors, working collaboratively on a wide range of geological, geochemical and archaeological projects. In addition, PRISE academic staff supervised activities of both RSES and international postgraduate students.

Through the provision of research and analytical expertise to industry and Government agencies on a commercial basis and enhanced cost recovery on collaborative projects, the PRISE group generated income of \$1,189K during 2013. Of this, 52% derived from commercial projects and 40% from international collaborations. A total of \$390,709 was transferred to Areas within the School for instrument and laboratory use and a further \$242,275 was paid into School funds in the form of invoice overheads.

In addition, thirty-three peer-reviewed articles were co-authored by PRISE staff, working mainly with international collaborators. Most of these were published in highly ranked national and international journals.

Technical support from the Mineral Separation laboratory staff has been pivotal to our continued success and we wish to extend our thanks and appreciation for the exceptional service provided by Shane Paxton. We are also grateful for assistance provided by technical staff responsible for instrument maintenance, including particularly SHRIMP support provided by Peter Holden.

Congratulations are due to Dr Bin Fu on the reclassification of his position and to Dr Richard Armstrong on his promotion to Senior Fellow during the 2013 academic promotions round.

We are grateful to our colleagues on the PRISE Board of Management for their continued support and advice.

Brenda Armstrong

PRISE Business Officer

IODP

PHASE 1, THE INTEGRATED OCEAN DRILLING PROGRAM BECAME

PHASE 2, INTERNATIONAL OCEAN DISCOVERY PROGRAM IN LATE 2013

IODP is the world's largest geoscience research program, with access to drilling facilities worth \$US1 billion, and annual operational costs of about \$US210 million. It is at the frontier of scientific challenges and opportunities, because ocean drilling is the best method of directly sampling the two-thirds of our world that is covered by the world's oceans. IODP aims to solve global scientific problems by taking continuous core of rocks and sediments at a great variety of sites in the world's oceans, from as deep as several kilometres below the sea bed. Its broad aim is to explore how the Earth has worked in the past and how it is working now. It uses a variety of platforms, and provides 'ground truthing' of scientific theories that are based largely on remote sensing techniques.

IODP's key research areas in Phase 1 (to September 2013) were:

- Deep biosphere and ocean floor
- Environmental changes, processes and effects
- Solid earth cycles and geodynamics.

In Phase 2 (from October 2013) they are:

- Climate and Ocean Change
- Biosphere frontiers
- Earth connections
- Earth in Motion

Australia and New Zealand are partners (www.iodp.org.au; <http://drill.gns.cri.nz>) in the ANZIC consortium within IODP, which involves both geoscientists and microbiologists. We are making important contributions to IODP's scientific endeavours, and a number of major coring expeditions in our region and elsewhere have improved and will improve our understanding of global scientific questions. IODP is a scientific crucible for bringing our scientists in contact with research teams from around the world, and post-cruise research activities often extend far beyond IODP activities.

Membership of IODP helps us maintain our leadership in Southern Hemisphere marine research. For geographic, climatic, oceanographic and plate tectonic reasons, our region is vital to addressing various global science problems. Accordingly, the Australasian region has seen a great deal of ocean drilling since 1968, when the first program was established. Australia will provide two Co-Chief Scientists in the near future, one in 2014 (ANU's Richard Arculus) and one in 2015 (University of Melbourne's Stephen Gallagher). There is one confirmed IODP Expedition in

Australia's region in late 2015, and we expect more in the Australia-New Zealand-Antarctica region in 2016 and 2017

Australian scientists gain in various ways from IODP: by being on international IODP panels, through shipboard and post-cruise participation in cutting edge science, by building partnerships with overseas scientists, by being research proponents and co-chief scientists who can steer programs and scientific emphasis, and by early access to key samples and data. Post-doctoral and doctoral students have an opportunity of training in areas of geoscience and microbiology that could not be obtained in any other way.

The Australian IODP budget, administered at RSES, was \$A2.2 million until 30 September 2013, of which \$US1.4 million went to the US National Science Foundation (NSF) as a membership fee. The new budget is \$A3 million, of which \$US1.5 million goes to NSF and \$US300,000 to the Japanese program. The Australian IODP Office (AIO) is headed by ANZIC Program Scientist, Professor Neville Exon, and Professor Richard Arculus is the lead Chief Investigator. Ms Catherine Beasley is the Program Administrator.

Prof Neville Exon

Program Scientist, Australian IODP Office

RESEARCH SUPPORT

ELECTRONICS GROUP

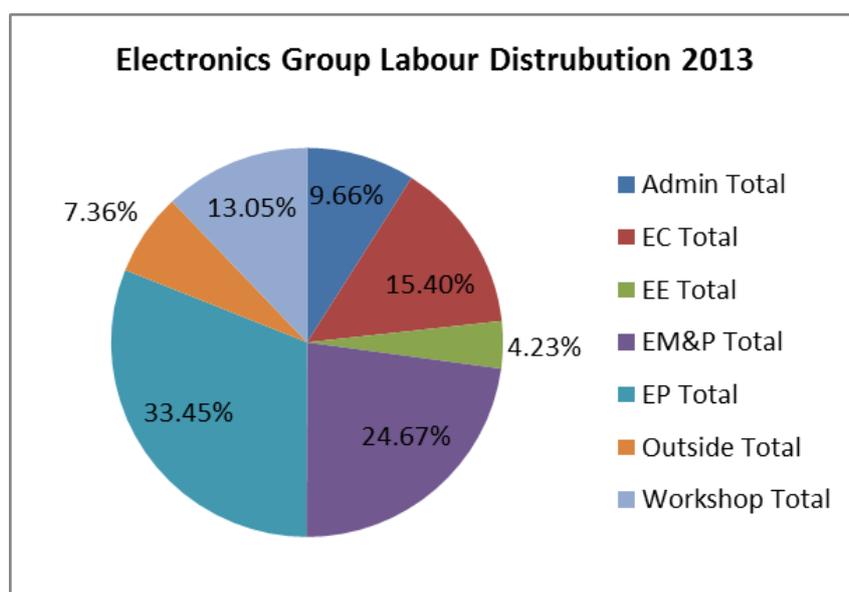
Introduction

The Electronics Group provides technical support to all Earth Sciences' academic research. The Group consists of one engineer, two senior technical offers and four technical officers. The Group holds the responsibility for maintaining and servicing electronic systems within RSES and offers a development facility able to engineer innovative electronic solutions. The Group provides a fast electronic circuit production facility utilising an automated component placement machine and reflow oven. This facility has improved our capability and allows us to construct new electronic designs in appropriate time. The Electronics Group endeavours to ensure the Research School of Earth Sciences remains a state of the art institution.

Administration

The Electronics Group functioned under new financial and management processes starting 2013, gaining responsibility for recovering one third salary costs to make the Group coherent with other Earth Sciences' technical positions. RSES administration introduced an apt increase to the Groups hourly charge rate to \$30/h for 2013. The Group maintained over 80% chargeable hours against capacity for 2013.

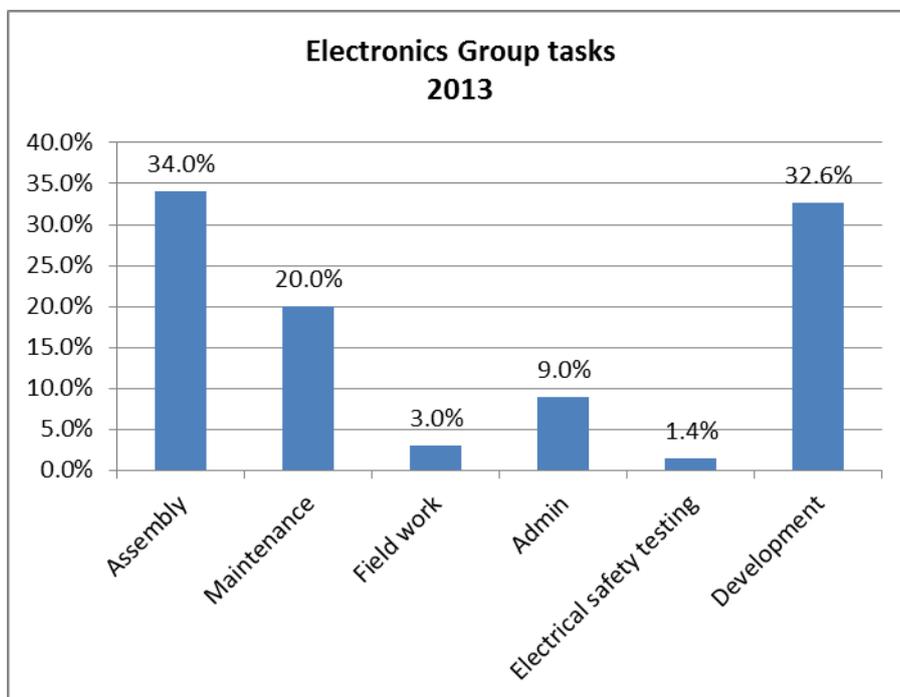
This year the Group has worked on various other engineering developments which resulted in a distribution of resources across Earth Sciences' research areas. The Groups time allocations were 33% Earth Physics, 25% Earth Materials & Processes, 15% Earth Chemistry 4% Earth Environment, 7% external clients, 10% Admin (including Safety tagging) and 13% Electronics Group internal developments and administration.



Engineering Developments

The Electronics Group began 2013 with the ANU Seismic Recorder project in progress; the Group successfully completed the shipment of 260 seismic recorder units, 330 batteries and controllers by the August deadline. During 2013 this device has been operating in remote areas of NSW, Jakarta Indonesia, Antarctica and Northern Territory, immediately returning accurate data and demonstrating the robustness of the project. This achievement has only been possible with the professionalism and commitment of the Electronics Group, each member contributed to realising the project goal.

The Electronics Group has kept up with the heavy electronics maintenance load of the school using 20% of labour resources to fault find and repair equipment. This year the Electronics Group provided maintenance services and consultation with zero waiting periods. The operation of school facilities carries the highest priority and staff members promptly attend failures.



The Electronics Group's Research and Development projects conducted this year:

Earth Materials and Processes

- ARGUS VI sample manipulator.
- ARGUS VI furnace design.
- ARGUS VI cryogenic cooler controller design and fabrication.
- Attenuation apparatus electronics system upgrade and implementation.
- RIG 1 Electronics system upgrade and implementation.
- One atmosphere furnace mass flow system design.
- New generation 200T press design.
- High pressure piston cylinder 500T press automation.

- Sandbox actuator design and implementation.

Earth Physics

- ANU Seismic Recorder fabrication.
- ANU Seismic Recorder engineering developments.

Earth Chemistry

- IFLEX design update.
- Tesla Tamer design update and fabrication.
- Digital motor controller development.
- MAT261 Electronics system upgrade and implementation.
- Graphitization furnace automation software development.
- STE microprocessor update to printed circuit board.

Earth Environment

- Laser ablation cell motorisation implementation.
- Laser ablation cell alignment and gas shield unit.
- Cell spectrometer pump and valve controller.

During 2013 the Electronics Group has broadened its range of support to the Research School of Earth Sciences by providing technical expertise on several field trips locally and abroad. The Electronics Group sent technical officers to participate with Seismology and Mathematical Geophysics research group's field trips to upgrade to its Southern Queensland / Eastern Australian and Jakarta seismic arrays.

Outlook

The Electronics Group's budget for 2014 contains purchases including, high speed oscilloscope Agilent MSO6052 instrument, accurate high speed counting unit, signal generator and magnetic field meter. Other purchases include upgrading the Group's field work laptops and extraction system for reflow oven. 2014 promises to be a challenging year for the Electronics Group with the end of long term projects allowing resources to be focused on different areas and projects. The Groups succession planning remains steady for the foreseeable future with all members indicating their intention to stay and contribute to the year ahead.

ENGINEERING WORKSHOP

Introduction

Continuation of two projects along with development of existing equipment kept the staff busy. The usual number of smaller jobs was mostly apparent during the first half of the year.

A relatively high percentage of time (15.4%) was spent on work external to the ANU however much of this time was worked as overtime outside regular hours. Training, maintenance and administration time was higher than in previous years.

Workshop income now contributes 1/3 of workshop salaries to the school. This brings workshop staff in line with the funding arrangements in place for other technical staff in the school.

Engineering Workshop Highlights

High temperature furnaces and sample changers for Argus6 Mass Spectrometer, Dr Marnie Forster (Thomson, Wilson, Woodward)

Seismic Recorders, Dr Nick Rawlinson (Thomson, Butler, Were, Miller)

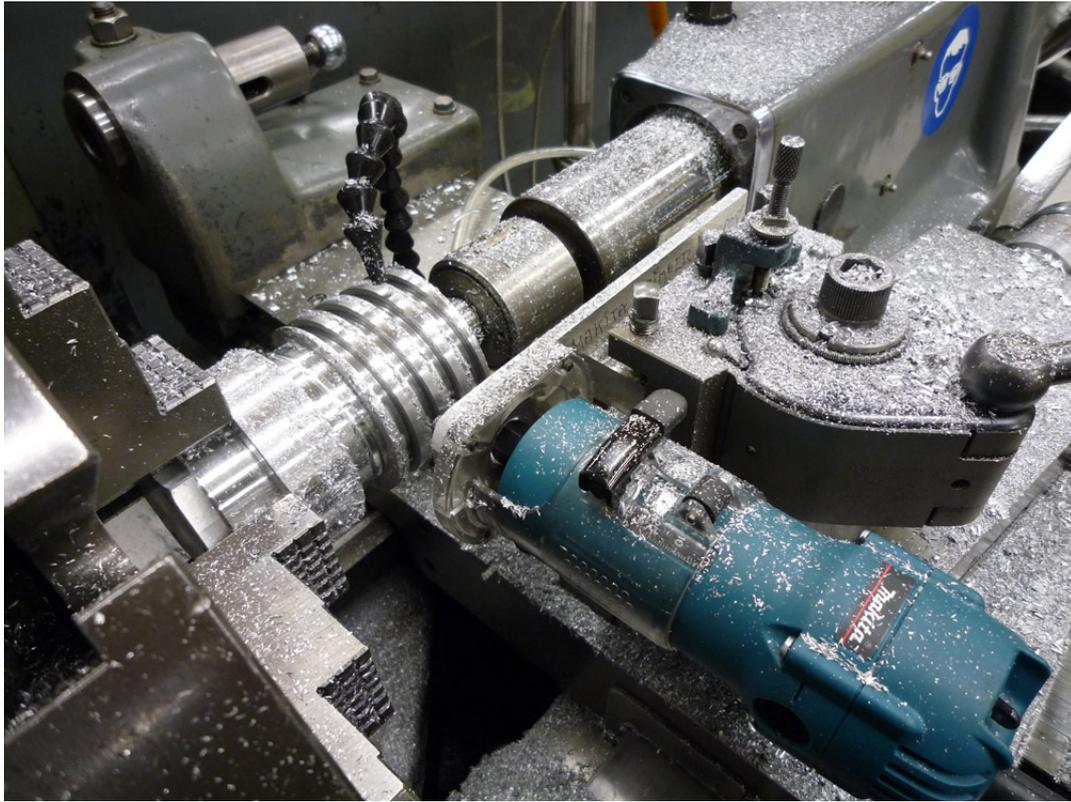
SHRIMP Development (Thomson, Miller, Butler)

Gas Shield and motorisation of position actuators for Laser ICPMS, Dr Stephen Eggins (Woodward, Were)

Deformation Sandbox, Prof Stephen Cox (Butler, Woodward)

Press refurbishments, Prof Hugh O'Neill (Were, Thomson, Butler, Wilson)

Table1: RSES Engineering Workshop Resource Distribution		
Labour Totals	Hours	%
Uncharged Jobs	1725	22.7
Research Support	4691	61.9
External Work	1166	15.4
Total	7582	
Uncharged Work		
Staff Training	332	19.3
Administration	662	38.4
Workshop Infrastructure	147	8.5
Machine Maintenance	439	25.4
Other	145	8.4
Total	1725	
Research Support Distribution		
Earth Chemistry	969	20.7
Earth Environment	893	19.1
Earth Materials	1986	42.3
Earth Physics	682	14.5
Other ANU Clients	161	3.4
Total	4691	



Improvisation- Cryogenic insert for Argon Line.

PUBLICATIONS

Earth Chemistry

Adams C.J., Bradshaw J.D., Ireland T.R. (2013) Provenance connections between late Neoproterozoic and early Paleozoic sedimentary basins of the Ross Sea region, Antarctica, southeast Australia and southern Zealandia, *Antarctic Science* (Published on-line 17 Jul 2013).

Álvarez-Fernández E., Carriol R.P., Jordá J.F., Aura J.E., Avezuela B., Badal E., Carrión Y., García-Guinea J., Maestro A., Morales J.V., Perez G., Perez-Ripoll M., Rodrigo M.J., Scarff J.E., Villalba M.P., Wood R. (in press) Occurrence of whale barnacles in Nerja Cave (Málaga, Southern Spain), an indirect evidence of whale consumption by humans in the Upper Magdalenian, *Quaternary International*.

Amelin Y. (in press) Uranium-Lead, Extraterrestrial, Early Solar System, in Rink, W.J., Thompson, J.W. (Eds.) *Encyclopedia of Scientific Dating Methods*, Springer-Verlag, Berlin-Heidelberg.

Amelin Y. and Ireland T.R. (2013) The Solar System before planets: dating the oldest rocks and minerals, *Elements*, 9, 23-28.

Amelin Y. and Ireland T.R. (2013) Dating the oldest rocks and minerals in the Solar System, *Elements*, 9, 39-44.

Ávila J.N., Ireland T.R., Gyngard F., Zinner E., Mallmann G., Lugaro M., Holden P., Amari S. (2013) Ba isotopic compositions in stardust SiC grains from the Murchison meteorite: Insights into the stellar origins of large SiC grains, *Geochimica et Cosmochimica Acta*, 120, 628-647.

Ávila J.N., Ireland T.R., Lugaro M., Gyngard F., Zinner E., Cristallo S., Holden P., Rauscher T. (2013) Europium s-process signature at close-to-solar metallicity in stardust SiC grains from AGB stars, *Astrophysical Journal Letters*, 768, L18.

Bovaird T. and Lineweaver C.H. (2013) Exoplanet predictions based on the generalized Titius-Bode relation, *Monthly Notices of the Royal Astronomical Society*, 435, 1126, doi:10.1093/mnras/stt1357.

Brocks J.J., and Hope J.M. (2013) Tailing of chromatographic peaks in GC-MS caused by interaction of halogenated solvents with the ion source, *Journal of Chromatographic Science*, doi:10.1093/chromsci/bmt068, 1-5.

Carosi R., Montomoli C., Rubatto D., Visona D. (2013) Luecogranite intruding the South Tibetan Detachment in western Nepal: implications for exhumation models in the Himalayas, *Terra Nova*, 25, 478-489.

Buchholz B.A., Fallon S. J., Zermeno P., Bench G., Schichtel B. A. (2013) Anomalous elevated radiocarbon measurements of PM2.5, *Nuclear Instruments and Methods in Physics Research B*, 294, 631-635.

Cooper A.F. and Ireland T. R. (2013) Ages of sedimentation and metamorphism of the western Alpine Schists associated with the Pounamu Ultramafic Belt, Westland, New Zealand, *New Zealand Journal of Geology and Geophysics* (published on-line 06 Aug 2013).

Darrenougue N., De Deckker P., Payri C., Eggins S., Fallon S. (2013) Growth and chronology of the tropical, rhodolith-forming (*Sporolithon durum*) coralline red algae, *Marine Ecology Progress Series* 474, 105-119.

Demaiffe D., Wiszniewska J., Krzemińska E., Williams I.S., Stein H., Brassinnes S., Ohnenstetter D., Deloule E. (2013) A hidden alkaline and carbonatite province of Early Carboniferous age in Northeast Poland: zircon U-Pb and pyrrhotite Re-Os geochronology, *Journal of Geology*, 121, 91–104.

Douka K., Higham T.F.G., Wood R., Boscato P, Gambassini P, Karkanas T., Peresani M., Ronchitelli A. (in press) On the Uluzzian chronology, *Journal of Human Evolution*.

Espanon V. R., Honda M., Chivas A. R. (in press) Cosmogenic noble gas dating of young basaltic lavas from southern Mendoza, Argentina, *Quaternary Geochronology*.

Ewing T., Hermann J., Rubatto D. (2013) The robustness of the Zr-in-rutile and Ti-in-zircon thermometers during high-temperature metamorphism (Ivrea-Verbano Zone, northern Italy), *Contributions to Mineralogy and Petrology* 165:757-77.

Fallon S.J., Thresher R.E., Adkins J. (in press; available online 16th November, 2013) Age and growth of the cold-water scleractinian *Solenosmilia variabilis* and its reef on SW Pacific seamounts, *Coral Reefs*.

Fiannacca P., Williams I.S., Cirrincione R. & Pezzino A. (2013) The augen gneisses of the Peloritani Mountains (NE Sicily): Granitoid magma production during rapid evolution of the northern Gondwana margin at the end of the Precambrian, *Gondwana Research*, 23, 782–796.

Hermann J., Zheng Y.F., Rubatto D. (2013) Deep Fluids in Subducted Continental Crust, *Elements*, 9, 281-287.

Higham T., Wood R., Moreau L., Ramsey C.B. (2013) Comments on 'Human-climate interaction during the early Upper Palaeolithic: Testing the hypothesis of an adaptive shift between the Proto-Aurignacian and the Early Aurignacian' by Banks et al, *Journal of Human Evolution*, 65, 806-809.

Honda M., Phillips D., Kendrick M.A., Gagan M.K. and Taylor W.R. (2012) Noble gas and carbon isotope ratios in Argyle diamonds, Western Australia: Evidence for a deeply-subducted volatile component, *Australian Journal of Earth Sciences*, 59, 1135-1142.

Ireland T.R. (2013) Recent developments in isotope-ratio mass spectrometry for geochemistry and cosmochemistry, *Review of Scientific Instruments*, 84, 011101.

Jarrett A., Schinteie R., Hope J.M., Brocks J.J. (2013) Micro-ablation, a new technique to remove drilling fluids and other contaminants from fragmented and fissile rock material, *Organic Geochemistry*, 61, 57-65.

Jenner F.E. Bennett V.C., Yaxley G., Friend C.R.L., Nebel, O. (2013) Eoarchean within-plate basalts from S.W. Greenland, *Geology*, 41, 327-330.

Jorda Pardo J.F., Menendez Fernández M., Carral Gonzalez P.C., Quesada Lopez J.M., Wood R. (2013) Geoarchaeology and chronostratigraphy of the Middle-Upper Palaeolithic transition at the cave of La Guelga (Cangas de Onis, Asturias, Spain), In Pastoors A., Auffermann B. (Eds.) *Pleistocene Foragers on the Iberian Peninsula: Their culture and environment. Festschrift in honour of Gerd-Christian Weniger for his sixtieth birthday. Wissenschaftliche Schriften des Neanderthal Museums*, 7, Mettmann, 85-106.

Kehl M., Burrow C., Hilgers A., Navazo M., Pastoors A., Weniger G.-C., Wood R., Jorda Pardo J.F. (2013) Late Neanderthals at Jarama VI (central Iberia)?, *Quaternary Research*, 80, 218-234.

Kendrick M.A., Honda M., Pettke T., Scambelluri M., Phillips D., Giuliani A. (2013) Subduction zone fluxes of halogens and noble gases in seafloor and forearc serpentinites, *Earth and Planetary Science Letters*, 365, 86-96.

Kendrick M.A., Arculus R.J., Burnard P., Honda M., (2013) Quantifying brine assimilation by submarine magmas: Examples from the Galápagos Spreading Centre and Lau Basin, *Geochimica et Cosmochimica Acta*, 123, 150-165.

Komugabe, A.F., Fallon, S.J., Thresher, R.E., Eggins, S.M. (in press) Modern Tasman Sea surface reservoir ages from deep-sea black corals, *Deep-Sea Research Part II: Topical Studies in Oceanography*.

Lineweaver C.H., Davies P.C.W., Ruse M. Editors (2013) *Complexity and the Arrow of Time*, Cambridge University Press.

Lineweaver C.H., Davies P.C.W., Ruse, M. (2013) "What is Complexity? Is it Increasing?" introductory chapter in Lineweaver C.H., Davies P.C.W., Ruse M. (Editors) *Complexity and the Arrow of Time*, Cambridge University Press, 3-16.

Lineweaver C.H. (2013) A Simple Treatment of Complexity: Cosmological Entropic Boundary Conditions on Increasing Complexity, In Lineweaver C.H., Davies P.C.W., Ruse M. (Eds) *Complexity and the Arrow of Time*, Cambridge University Press.

Ling M., Liu Y., Williams I.S., Teng F., Yang X., Ding X., Wei G., Xie L., Deng W., Sun W., (2013) Formation of the world's largest REE deposit through protracted fluxing of carbonatite by subduction-derived fluids, *Scientific Reports*, 3, 1776.

Maidment D.W., Hand M., Williams, I.S. (2013) High grade metamorphism of sedimentary rocks during Palaeozoic rift basin formation in central Australia, *Gondwana Research*, 24, 865–885.

McCoy-West A.J., Bennett V.C., Puchtel I.S., Walker, R.J., (2013) Extreme persistence of cratonic lithosphere in the Southwest Pacific: Paleoproterozoic Os isotopic signatures in Zealandia, *Geology*, 41, 231-234.

McKibbin S.J., Ireland T.R., Amelin Y., O'Neill H.St.C., Holden P. (2013) Mn–Cr relative sensitivity factors for Secondary Ion Mass Spectrometry analysis of Mg–Fe–Ca olivine and implications for the Mn–Cr chronology of meteorites, *Geochimica and Cosmochimica Acta*, 110, 216-228.

McKibbin S.J., Ireland T.R., Amelin Y., Holden P., Sugiura N. (2013) A re-evaluation of the Mn–Cr systematics of olivine from the angrite meteorite D'Orbigny using Secondary Ion Mass Spectrometry, *Geochimica and Cosmochimica Acta*, 123, 181-194.

Mikulski S., Williams I.S., Baginski, B. (2013) Early Carboniferous (Viséan) emplacement of the collisional Kłodzko-Złoty Stok granitoids (Sudetes, SW Poland): constraints from geochemical data and zircon U-Pb ages, *International Journal of Earth Science*, 102, 1007–1027.

Milicich S.D., Wilson C.J.N., Bignall G., Pezaro B., Charlier B.L.A., Wooden J.L., Ireland T.R. (2013) U-Pb dating of zircon in hydrothermally altered rocks of the Kawerau geothermal field, Taupo Volcanic Zone, New Zealand, *Journal of Volcanology and Geothermal Research*, 253, 97-113.

Nutman A.P. Mohajjel M., Bennett V.C., Fergusson C., (in press) A dismembered Gondwanan Eoarchean – Neoproterozoic microcontinent in Iran and Turkey: Zircon U-Pb-Hf isotopic evidence, *Canadian Journal of Earth Sciences*.

Nutman A., Bennett V., Friend C.R.L.F., Hidaka H., Yi K., Lee S-R., Kamiichi T. (2013) The Itsaq Gneiss Complex of Greenland: Episodic 3900 to 3660 Ma juvenile crust formation and recycling in the 3660 to 3600 Ma Isukasian orogeny, *American Journal of Science*, 313, 877–911.

Nutman A., Bennett V., Friend C.R.L.F. (2013) The emergence of the Eoarchean proto-arc: Evolution of a ca. 3700 Ma convergent plate boundary at Isua, southern West Greenland. Geological Society, London, Special Publications 389.

O'Connor S., Maloney T., Vannieuwenhuysse D., Balme J., Wood R. (in press) Occupation at Carpenter's Gap 3, Windjana Gorge, Kimberley, Western Australia, *Australian Archaeology*.

Pawlowska M.M., Butterfield N. J., Brocks J. J. (2013) Lipid taphonomy in the Proterozoic and the effect of microbial mats on biomarker preservation, *Geology*, 41, 103–106.

Rankin D.W., Tucker R.D., Amelin Y. (2013) Re-evaluation of the Piermont-Frontenac allochthon in the Upper Connecticut Valley: Restoration of a coherent Boundary Mountains -Bronson Hill stratigraphic sequence, *Geological Society of America Bulletin*, 125, 998-1024.

Rickard M.J. and Williams I.S. (2013) No zircon U-Pb evidence for a Precambrian component in the Late Eocene Yavuna trondhjemite, Fiji, *Australian Journal of Earth Sciences*, 60, 521–525.

Rubatto D. (2013) Uranium-Lead, *Metamorphic Rocks*, In Rink J (Ed) *Encyclopedia of Scientific Dating Methods*, Springer.

Rubatto D., Chakraborty S., Dasgupta S. (2013) Timescales of crustal melting in the Higher Himalayan Crystallines (Sikkim, Eastern Himalaya) inferred from trace element-constrained monazite and zircon chronology, *Contributions to Mineralogy and Petrology*, 165, 349-372.

Skinner L.C., Scrivner A.E., Vance D., Barker S., Fallon S., Waelbroeck C.I. (2013) North Atlantic versus Southern Ocean contributions to a deglacial surge in deep ocean ventilation, *Geology*, 41, 667-670.

Smith M., De Deckker P., Rogers J., Brocks J. J., Hope J., Schmidt S., Lopes dos Santos R., Schouten S. (2013) Comparison of Uk'37, TEXH86 and LDI temperature proxies for reconstruction of south-east Australian ocean temperatures, *Organic Geochemistry*, 64, 94-104.

Storm P., Wood R., Stringer C., Bartsiokas A., de Vos J., Aubert M., Kinsley L., Grun R. (2013) U-series and radiocarbon analyses of human and faunal remains from Wajak, *Journal of Human Evolution*, 64, 356-365.

Strzepek K.M., Thresher R. E., Revill A., Smith C.I., Komugabe A.F., Fallon S.F., (in press; available online 26th July, 2013) Preservation effects on the isotopic and elemental composition of skeletal structures in the deep-sea Bamboo Coral *Lepidisis* spp. (Isididae), *Deep Sea Research Part II: Topical Studies in Oceanography*.

Sun W., Liang H., Ling M., Zhan M., Ding X., Zhang H., Yang X., Li Y., Ireland T. R., Wei Q., Fan W. (2013) The link between reduced porphyry copper deposits and oxidized magmas, *Geochimica et Cosmochimica Acta*, 103, 263-275.

Sun, Wei-dong, Chan-chan Zhang, Hua-ying Liang, Ming-xing Ling, Cong-ying Li, Xing Ding, Hong Zhang, Xiao-yong Yang, Trevor Ireland, Wei-ming Fan. (2013) The genetic association between magnetite–hematite and porphyry copper deposits: Reply to Pokrovski, *Geochimica et Cosmochimica Acta* (published on-line 09 Aug 2013).

Sun, Wei-dong, Chan-chan Zhang, Hua-ying Liang, Ming-xing Ling, Cong-ying Li, Xing Ding, Hong Zhang, Xiao-yong Yang, Trevor Ireland, Wei-ming Fan. (2013) The genetic association between magnetite–hematite and porphyry copper deposits: Reply to Richards, *Geochimica et Cosmochimica Acta* (published on-line 08 Aug 2013).

Wan Y., Zhang Y., Williams I.S., Liu D., Dong C., Fan R., Shi Y., Ma M. (2013) Extreme zircon O isotopic compositions from 3.8 to 2.5 Ga magmatic rocks from the Anshan area, North China Craton, *Chemical Geology*, 352, 108–124.

Wimpenny J.B., Amelin Y., Yin Q.Z. (2013) Precise determination of the lutetium isotopic composition in rocks and minerals using Multicollector ICPMS, *Analytical Chemistry*, 85, 11258–11264.

Wood R.E., Arrizabalaga A., Camps M., Fallon S., Iriarte-Chiapusso M.-J., Jones R., Maroto J., de la Rasilla M., Santamaría D., Soler J., Soler N., Villaluenga A., Higham T.F.G. (in press) The chronology of the earliest Upper Palaeolithic in Northern Iberia: New insights from L'Arbreda, Labeko Koba and La Viña, *Journal of Human Evolution*.

Wood R.E., Barroso-Ruiz C., Caparros M., Jorda J.F., Galvan Santos B., Higham T.F.G. (2013) Radiocarbon dating casts doubt on the late chronology of the Middle to Upper Palaeolithic transition in southern Iberia, *Proceedings of the National Academy of Sciences of the United States of America*, 111(23) E2087.

Wood R.E., Barroso-Ruiz C., Caparros M., Jorda J.F., Galvan Santos B., Higham T.F.G. (2013) Reply to de la Penya: Radiocarbon dating and the paleoenvironmental record of Carhuela, *Proceedings of the National Academy of Sciences of the United States of America*, 110, E2087.

Wood R.E., Higham T.F.G., Buzilova A., Suvorov A., Heinemeier J., Olsen J. (2013) Freshwater radiocarbon reservoir effects at the burial ground of Minino, Northwest Russia, *Radiocarbon*, 55, 163-177.

Wood R.E., Higham T.F.G., Torres T, Tisnerat-Laborde N., Valladas H., Ortiz J.E., Lalueza-Fox C., Sanchez-Moral S., Canaveras J.C., Roses A., Santamaria D., de la Rasilla M. (2013) A new date for the Neanderthals from El Sidron Cave (Asturias, Northern Spain), *Archaeometry*, 55, 148-158.

Wright D., Nejman L., d'Errico F., Králík M., Wood R., Ivanov M., Hladilová S. (in press) An Early Upper Palaeolithic decorated bone tubular rod from Pod Hradem Cave, Czech Republic, *Antiquity*.

Xue Y., Campbell I., Ireland T., Holden P., Armstrong R. (2013) No mass-independent sulfur isotope fractionation in auriferous fluids supports magmatic origin for Archaean gold deposits, *Geology*, 41, 791-794.

Zanchetta S., Poli S., Rubatto D., Zanchi A., Bove G.M. (2013) Evidence for deep subduction of Austroalpine crust (Texel Complex, NE Italy) *Rendiconti Lincei, Scienze Fisiche e Naturali*, 24, 163-176.

Zartman R.E., Kempton P.D., Paces J.B., Downes H., Williams I.S., Dobosi G., Futa K. (2013) Lower-crustal xenoliths from Jurassic kimberlite diatremes, Upper Michigan (USA): Evidence for Proterozoic orogenesis and plume magmatism in the lower crust of the southern Superior Province, *Journal of Petrology*, 54, 575–608.

Earth Environment

Abram N.J., Mulvaney R., Wolff E.W., Triest J., Kipfstuhl S., Trusel L.D., Vimeux F., Fleet L., Arrowsmith C. (2013) Acceleration of snow melt in an Antarctic Peninsula ice core during the twentieth century, *Nature Geoscience*, 6, 404-411, doi:10.1038/NGEO1787.

Abram N.J., Wolff E.W., Curran M.A.J (2013) A review of sea ice proxy information from polar ice cores, *Quaternary Science Reviews*, doi:10.1016/j.quascirev.2013.01.011.

Abram N.J. (2013) Antarctic ice...going, going, gone? in Dayton L. (Ed.) *The Curious Country*, 11-19.

Ayliffe L., Gagan M., Zhao J.-x., Drysdale R., Hellstrom J., Hantoro W., Griffiths M., Scott-Gagan H., St Pierre E., Cowley J., Suwargadi B. (2013) Rapid interhemispheric climate links via the Australasian monsoon during the last deglaciation, *Nature Communications*, 4,2908, doi:10.1038/ncomms3908.

Benson A., Kinsley L., Defleur A., Kokkonen H., Mussi M., Grün R. (2013) Laser ablation depth profiling of U-series and Sr isotopes in human fossils, *Journal of Archaeological Science*, 40, 2991-3000.

Bolton C.T., Chang L., Clemens S., Kodama K., Ikehara M., Medina-Elizalde M., Paterson G.A., Roberts A.P., Rohling E.J., Yamamoto Y., Zhao X. (2013) A 500,000 year record of Indian summer monsoon dynamics recorded by eastern equatorial Indian Ocean upper water-column structure, *Quaternary Science Reviews*, 77, 167–180.

Bostock H.C., Barrows T.T., Carter L., Chase Z., Cortese G., Dunbar G.B., Ellwood M., Hayward B., Howard W., Neil H.L., Noble T.L., Mackintosh A., Moss P.T., Moy A.D., White D., Williams M.J.M., Armand L.K. (2013) A review of the Australian–New Zealand sector of the Southern Ocean over the last 30 ka (Aus-INTIMATE project), *Quaternary Science Reviews*, 74, 35-57.

Bizimis M., Salters V.J.M., Garcia M.O., Norman M.D. (2013) The composition and distribution of the rejuvenated component in the Hawaiian Plume: Hf-Nd-Sr-Pb isotope systematics of Kaula lavas and pyroxenite xenoliths, *Geochemistry, Geophysics, and Geosystems*, Accepted manuscript online: 19August, doi:10.1002/ggge.20250.

Chang L., Winkhofer M., Roberts A. P., Heslop D., Florindo F., Dekkers M. J., Krijgsman W., Kodama K., Yamamoto Y. (2013) Low-temperature magnetic properties of pelagic carbonates: oxidation of biogenic magnetite and identification of magnetosome chains, *Journal of Geophysical Research*, 118, doi:10.1002/2013JB010381.

Collins J.A., Govin S., Mulitza S., Heslop D., Zabel M., Hartmann J., Rohl U., Wefer G. (2013) Abrupt shifts of the Sahara-Sahel boundary during Heinrich stadials, *Climate of the Past*, 9, 1181-1191, doi:10.5194/cp-9-1181-2013.

Darrenougue N., De Deckker P., Payr, C., Eggins S., Fallon S. (2013) Growth and chronology of the rhodolith-forming, coralline red algal species *Sporolithon durum* from the tropics, *Marine Ecology Progress Series*, 474, 105-119.

De Deckker P. and Martens K. (2013) Extraordinary morphological changes in valve morphology during the ontogeny of several species of the Australian ostracod genus *Bennelongia* (Crustacea, Ostracoda), *European Journal of Taxonomy* 36, 1-37.

Dean L.F. and De Deckker P. (2013) Recent benthic foraminifera from Twofold Bay, Eden NSW: community structure, biotopes and distribution controls, *Australian Journal of Earth Sciences* 60, 475-496.

Duval M., Guilarte-Moreno V., Grün R. (2013) ESR dosimetry of fossil enamel: some comments about measurement precision, long-term signal fading and dose–response curve fitting, *Radiation Protection Dosimetry* 157, 463-476.

Egli R., Florindo F., Roberts A.P. (in press) Introduction to 'Sedimentary magnetism: environmental sensitivity and stability', *Global and Planetary Change*.

Ellwood M.J., Law C.S., Hall J., Woodward E.M.S., Strzepek R., Kuparinen J., Thompson K., Pickmere S., Sutton P., Boyd P.W., (2013) Relationships between nutrient stocks and inventories and phytoplankton physiological status along an oligotrophic meridional transect in the Tasman Sea, *Deep Sea Research Part I: Oceanographic Research Papers*, 72, 102-120.

Foster G.L. and Rohling E.J. (2013) The relationship between sea level and climate forcing by CO₂ on geological timescales, *Proceedings of the National Academy of Sciences*, 110, 1209–1214.

Gilbert S., Danyushevsky L., Robinson P., Wohlgemuth-Ueberwasser C., Pearson N., Savard D., Norman M., Hanley J. (2012) A comparative study of five reference materials and the Lombard meteorite for the determination of the platinum-group elements and gold by LA-ICP-MS, *Geostandards and Geoanalytical Research*, 37, 51-64. doi: 10.1111/j.1751-908X.2012.00170.x

Griffiths M., Drysdale R., Gagan M., Hellstrom J., Couchoud I., Ayliffe L., Vonhof H., Hantoro W. (2013) Australasian monsoon response to Dansgaard-Oeschger event 21 and teleconnections to higher latitudes, *Earth and Planetary Science Letters*, 369-370, 294-304.

Griffiths M., Drysdale R., Gagan M., Zhao J.-x., Hellstrom J., Ayliffe L., Hantoro W. (2013) Abrupt increase in east Indonesian rainfall from flooding of the Sunda Shelf ~9,500 years ago, *Quaternary Science Reviews*, 74, 273-279.

Hansen J., Kharecha P., Sato M., Masson-Delmotte V., Ackerman F., Beerling D., Hearty P.J., Hoegh-Guldberg O., Hsu S.-L., Parmesan C., Rockstrom J., Rohling E.J., Sachs J., Smith P., Steffen K., Van Susteren L., von Schuckmann K., Zachos J.C. (in press) Assessing 'dangerous climate change': required reduction of carbon emissions to protect young people, future generations and nature, *PLoS ONE*.

Hassler C., Ridgway K., Bowie A., Butler E., Clementson L., Doblin M., Davies D., Law C., Ralph P., van der Merwe P., Watson R., Ellwood M., (in press) Primary productivity induced by iron and nitrogen in the Tasman Sea â An overview of the PINTS expedition, *Marine and Freshwater Research*.

Heslop D. and Roberts A.P. (2013) Calculating uncertainties on predictions of palaeoprecipitation from the magnetic properties of soils, *Global and Planetary Change*, 110, 379-385, doi:10.1016/j.gloplacha.2012.11.013.

Heslop D., Roberts A.P., Chang L., Davies M., Abrajevitch A., De Deckker P. (2013) Quantifying magnetite magnetofossil contributions to sedimentary magnetizations, *Earth and Planetary Science Letters*, 382, 58-65, doi:10.1016/j.epsl.2013.09.011.

Hönisch B., Allen K.A., Lea D.W., Spero H.J., Eggins S.M., Arbuszewski J., deMenocal P., Rosenthal Y., Russell A.D., Elderfield H. (2013) The influence of salinity on Mg/Ca in planktic foraminifers - Evidence from cultures, core-top sediments and complementary $\delta^{18}\text{O}$, *Geochimica et Cosmochimica Acta*, 121, 196-213.

Johnson M.O., Gloor M., Mudd S.M., Pillans B., Spooner N.A., Fifield L.K. (in press). Quantifying the intensity and depth dependence of bioturbation based on optically stimulated luminescence (OSL) dates and meteoric ^{10}Be , *Earth Surface Processes & Landforms*.

Kamenetsky V.S., Maas, R., Fonseca R.O.C., Ballhaus C. , Heuser A., Brauns M., Norman M.D., Woodhead J.D., Rodemann T., Kuzmin D.V., Bonatti E. (2013) Noble metals potential of sulfide-saturated melts from the subcontinental lithosphere, *Geology* 41, 575-578.

Komugabe A.F., Fallon S.J., Thresher R.E., Eggins S.M. (in press) Modern Tasman Sea surface reservoir ages from deep-sea black corals, *Deep-Sea Research Part II: Topical Studies in Oceanography*.

Kuroyanagi A., da Rocha R.E., Bijma J., Spero H.J., Russell A.D., Eggins S.M., Kawahata H. (2013) Effect of dissolved oxygen concentration on planktonic foraminifera through laboratory culture experiments and implications for oceanic anoxic events, *Marine Micropaleontology*, 101, 28-32.

Larrasoaña J.C., Roberts A.P., Rohling E.J. (2013) Dynamics of green Sahara periods and their role in hominin evolution. *PLoS ONE*, 8, e76514, doi:10.1371/journal.pone.0076514.

Lopes dos Santos R., De Deckker P., Sinninghe J.S., Schouten S. (2013) A late Quaternary sedimentary record of steryl alkyl ethers from offshore southeastern Australia, *Organic Geochemistry*, 54, 140-145.

Lopes dos Santos R.A., De Deckker P., Hopmans E.C., Magee J.W., Mets A., Sinninghe Damsté J.S., Schouten S. (2013) Abrupt vegetation change after the Late Quaternary megafaunal extinction in southeastern Australia, *Nature Geoscience*, DOI: 10.1038/NCEO1856.

Lopes dos Santos R.A., Spooner M.I., Barrows T.T., De Deckker P., Sinninghe Damsté J.S. and Schouten S. (2013) Comparison of organic (UK'37, TEXH86, LDI) and faunal proxies (foraminiferal assemblages) for reconstruction of late Quaternary sea surface temperature variability from offshore southeastern Australia, *Paleoceanography* 28, 1–11, doi:10.1002/palo.20035,

Ma M., Liu X., Pillans B.J., Hu S., Lu B., Liu H. (2013) Magnetic properties of Dashing Rocks loess at Timaru, South Island, New Zealand, *Geophysical Journal International*, 195, 75-85.

McGregor H., Fischer M., Gagan M., Fink D., Phipps S., Wong H., Woodroffe C. (2013) A weak El Niño/Southern Oscillation with delayed seasonal growth around 4,300 years ago, *Nature Geoscience*, 6:949-953, doi:10.1038/NCEO1936.

Menviel L., England M.H., Meissner K.J., Mouchet A., Yu J. (2013) Atlantic-Pacific seesaw and its role in outgassing CO₂ during Heinrich events, *Paleoceanography*, doi:10.1002/2013PA002542.

Munday C.I., O'Loingsigh T., Tapper N.J., De Deckker P., Allison G.E. (2013) Utilisation of Rep-PCR to track microbes in aerosols collected adjacent to their source, a saline lake in Victoria, Australia, *Science of the Total Environment* 450-451, 317-325.

Muxworthy A.R., Williams W., Roberts A.P., Winklhofer M., Chang L., Pósfai M. (in press) Critical single domain grain sizes in chains of interacting greigite particles: implications for magnetosome crystals, *Geochemistry, Geophysics, Geosystems*, doi:10.1002/2013GC004973.

Nash M.C., Opdyke B.N., Wu Z., Xu H., Trafford J.M. (2013) Simple X-ray diffraction techniques to identify Mg Calcite, Dolomite, and Magnesite in tropical coralline algae and assess peak asymmetry, *Journal of Sedimentary Research*, 83, 1084-1098, doi: 10.2110/jsr.2013.67.

Nebel O., Arculus R.J., van Westrenen W., Woodhead J.D., Jenner F.E., Nebel-Jacobsen Y.J., Wille M., Eggins S.M. (2013) Coupled Hf-Nd-Pb isotope co-variations of HIMU oceanic island basalts from Mangaia, Cook-Austral islands, suggest an Archean source component in the mantle transition zone, *Geochimica et Cosmochimica Acta*, 112, 87-101.

Necula C., Panaiotu C., Heslop D., Dimofte D. (2013) Climatic control of magnetic granulometry in the Mircea Vodă loess/paleosol sequence (Dobrogea, Romania), *Quaternary International*, 293, 5-14, doi:10.1016/j.quaint.2012.03.043.

Norman M.D. and Nemchin A.A. (in press) A 4.2 Billion Year Old Impact Basin on the Moon: U-Pb Dating of Zirconolite and Apatite in Lunar Melt Rock 67955, *Earth and Planetary Science Letters*.

Pietruszka A.J., Norman M.D., Garcia M.O., Marske J.P., Burns D.H. (2013) Chemical heterogeneity in the Hawaiian mantle plume from the alteration and dehydration of recycled oceanic crust. *Earth and Planetary Science Letters* 361, 298-309.

Pillans B. (2013) Chronostratigraphy. In: Elias, S.A. (Ed.), *Encyclopedia of Quaternary Science*, 4, 215-222, Elsevier.

Pillans B. (2013) Quaternary stratigraphy overview. In: Elias, S.A. (Ed.), *Encyclopedia of Quaternary Science*, 4, 189-205, Elsevier.

Pillans B. and Fifield L.K. (2013) Erosion rates and weathering history of rock surfaces associated with Aboriginal rock art engravings (petroglyphs) on Burrup Peninsula, Western Australia, from cosmogenic nuclide measurements, *Quaternary Science Reviews*, 69, 98-106.

Rabe B., Dodd P., Hansen E., Falck E., Schauer U., Mackensen A., Beszczynska-Möller A., Kattner G., Rohling E.J., Cox K. (2013) Export of Arctic freshwater components through the Fram Strait 1998 – 2010, *Ocean Science*, 9, 91-109.

Reeves J., Bostock H., Ayliffe L., Barrows T., De Deckker P., Devriendt L., Dunbar G., Drysdale R., Fitzsimmons K., Gagan M., Griffiths M., Haberle S., Jansen J., Krause C., Lewis S., McGregor H., Mooney S., Moss P., Nanson G., Purcell A., van der Kaars S. (2013) Palaeoenvironmental change in tropical Australasia over the last 30,000 years – a synthesis by the OZ-INTIMATE group, *Quaternary Science Reviews*, 74, 97-114.

Roberts A.P. and Turner G.M. (2013) Geomagnetic excursions and secular variations, In: Elias, S.A. (Ed.), *The Encyclopedia of Quaternary Science* (2nd Edition), 1, 705-720, Elsevier.

Roberts A. P., Florindo F., Chang L., Heslop D., Jovane L. (2013) Magnetic properties of pelagic marine carbonates, *Earth-Science Reviews*, 127, 111-139.

Roberts A.P., Sagnotti L., Florindo F., Bohaty S.M., Verosub K.L., Wilson G.S., Zachos J.C. (2013) Environmental magnetic record of paleoclimate, unroofing of the Transantarctic Mountains, and volcanism in late Eocene to early Miocene glaci-marine sediments from the Victoria Land Basin, Ross Sea, Antarctica, *Journal of Geophysical Research*, 118, 1845-1861.

Roberts A. P., Tauxe L., Heslop D. (2013) Magnetic paleointensity stratigraphy and high resolution Quaternary geochronology: successes and future challenges, *Quaternary Science Reviews*, 61, 1-16, doi:10.1016/j.quascirev.2012.10.036.

Rohling E.J. (2013) Quantitative assessment of glacial fluctuations in the level of Lake Lisan, Dead Sea rift, *Quaternary Science Reviews*, 70, 63–72.

Rohling E.J. (2013) Oxygen isotope composition of seawater, In: Elias, S.A. (Ed.), *The Encyclopedia of Quaternary Science*, 2, 915–922, Elsevier.

Rohling E.J., Grant K.M., Roberts A.P., Larrasoana J.C. (in press) Palaeoclimate variability in the Mediterranean and Red Sea regions during the last 500,000 years; implications for hominin migrations, *Current Anthropology* (re. Wenner Gren symposium, June 2012).

Rohling E.J., Haigh I.D., Foster G.L., Roberts A.P., Grant K.M., (in press) A geological perspective on potential future sea-level rise, *Scientific Reports*.

Smith M., De Deckker P., Rogers J., Brocks J., Hope J., Schmidt S., Lopes dos Santos R., Schouten S. (2013) Comparison of UK37, TEXH 86 and LDI temperature proxies for reconstruction of south-east Australian ocean temperatures, *Organic Geochemistry*, 64, 94-104.

Stopar J.D., Taylor G.J., Velbel M.A., Norman M.D., Vicenzi E.P., Hallis L.J. (2013) Element abundances, patterns, and mobility in Nakhlite Miller Range 03346 and implications for aqueous alteration, *Geochimica et Cosmochimica Acta*, 112, 208-225.

Storm P., Grün R., Stringer C., Bartsiokas A., de Vos J., Aubert M., Kinsley L. (2013) New dates for "Wajak Man" (Java, Indonesia) suggest a Late Pleistocene age, *Journal of Human Evolution*, 64, 356-365.

St Pierre E., Westaway K., Zhao J.-x., Gagan M., Lentfer C., Awe Due R., Morwood M., Hantoro W., Djubiantono T., Suwargadi B. (2013) Preliminary U-series and thermoluminescence dating of excavated deposits in Liang Bua sub-chamber, Flores, Indonesia, *Journal of Archaeological Science*, 40, 148-155.

Stuut J-B.W., Temmensfeld F., De Deckker P. (accepted) A 550 kyr record of aeolian activity near North West Cape, Australia: inferences from grain-size distributions and bulk chemistry of SE Indian Ocean deep-sea sediments, *Quaternary Science Reviews*.

Thompson C.M., Ellwood M.J., Wille M. (2013) A solvent extraction technique for the isotopic measurement of dissolved copper in seawater, *Analytica Chimica Acta*, 775, 106-113.

Treble P., Bradley C., Wood A., Baker A., Jex C., Fairchild I., Gagan M., Cowley J., Azcurra C. (2013) An isotopic and modelling study of flow paths and storage in Quaternary calcarenite, SW Australia: implications for speleothem paleoclimate records, *Quaternary Science Reviews*, 64, 90-103.

Vetter L., Kozdon R., Mora C.I., Eggins S.M., Valley J.W., Hönisch B., Spero H.J. (2013) Micron-scale intrashell oxygen isotope variation in cultured planktic foraminifers, *Geochimica et Cosmochimica Acta*, 107, 267-278.

Wilhelm S.W., King A.L., Twining B.S., LeClerc G.R., DeBruyn J.M., Strzepek R.F., Breene C.L., Pickmere S., Ellwood M.J., Boyd P.W., Hutchins D.A. (2013) Elemental quotas and physiology of a southwestern Pacific Ocean plankton community as a function of iron availability, *Aquatic Microbial Ecology*, 68, 185-194.

Wilkins D., Gouramanis C., De Deckker P., Fifield L.K., Olley J. (2013) Holocene lake-level fluctuations in Lakes Keilambete and Gnotuk, southwestern Victoria, Australia, *The Holocene* 23, 804-815.

Wille M., Nebel O., Van Kranendonk M.J., Schoenberg R., Kleinhanns I., Ellwood, M.J. (2013) Mo-Cr isotope evidence for a reducing Archean atmosphere in 3.46-2.76 Ga black shales from the Pilbara, Western Australia, *Chemical Geology*, 340, 68-76.

Yaxley G.M., Kamenetsky V.S., Nichols G.T., Maas R., Belousova B., Rosenthal, A., Norman, M. (accepted) Diamonds in Antarctica? Discovery of Antarctic kimberlites extends vast Gondwanan Cretaceous kimberlite province, *Nature Communications*.

Yu J., Anderson R.F., Jin Z., Rae J.W.B., Opdyke B.N., Eggins S.M. (2013) Responses of the deep ocean carbonate system to carbon reorganization during the Last Glacial-interglacial cycle, *Quaternary Science Reviews*, 76, 39-52.

Yu J., Anderson R.F., Rohling E.J., (in press) Deep ocean carbonate chemistry and glacial-interglacial atmospheric, *Oceanography*.

Yu J., Thornalley D.J.R., Rae J.W.B., McCave I.N. (2013) Calibration and application of B/Ca, Cd/Ca and $\delta^{11}\text{B}$ in *Neogloboquadrina pachyderma* (sinistral) to constrain CO₂ uptake in the subpolar North Atlantic during the last deglaciation, *Paleoceanography*, doi: 10.1029/2012PA002432.

Zhang F., Jin Z.D., Li F., Yu J., You C.F., Zhou L. (2013) The dominance of loess weathering on water and sediment chemistry within the Daihai Lake catchment, northeastern Chinese Loess Plateau, *Applied Geochemistry*, 35, 51-63.

Zhang F., Jin Z.D., Li F., Yu J., and Xiao J. (2013) Controls on seasonal variations of silicate weathering and CO₂ consumption in two river catchments on the NE Tibetan Plateau, *Journal of Asian Earth Sciences*, 62, 547-560.

Zhao C., Liu Z., Rohling E.J., Yu Z., Liu W., He Y., Zhao Y., Chen F. (2013) Holocene temperature fluctuations in the Northern Tibetan Plateau. *Quaternary Research*, 80, 55-65.

Earth Materials & Processes

Alt J.C., Schwarzenbach E.M., Fruh-Green G.L., Shanks Iii W.C., Bernasconi S.M., Garrido C.J., Crispini L., Gaggero L., Padrón-Navarta J.A. and Marchesi C. (2013) The role of serpentinites in cycling of carbon and sulfur: Seafloor serpentinitization and subduction metamorphism, *Lithos*, 15, 40-54.

Benard A. and Ionov D.A. (2013) Melt- and fluid-rock interaction in supra-subduction lithospheric mantle: Evidence from andesite-hosted veined peridotite xenoliths, *Journal of Petrology*, 54, 2339-2378.

Berry A.J., Yaxley G.M., Hanger B.J., Woodland A.B., de Jong, M.D., Howard D.L., Paterson D., Kamenetsky V.S. (2013) Quantitative mapping of the oxidative effects of mantle metasomatism, *Geology*, 41, 683-686.

Buchs D.M., Bagheri S., Martin L., Hermann J., Arculus R. (2013) Paleozoic to Triassic ocean opening and closure preserved in Central Iran: Constraints from the geochemistry of meta-igneous rocks of the Anarak area, *Lithos*, 172, 267-287.

Campbell J.L., Perrett G.M., Maxwell J.A., Nield E., Gellert R., King P.L., Lee M., O'Meara J.M., Pradler I. (2013) Refinement of the Compton–Rayleigh scatter ratio method for use on the Mars Science Laboratory alpha particle X-ray spectrometer, *Nuclear Instruments and Methods in Physics Research B*, 302, 24–31.

Cottam M.A., Hall R., Sperber C., Kohn B.P., Forster M.A., Batt G.E. (2013) Neogene rock uplift and erosion in northern Borneo: evidence from the Kinabalu granite, Mount Kinabalu, *Journal of the Geological Society*, Doi 10.1144 /jgs2011-130

David E. C., Fortin J., Schubnel A., Guéguen Y., Zimmerman R. W. (2013) Laboratory measurements of low and high-frequency elastic moduli in Fontainebleau sandstone, *Geophysics*, 78, 369-379.

de Moor J.M., Fischer T.P., Sharp Z.D., King P.L., Wilke M., Botcharnikov R.E., Cottrell E., Zelenski M., Marty B., Klimm K., Rivard C., Ayalew D., Ramirez C. Kelley K.A. (2013) Sulfur degassing at Erta Ale (Ethiopia) and Masaya (Nicaragua) volcanoes: Implications for the degassing processes and oxygen fugacities of basaltic systems, *Geochemistry, Geophysics, Geosystems*, 14, doi: 10.1002/ggge.20255.

de Moor J.M., Fischer T.P., King P.L., Botcharnikov R.E., Hervig R.L., Hilton D., Barry P., Mangasini F., Ramirez C. (2013) Volatile-rich silicate melts from Oldoinyo Lengai volcano (Tanzania): implications for carbonatite genesis and eruptive behaviour, *Earth and Planetary Science Letters*, 361, 379-390.

Ewing T.A., Hermann J., Rubatto D. (2013) The robustness of the Zr-in-rutile and Ti-in-zircon thermometers during hightemperature metamorphism (Ivrea-Verbanò Zone, northern Italy), *Contributions to Mineralogy and Petrology* 165, 757-779.

Forster M. and Lister G. (2013) $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology and the diffusion of ^{39}Ar in phengite-muscovite intergrowths during step-heating experiments *in vacuo*, in Jourdan F., Mark D.F., Verati, C. (Eds.) $^{40}\text{Ar}/^{39}\text{Ar}$ Dating: from Geochronology to Thermochronology, from Archaeology to Planetary Sciences, Geological Society, London, Special Publications, SP378, doi:10.1144/SP378.

Griffin J.M., Berry A.J., Frost D.J., Wimperis S., Ashbrook S.E. (2013) Water in the Earth's mantle: a solid-state NMR study of hydrous wadsleyite, *Chemical Science*, 4, 1523-1538.

Hermann J. and Rubatto D. (2013) Subduction of continental crust to mantle depth: Geochemistry of ultrahigh-pressure rocks, in Rudnick R.L. (Ed.) Treatise on Geochemistry, 2nd edition, Vol 3: The crust, 309-340.

Hermann J., Zheng Y.-F., Rubatto D. (2013) Deep fluids in subducted continental crust, *Elements*, 9, 281-287.

Hidas K., Garrido C.J., Tommasi A., Padrón-Navarta J.A., Thielmann M., Konc Z., Frets E., Marchesi C. (2013) Strain Localization in Pyroxenite by Reaction-Enhanced Softening in the Shallow Subcontinental Lithospheric Mantle, *Journal of Petrology*, 54, 1997-2031.

Iizuka T., Campbell I.H., Allen C.M., Gill J.B., Maruyama S. and Makoka F. (2013) Evolution of the African continental crust as recorded by U–Pb, Lu–Hf and O isotopes in detrital zircons from modern rivers, *Geochimica et Cosmochimica Acta*, 107, 96-120. doi: 10.1016/j.gca.2012.12.028.

Ionov D.A., Benard A., Plechov P.Yu., Shcherbakov V.D. (2013) Along-arc variations in lithospheric mantle compositions in Kamchatka, Russia: First trace element data on mantle xenoliths from the Klyuchevskoy Group volcanoes, *Journal of Volcanology and Geothermal Research*, 263, 122-131.

Jackson I., Faul U.H., Skelton R. (in press) Elastically accommodated grain-boundary sliding: New insights from experiment and modelling, *Physics of the Earth and Planetary Interiors*.

Jenner F.E., Bennett V.C., Yaxley G., Friend C.R.L., Nebel O. (2013) Eoarchean within-plate basalts from southwest Greenland, *Geology*, 41, 327-330.

Kendrick M.A., Arculus R. J., Burnard P., Honda M (2013) Quantifying brine assimilation by submarine magmas: Examples from the Galapagos Spreading Centre and Lau Basin, *Geochimica Cosmochimica Acta*, 123, 150-165.

King P.L. and Larsen J.F. (2013) A new micro-reflectance IR spectroscopy method for analyzing volatile species in basaltic, andesitic, rhyolitic and phonolitic glasses, *American Mineralogist*, 98, 1162-1171.

King P.L., Sham T.K., Gordon R. & Dyar M.D. (2013) Microbeam X-ray analysis of Ce³⁺/Ce⁴⁺ in Ti-rich minerals: A case study of titanite (sphene) with implications for multi-valent element substitution in minerals, *American Mineralogist*, 98, 110-119.

Kiseeva E.S., Litasov K.D., Yaxley G.M., Ohtani E., Kamenetsky V.S. (2013) Melting and Phase Relations of Carbonated Eclogite at 9-21 GPa and the Petrogenesis of Alkali-Rich Melts in the Deep Mantle, *Journal of Petrology*, 54, 1555-1583.

Kiseeva E.S., Yaxley G.M., Stepanov A.S., Tkalcic H., Litasov K.D., Kamenetsky V.S., (2013) Metapyroxenite in the mantle transition zone revealed from majorite inclusions in diamonds, *Geology*, 41, 883-886.

Lee R.J., Ramsey M.S., King P.L. (2013) Development of a novel laboratory technique for thermal emission spectroscopy of melts, *Journal of Geophysical Research – Solid Earth*, 118, 1–16, doi:10.1002/jgrb.50197.

Liu Q., Hermann J., Zhang J. (2013) Polyphase inclusions in the Shuanghe UHP eclogites formed by subsolidus transformation and incipient melting during exhumation of deeply subducted crust, *Lithos*, 177, 91-109.

Marchesi C., Garrido C.J., Padrón-Navarta J.A., López Sánchez-Vizcaíno V., Gómez-Pugnaire M.T. (2013) Element mobility from seafloor serpentinization to high-pressure dehydration of antigorite in subducted serpentinite: Insights from the Cerro del Almiraz ultramafic massif (southern Spain), *Lithos*, 15, 128–142.

McGoldrick K.L., Squire R.J., Cas RA.F., Briggs M., Tunjic J., Allen C.M., Campbell I.H. (2013) The largest Au deposits in the St Ives Goldfield (Yilgarn Craton, Western Australia) may be located in a major Neoproterozoic volcano-sedimentary depo-centre, *Mineralium Deposita*, 1-21, doi: 10.1007/s00126-013-0462-7.

McLennan S.M., Anderson R.B., Bell III J.F., Bridges J.C., Calef III F., Campbell J.L., Clark B.C., Clegg S., Conrad P., Cousin A., Des Marais D.J., Dromart G., Dyar M.D., Edgar L.A., Ehlmann B.L., Fabre C., Forni O., Gasnault O., Gellert R., Gordon S., Grant J.A., Grotzinger J.P., Gupta S., Herkenhoff K.E., Hurowitz J.A., King P.L., Le Mouélic S., Leshin L.A., Léveillé R., Lewis K. W., Mangold N., Maurice S., Ming D.W., Morris R.V., Nachon M., Newsom H.E., Ollila H.M., Perrett G.M., Rice M.S., Schmidt M.E., Schwenzer S.E., Stack K., Stolper E.M., Sumner D.Y., Treiman A.H., van Bommel S., Vaniman D.T., Vasavada A., Wiens R.C., Yingst R.A. and The MSL Team (2013) Elemental Geochemistry of Sedimentary Rocks in Yellowknife Bay, Gale Crater, Mars, *Science*, doi:0.1126/science.1244734.

Nebel O., Arculus R.J., Ivanic T.J., Nebel-Jacobsen Y. J (2013) Lu-Hf isotopic memory of plume-lithosphere interaction in the source of layered mafic intrusions, Windimurra Igneous Complex, Yilgarn Craton, Australia, *Earth and Planetary Science Letters*, 380, 151-161.

Nebel O., Arculus R.J., Ivanic T.J., Rapp R., Wills K.J.A. (2013) Upper Zone of the Archean Windimurra layered mafic intrusion, Western Australia: insights into fractional crystallisation in a large magma chamber, *Neues Jahrbuch für Mineralogie-Abhandlungen*, 191, 83-107.

Nebel O., Arculus R.J., Sossi P.A., Jenner F.E., Whan T.H.E. (2013) Iron isotopic evidence for convective resurfacing of recycled arc-front mantle beneath back-arc basins, *Geophysical Research Letters*, 40, 1-5.

Nebel O., Arculus R.J., van Westrenen W., Woodhead J.D., Jenner F.E., Nebel-Jacobsen Y.J., Wille M., Eggins S.M. (2013) Coupled Hf-Nd-Pb isotope co-variations of HIMU oceanic island basalts from Mangaia, Cook-Austral islands, suggest an Archean source component in the mantle transition zone, *Geochimica et Cosmochimica Acta*, 112, 87-101.

Ollila A., Newsom H.E., Clark III B.C., Wiens R.C., Cousin A., Blank J.G., Mangold N., Sautter V., Maurice S., Clegg S.M., Gasnault O., Forni O., Tokar R., Lewin E., Dyar M.D., Lasue J., Anderson R., McLennan S.M., Bridges J., Vaniman D., Lanza N., Fabre C., Mlikechi N., Perrett G.M., Campbell J.L., King P.L., Barraclough B., Delapp D., Johnstone S., Mesline P.-Y., Rosen-Gooding A., Williams J. and the MSL Science Team (2013) Trace Element Geochemistry (Li, Ba, Sr, and Rb) using Curiosity's ChemCam: Early Results for Gale Crater from Bradbury Landing Site to Rocknest, *Journal of Geophysical Research – Planets*, doi: 10.1002/2013JE004517.

Padron-Navarta J.A., Lopez Sanchez-Vizcaino V., Hermann J., Connolly J.A.D., Garrido C.J., Gomez- Pugnaire M.T., Marchesi C. (2013) Tschermak's substitution in antigorite and consequences for phase relations and water liberation in high-grade serpentinites, *Lithos*, 178, 186-196.

Park J.W ., Campbell I.H., Arculus R.J. (2013) Platinum-alloy and sulfur saturation in an arc-related basalt to rhyolite suite: Evidence from the Pual Ridge lavas, the Eastern Manus Basin, *Geochimica et Cosmochimica Acta*, 101, 76-95.

Park J-W., Campbell I. H., Ichert R. B., Allen C. M. (2013) Chalcophile element geochemistry of the Boggy Plain zoned pluton, southeastern Australia: a S-saturated barren compositionally diverse magmatic system. *Contributions to Mineralogy and Petrology* 166, 217-236, doi: 10.1007/s00410-012-0806-9.

Pirard C., Hermann J., O'Neill H.St.C (2013) Petrology and geochemistry of the crust-mantle boundary in a nascent arc, Massif du Sud ophiolite, New Caledonia, South-West Pacific, *Journal of Petrology*, 54, 1759-1792.

Pownall J.M., Hall R., Armstrong R.A., Forster M.A. (Accepted December 2013) Earth's youngest-known ultrahigh-temperature granulites discovered on Seram, eastern Indonesia, *Geology*.

Qing Q. and Hermann J. (2013) Partial melting of lower crust at 10-15 kbar: Constraints on adakite and TTG formation, *Contributions to Mineralogy and Petrology* 165, 1195-1224.

Saygin E., McQueen H., Hutton L.J., Kennett B.L.N., Lister G. (2013) Structure of the Mt Isa region from seismic ambient noise tomography, *Australian Journal of Earth Sciences*, 60, 707-718, doi: 10.1080/08120099.2013.837098.

Schmidt M., Campbell J.L., Gellert R., Perrett G., Treiman A., Blaney D., Calef F., Edgar L., Elliott B., Grotzinger J., Hurowitz J., King P.L., Minitti M., Sautter V., Stack K., Berger J., Bridges J.C., Ehlmann B., Forni O., Leshi, L., Lewis K., McLennan S., Ming D., Newsom H., Ollila A., Pradler I., Squyres S.W, Stolper E., Thompson L., VanBommel S., Wiens R.C. and the MSL Team (2013) Geochemical diversity in first rocks examined by the Curiosity Rover in Gale Crater: Evidence and significance of an alkali and volatile-rich igneous source, *Journal of Geophysical Research – Planets*, doi: 10.1002/2013JE004481.

Stenhouse I.R., Forster M.A., Lister G.S. (Accepted December 2013) The timing of sedimentation and Buchan metamorphism in the Grampian Terrane in Scotland from $^{40}\text{Ar}/^{39}\text{Ar}$ apparent age spectra, *Journal of the Geological Society*.

Stepanov A.S. and Hermann J. (in press) Fractionation of Nb and Ta by biotite and phengite: Implications for the "missing Nb paradox", *Geology*, 41, 303-306.

Stolper E.M., Baker M.B., Cousin A., Dyar M.D., Fisk M., Gellert R., King P.L., McLennan S.M., Minitti M., Newcombe M., Perrett G., Rowland S., Sautter V., Schmidt M.E., Treiman A.H., Wiens R. and the MSL Science Team (2013) The Petrochemistry of Jake_M: A Martian Mugearite, *Science*, 341, doi:10.1126/science.1239463.

Suggate S., Cottam M. Hall R., Sevastjanova I., Forster M.A., White L., Armstrong R., Carter A., Mojares E. (Accepted July 2013) South China continental margin signature for sandstones and granites from Palawan, Philippines, *Gondwana Research*.

Viète D.R., Oliver G.J.H., Fraser G.L., Forster M.A., Lister G.S. (2013) Timing and heat sources for the Barrovian metamorphism, Scotland, *Lithos*, 177, 148-163.

Wang T., Wei W.H., Shen X., Wang R.P., Luther Davies B., Jackson I. (2013) Elatic transition thresholds in Ge-As(Sb)-Se glasses, *Journal of Applied Physics*, 46, 165302.

White L.T., Gibson G.M., Lister G.S. (2013) A reassessment of paleogeographic reconstructions of eastern Gondwana: Bringing geology back into the equation, *Gondwana Research* 24, 984-998.

White L.T., Lister G.S., Ahmad T., Forster M.A. (2013) Comment on Dextral transpression and late-Eocene magmatism in the trans-Himalayan Ladakh Batholith (North India): implications for tectono-magmatic evolution of the Indo-Eurasian collisional arc, *International Journal of Earth Sciences* 102, 969-972.

Xue Y., Campbell I.H., Ireland T.R., Holden P., Armstrong, R. (2013) No mass-independent sulfur isotope fractionation in auriferous fluids supports a magmatic origin for Archean gold deposits, *Geology*, 41, 791-794, doi:10.1130/G34186.1.

Yaxley G.M., Kamenetsky V.S., Nichols G.T., Maas R., Belousova E., Rosenthal A., Norman M. (2013) Discovery of kimberlites in Antarctic extends vast Gondwanan Cretaceous province, *Nature Communications*, 4, 2921, doi:10.1038/ncomms3921.

Yingst R.A., Kah L.C., Palucis M., Williams R.M.E., Garvin J., Bridges J.C., Bridges N., Deen R., Farmer J., Gasnault O., Goetz W., Hamilton V.E., Hipkin V., Jensen J., King P.L., Le Mouélic S.P., Madsen M., Mangold N., Martinez Frias J., Maurice S., McCartney E.M., Newsom H., Pariser O., Wiens R. and the MSL Team (2013) Characteristics of pebble and cobble-sized clasts along the Curiosity rover traverse from Bradbury Landing to Rocknest, *Journal of Geophysical Research – Planets*, 118, 2361-2380, doi:10.1002/2013JE004435.

Earth Physics

Aitken A.R.A., Salmon M.L., Kennett B.L.N. (2013) Australia's Moho: A test of the usefulness of gravity modelling for the determination of Moho depth, *Tectonophysics*, 609, 468-479. doi: 10.1016/j.tecto.2012.06.049.

Allgeyer S., Daubord C., Loevenbruck A., Hébert H., Schindelé F. (2013) Could a 1755-like tsunami reach the French atlantic coastline? Constraints from 20th century observations and numerical modeling, *Pure and Applied Geophysics*.

Allgeyer S., Hébert H., Madariaga R. (2013) Modelling the tsunami free oscillations in the Marquesas (French Polynesia), *Geophysical Journal International*.

Austermann J. and Iaffaldano G. (2013) The role of the Zagros orogeny in slowing down Arabia-Eurasia convergence since ~5 Ma. *Tectonics*, 32, 351-363.

Barruol G., Cordier E., Bascou J., Fontaine F. R., Legresy B., Lescarmontier L. (2013) Tide-induced micro-seismicity in the Mertz glacier area, East Antarctica, *Geophysical Research Letters*, 40(20) 5412-5416, doi:10.1002/2013GL057814.

Benavente, R. and Cummins P. (2013) Simple and reliable finite fault solutions for large earthquakes using the W-phase: The Maule (Mw = 8.8) and Tohoku (Mw = 9.0) earthquakes, *Geophysical Research Letters*, DOI: 10.1002/grl.50648.

Boudin F., Allgeyer S., Bernard P., Hebert H., Olcay M., El-Madani M., Schurr B., Esnault M-F., Madariaga R., Asch G., Kammenthaler M. (2013) Analysis and modeling of tsunami-induced tilt for the 2007, M=7.6, Tocopilla and the 2010, M=8.8 Maule earthquakes, Chili, from long base tiltmeter and broad-band seismometer records., *Geophysical Journal International*.

Brookhouse M. T., Farquhar G. D., Roderick M. L. (2013) The impact of bushfires on water yield from south-east Australia's ash forests, *Water Resources Research*, 49, 4493-4505, 10.1002/wrcr.20351.

Burgette R., Watson C.S., Church J.A., Tregoning P., Coleman R. (2013) Characterizing and minimizing the effects of noise in tide gauge time series: relative and geocentric sea level rise around Australia, *Geophysical Journal International* 194, 719-736.

Chalamalla V., Gayen B., Scotti A., Sarkar S. (2013) Near critical reflection of internal gravity waves on a sloping boundary, *Journal of Fluid Mechanics*, 729, 47-68.

Chapman C.C. and Hogg A. McC. (2013) Jet Jumping: Low-Frequency Variability in the Southern Ocean, *Journal of Physical Oceanography*, 43, 990–1003.

Chapman C.C. and Morrow R. (in press) The Variability of Southern Ocean Jets Near Topography, *Journal of Physical Oceanography*.

Chen K.H., Kennett B.L.N., Furumura T. (2013) High-frequency waves guided by the subducted plates underneath Taiwan and their association with seismic intensity anomalies, *Journal of Geophysical Research: Solid Earth*, 118, 665-680. doi: 10.1002/jgrb.50071.

Neda Darbeheshti, Li Zhou, Paul Tregoning, Simon McClusky, Anthony Purcell (2013) The ANU GRACE visualisation web portal, *Computers & Geosciences*, 52:227–233. DOI:10.1016/j.cageo.2012.10.005.

Davies D. R., Davies J. H., Bollada P. C., Hassan O., Morgan K., Nithiarasu P. (2013) A hierarchical mesh refinement technique for global 3-D spherical mantle convection modeling: *Geoscientific Model Development*, 6, 1095-1107.

Donohue R. J., Roderick M. L., McVicar T. R., Farquhar G. D. (2013) Impact of CO₂ fertilization on maximum foliage cover across the globe's warm, arid environments. *Geophysical Research Letters* 40, 3031-3035, doi:10.1002/grl.50563.

Downes S. M. and Hogg A. McC. (2013) Southern Ocean circulation and eddy compensation in CMIP5 models, *Journal of Climate*, 26, 7198–7220, doi: 10.1175/JCLI-D-12-00504.1.

Druken K.A., Kincaid C., Griffiths R.W. (2013) Directions of seismic anisotropy in laboratory models of mantle plumes. *Geophysical Research Letters* 40, 3544-3549, doi:10.1002/grl.50671.

Fichtner A., Kennett B.L.N., Trampert J. (2013) Separating intrinsic and apparent anisotropy, *Physics of the Earth and Planetary Interiors*, 219, 11-20, doi: 10.1016/j.pepi.2013.03.006.

Fichtner A., Saygin E., Taymaz T., Cupillard P., Capdeville Y., Trampert J. (2013) The deep structure of the North Anatolian Fault Zone, *Earth and Planetary Science Letters*, Volume 373, p 109-117.

Fichtner A., Trampert J., Cupillard P., Saygin E., Taymaz T., Capdeville Y., Villaseñor A. (2013) Multiscale waveform Inversion, *Geophysical Journal International*, doi: 10.1093/gji/ggt118.

Fontaine F., Tkalčić H., Kennett B.L.N. (2013) Imaging crustal structure variation across southeastern Australia, *Tectonophysics*, 582, 112-125.

Fontaine F., Tkalčić H., Kennett B. (2013) Crustal complexity in the Lachlan Orogen revealed from teleseismic receiver functions, *Australian Journal of Earth Sciences*, 60, 413-430. doi:10.180/08120099.2013.787646.

Frankcombe L. M., Spence P., Hogg A. McC., England M. H., Griffies S. M. (2013) Sea level changes forced by Southern Ocean winds, *Geophysical Research Letters*, 40, 5710-5715.

Gayen B. and Sarkar S. (2013) Degradation of an internal wave beam by parametric subharmonic instability in an upper ocean pycnocline. *Journal of Geophysical Research* 118, 4689-4968.

Gayen B., Hughes G.O., Griffiths R.W. (2013) Completing the mechanical energy pathways in turbulent Rayleigh-Bénard convection. *Physical Review Letters* 111, 124301.

Gayen B., Griffiths R.W., Hughes G.O., Saenz J.A. (2013) Energetics of horizontal convection. *Journal of Fluid Mechanics* 716, R10, doi:10.1017/jfm.2012.592.

Glikson A., Uysal T., Fitzgerald J., Saygin E. (2013) Geophysical anomalies and quartz microstructures, Eastern Warburton Basin, North-east South Australia: Tectonic or impact shock metamorphic origin?, *Tectonophysics*, doi:10.1016/j.tecto.2012.12.036.

Gorbatov A., Kennett B.L.N., Saygin E. (2013) Crustal properties from seismic station autocorrelograms, *Geophysical Journal International*, 192, 861-870. doi: 10.1093/gji/ggs064

Gowan E.J. (2013) An assessment of the minimum timing of ice free conditions of the western Laurentide Ice Sheet. *Quaternary Science Reviews*, 75, 100-113.

Griffiths R.W., Hughes G.O., Gayen B. (2013) Horizontal convection dynamics: insights from transient adjustment, *Journal of Fluid Mechanics*, 726, 559–595.

Hogg A.McC., Dijkstra H.A., Saenz J.A. (2013) The energetics of a collapsing meridional overturning circulation, *Journal of Physical Oceanography*, 43, 1512–1524.

Hughes G.O., Gayen B., Griffiths R.W. (2013) Available potential energy in Rayleigh-Bénard convection, *Journal of Fluid Mechanics*, 729, R3, doi:10.1017/jfm.2013.353.

Hutchinson D.K., England M. H., Santoso A., Hogg A.McC. (2013) Interhemispheric asymmetry in transient global warming: The role of Drake Passage, *Geophysical Research Letters*, 40, 1587–1593.

Iaffaldano G. (in press) A geodynamical view on the steadiness of geodetically-derived plate motions over geological time, *Geochemistry, Geophysics, Geosystems*.

G. Iaffaldano T. Bodin M. Sambridge (2013) Slow-downs and speed-ups of India-Eurasia convergence since ~20 Ma: Data-noise, uncertainties and dynamic implications. *Earth and Planetary Science Letters*, 367, 146-156.

Johnson S.P., Thorne A.M., Tyler I.M., Korsch R.J., Kennett B.L.N., Cutten H.N., Goodwin J., Blay O., Blewett R.S., Joly A., Dentith M.C., Aitken A.R.A., Holzschuh J., Salmon M., Reading A., Heinson G., Boren G., Ross J., Costelloe R.D., Fomin T. (2013) Crustal architecture of the Capricorn Orogen, Western Australia and associated metallogeny, *Australian Journal of Earth Sciences*, 60, 681–705, doi: 10.1080/08120099.2013.826735.

Kennett B.L.N. and Furumura T. (2013) High-frequency Po/So guided waves in the oceanic lithosphere: I—long-distance propagation, *Geophysical Journal International*, 195, 1862-1877, doi: 10.1093/gji/ggt344.

Kennett B.L.N. and Iaffaldano G. (2013) Role of lithosphere in intra-continental deformation: Central Australia, *Gondwana Research*, 24, 958-968.

Kennett B.L.N., Fichtner A., Fishwick S., Yoshizawa K. (2013) Australian Seismological Reference Model (AuSREM): mantle component, *Geophysical Journal International*, 192, 871-887, doi: 10.1093/gji/ggs065

Kennet, B.L.N., Saygin E., Fomin T., Blewett R.S. (2013) Deep Crustal Seismic Reflection Profiling Australia 1978–2011, pp iii+180, ANU E-Press. ISBN: 9781925021127

Kincaid C., Druken K.A., Griffiths R.W., Stegman D.R. (2013) Bifurcation of the Yellowstone plume driven by subduction-induced mantle flow, *Nature Geoscience*, 6, 395-399, doi:10.1038/Ngeo1774.

Kiseeva E.S., Yaxley G.M., Stepanov A.S., Tkalčić H., Litasov K.D., Kamenetsky V.S. (2013) Metapyroxenite in the mantle transition zone revealed from majorite inclusions in diamonds, *Geology*, doi:10.1130/G34311.1.

Klootwijk C. (2013) Middle-Late Paleozoic Australia-Asia convergence and tectonic extrusion of Australia, *Gondwana Research*, 24, 5-54.

Kwon E.Y., Downes S. M., Sarmiento J. L., Farneti R., Deutsch C. (2013) Role of the seasonal cycle in the subduction rates of upper Southern Ocean waters, *Journal of Physical Oceanography*, 43, 1096-1113.

Lau H.C.P., Goes S., Davies D. R. (in press) Reconciling physical and seismic reference mantle models - the significance of geographical sampling bias, *Springer Mono - Earth's deep interior*.

Le Voci G., Davies D. R., Goes S., Kramer S. C., Wilson C. R. (in press) A systematic 2-D investigation into the mantle wedge's transient flow regime and thermal structure: complexities arising from buoyancy and a hydrated rheology, *Geochemistry Geophysics, Geosystems*.

Lim W. H., Roderick M. L., Hobbins M. T., Wong S. C., Farquhar G. D. (2013) The energy balance of a US Class A evaporation pan, *Agricultural and Forest Meteorology*, 182–183, 314-331, <http://dx.doi.org/10.1016/j.agrformet.2013.07.001>.

Mattesini M., Belonoshko A.B., Tkalčić H., Buforn E., Udias A., Ahuja R. (2013) Candy wrapper for the Earth's inner core, *Scientific Reports*, 3:2096, doi:10.1038/srep02096.

Mayet C., Testut L., Legresy B., Lescarmonnier L. (2013) Impact of the tides on the calving of Mertz Glacier, East Antarctica, *Journal of Geophysical Research*, 118, 5267–5279, doi:10.1002/jgrc.20339.

Montillet J.P. (2013) The Generalization of the Decomposition of Functions by Energy Operators, *Acta Applicandae Mathematicae*, DOI: 10.1007/s10440-013-9829-0

Montillet J.P., McClusky S., Yu K. (2013) Extracting Coloured Noise Statistics in Time Series via Negentropy, *IEEE Signal Processing Letters*, 20, 857-860, doi: 10.1109/LSP.2013.2271241.

Montillet J.-P., Bonenberg L.K., Hancock C.M., Roberts G.W. (2013) On the improvements of the single point positioning accuracy with Locata technology, *GPS Solutions*, DOI: 10.1007/s10291-013-0328-6.

Montillet J.-P., Tregoning P., McClusky S.C., Yu K. (2013) Extracting white noise statistics in GPS coordinate time series, *IEEE Geoscience and Remote Sensing Letters*, 10, 563-567.

Morrison A.K. and Hogg A.McC. (2013) On the Relationship between Southern Ocean Overturning and ACC Transport, *Journal of Physical Oceanography*, 43, 140–148.

Morrison A.K., Saenko O.A., Hogg A.McC., Spence P. (2013) The role of vertical eddy flux in Southern Ocean heat uptake, *Geophysical Research Letters*, 40, 5445–5450.

Pilia S., Rawlinson N., Direen N.G., Cummins P.R., Balfour N. (2013) Structural controls on localized intraplate deformation and seismicity in Southern Australia: Insights from local earthquake tomography of the Flinders Ranges, *Journal of Geophysical Research: Solid Earth* 118, 2176 – 2190, doi:10.1002/jgrb.50168.

Prodehl C., Kennett B., Artiemeva I.M., Thybo H. (2013) 100 years of seismic research on the Moho, *Tectonophysics*, 609, 9-44 doi: 10.1016/j.tecto.2013.05.036.

Rapaka N.R., Gayen B., Sarkar S. (2013) Tidal conversion and turbulence at a model ridge: direct and large eddy simulations, *Journal of Fluid Mechanics*, 715, 181-209.

Reeves J.M., Bostock H.C., Ayliffe L.K., Barrows T.T., De Deckker P., Devriendt L.S., Dunbar G.B., Drysdale R.N., Fitzsimmons K.E., Gagan M.K., Griffiths M.L., Haberle S.G., Jansen J.D., Krause C., Lewis S., Mcgregor H.V., Mooney S.D., Moss P., Nanson G.C., Purcell A., Van Der Kaars S. (2013) Palaeoenvironmental change in tropical Australasia over the last 30,000 years - a synthesis by the OZ-INTIMATE group, *Quaternary Science Reviews*, 74, 97-114.

Robinson D. J., Sambridge M., Snieder R., Hauser J. (2013) Relocating a cluster of earthquakes using a single seismic station, *Bulletin of the Seismological Society of America*, 103, 3057-3072, doi: 10.1785/0120130004.

Salmon M., Kennett B.L.N., Saygin E. (2013) Australian Seismological Reference Model (AuSREM): crustal component, *Geophysical Journal International*, 192, 190-206, doi: 10.1093/gji/ggs004.

Salmon M., Kennett B.L.N., Stern T., Aitken A.R.A. (2013) The Moho in Australia and New Zealand, *Tectonophysics*, 609, 288-298. doi: 10.1016/j.tecto.2012.07.009.

Sambridge M., Bodin T., Gallagher K., Tkalčić H. (2013) Transdimensional inference in the geosciences, *Philosophical Transactions of the Royal Society A*, 371, 20110547, doi:10.1098/rsta.2011.0547.

Saygin E., McQueen H., Hutton L., Kennett B.L.N., Lister G. (2013) Structure of the Mt. Isa region from seismic ambient noise tomography, *Australian Journal of Earth Sciences*, 60, 707-718, doi:10.1080/08120099.2013.837098.

Simms A.R., Anderson J.B., DeWitt R., Lambeck K., Purcell A. (2013) Quantifying rates of coastal subsidence since the last interglacial and the role of sediment loading, *Global and Planetary Change*, 111:296–308.

Stern T., Houseman G., Salmon M., Evans L. (2013) Instability of a lithospheric step beneath western North Island, New Zealand, *Geology*, 41, 423-426.

Tajima F., Mori J., Kennett B.L.N. (2013) A review of the 2011 Tohoku-Oki earthquake (Mw 9.0): Large-scale rupture across heterogeneous plate coupling, *Tectonophysics*, 586, 15-34. doi: 10.1016/j.tecto.2012.09.014.

Thybo H., Artemieva I.M., Kennett B. (2013) Moho: 100 years after Andrija Mohorovičić, *Tectonophysics*, 609, 1-8, doi: 10.1016/j.tecto.2013.10.004.

Tkalčić H., Bodin T., Young K., and Sambridge M. (2013) On the nature of the P-wave velocity gradient in the inner core beneath Central America, *Journal of Earth Science*, 24, 699-705, doi: 10.1007/s12583-013-0365-7.

Tkalčić H., Young M., Bodin T., Ngo S. and Sambridge M. (2013) The shuffling rotation of the Earth's inner core revealed by earthquake doublets, *Nature Geoscience*, 6, 497-502.

Tregoning P., Burgette R., McClusky S.C., Lejeune S., McQueen H., Watson C.S. (2013) A decade of horizontal deformation from great earthquakes, *Journal of Geophysical Research*, 118, 2371-2381, doi:10.1002/jgrb.50154.

Urakawa L.S., Saenz J. A., Hogg A.McC. (2013) Available potential energy gain from mixing due to the nonlinearity of the equation of state in a global ocean model, *Geophysical Research Letters*, 40, 2224–2228.

Vanacore E., Taymaz T., Saygin E. (2013) Moho Structure of the Anatolian Plate from Receiver Function Analysis, *Geophysical Journal International*, doi: 10.1093/gji/ggs107.

Young M., Cayley R., McClean M., Rawlinson N., Arroucau P., Salmon M. (2013) Crustal structure of the east Gondwana margin in southeast Australia revealed by transdimensional ambient seismic noise tomography, *Geophysical Research Letters*, 40, 4266-4271.

Young M.K., Rawlinson N., Bodin T. (2013) Transdimensional inversion of ambient seismic noise for 3D shear velocity structure of the Tasmanian crust, *Geophysics*, 78, 49-62.

Young M.K., Tkalčić H., Bodin T., Sambridge M. (2013) Global P- wave Tomography of Earth's Lowermost Mantle from Partition Modeling, *Journal of Geophysical Research*, 118, 5467-5486, doi: 10.1002/jgrb.50391.

Zaroli C., Sambridge M., Lévêque J.-J., Debayle E., Nolet G. (2013) An objective rationale for the choice of regularisation parameter with application to global multiple-frequency S-wave tomography, *Solid Earth*, 4, 357-371, doi:10.5194/se-4-357-2013.

PRISE

Babinski, M., Boggiani, P.C., Trindade, R.I.F., Fanning, C.M. (2013) Detrital zircon ages and geochronological constraints on the Neoproterozoic Puga diamictites and associated BIFs in the southern Paraguay Belt, Brazil, *Gondwana Research*, 23, 988-997.

Balgord, E.A., Yonkee, W.A., Link, P.K., Fanning, C.M. (2013) Stratigraphic, geochronologic, and geochemical record of the Cryogenian Perry Canyon formation, northern Utah: Implications for Rodinia rifting and snowball Earth glaciation, *Bulletin of the Geological Society of America*, 125, 1442-1467.

Bicca, M.M., Chemale, F., Jelinek, A.R., de Oliveira, C.H.E., Guadagnin, F., Armstrong, R. (2013) Tectonic evolution and provenance of the Santa Bárbara Group, Camaquã Mines region, Rio Grande do Sul, Brazil, *Journal of South American Earth Sciences*, 48, 173-192.

Bostelmann, J.E., Le Roux, J.P., Vásquez, A., Gutiérrez, N.M., Oyarzún, J.L., Carreño, C., Torres, T., Otero, R., Llanos, A., Fanning, C.M., Hervé, F. (2013) Burdigalian deposits of the Santa Cruz formation in the Sierra Baguales, Austral (Magallanes) basin: Age, depositional environment and vertebrate fossils [Depósitos burdigalianos de la formación Santa Cruz en Sierra Baguales, Cuenca Austral (Magallanes): Edad, ambiente de deposición y vertebrados fósiles], *Andean Geology*, 40, 458-489.

Casquet, C., Hervé, F., Pankhurst, R.J., Baldo, E., Calderón, M., Fanning, C.M., Rapela, C.W., Dahlquist, J. (in press) The Mejillonia suspect terrane (Northern Chile): Late Triassic fast burial and metamorphism of sediments in a magmatic arc environment extending into the Early Jurassic, *Gondwana Research*.

Cubley, J.F., Pattison, D.R.M., Tinkham, D.K., Fanning, C.M. (2013) U-Pb geochronological constraints on the timing of episodic regional metamorphism and rapid high-T exhumation of the Grand Forks complex, British Columbia, *Lithos*, 156-159, 241-267.

Da Silva Filho, A.F., Guimarães, I.D.P., Van Schmus, W.R., Dantas, E., Armstrong, R., Concentino, L., Lima, D. (2013) Long-lived Neoproterozoic high-K magmatism in the Pernambuco-Alagoas Domain, Borborema Province, northeast Brazil, *International Geology Review*, 55, 1280-1299.

Deckart, K., Clark, A.H., Cuadra, P., Fanning, M. (2013) Refinement of the time-space evolution of the giant Mio-Pliocene Río Blanco-Los Bronces porphyry Cu-Mo cluster, Central Chile: New U-Pb (SHRIMP II) and Re-Os geochronology and $40\text{Ar}/39\text{Ar}$ thermochronology data, *Mineralium Deposita*, 48, 57-79.

dos Santos, E.J., Souza Neto, J.A., Carmona, L.C.M., Armstrong, R., Santos, L.C.M.L., Mendes, L.U.D.S. (2013) The metacarbonate rocks of Itatuba (Paraíba): A record of sedimentary recycling in a Paleoproterozoic collision zone of the Borborema province, NE Brazil, *Precambrian Research*, 224, 454-471.

Drew, D.L., Bindeman, I.N., Watts, K.E., Schmitt, A.K., Fu, B., McCurry, M. (2013) Crustal-scale recycling in caldera complexes and rift zones along the Yellowstone hotspot track: O and Hf isotopic evidence in diverse zircons from voluminous rhyolites of the Picabo volcanic field, Idaho, Earth and Planetary Science Letters, 381, 63-77.

Heilbron, M., Tupinambá, M., de Morisson Valeriano, C., Armstrong, R., do Eirado Siva, L.G., Seibel Melo, R., Simonetti, A., Pedrosa Soares, A.C., Machado, N. (in press) Corrigendum to "The Serra da Bolívia complex: The record of a new Neoproterozoic arc-related unit at Ribeira belt" [Precamb. Res. 238 (2013) 158-175] (DOI:10.1016/j.precamres.2013.09.014), Precambrian Research.

Heilbron, M., Tupinambá, M., Valeriano, C.D.M., Armstrong, R., Do Eirado Siva, L.G., Melo, R.S., Simonetti, A., Pedrosa Soares, A.C., Machado, N. (2013) The Serra da Bolívia complex: The record of a new Neoproterozoic arc-related unit at Ribeira belt, Precambrian Research, 238, 158-175.

Hervé, F., Calderón, M., Fanning, C.M., Pankhurst, R.J., Godoy, E. (2013) Provenance variations in the Late Paleozoic accretionary complex of central Chile as indicated by detrital zircons, Gondwana Research, 23, 1122-1135.

Iannizzotto, N.F., Rapela, C.W., Baldo, E.G.A., Galindo, C., Fanning, C.M., Pankhurst, R.J. (2013) The Sierra Norte-Ambargasta batholith: Late Ediacaran-Early Cambrian magmatism associated with Pampean transpressional tectonics, Journal of South American Earth Sciences, 42, 127-143.

Jayananda, M., Peucat, J.-J., Chardon, D., Rao, B.K., Fanning, C.M., Corfu, F. (2013) Neoproterozoic greenstone volcanism and continental growth, Dharwar craton, southern India: Constraints from SIMS U-Pb zircon geochronology and Nd isotopes, Precambrian Research, 227, 55-76.

Lana, C., Alkmim, F.F., Armstrong, R., Scholz, R., Romano, R., Nalini, H.A. (2013) The ancestry and magmatic evolution of Archaean TTG rocks of the Quadrilátero Ferrífero province, southeast Brazil, Precambrian Research, 231, 157-173.

Macey, P.H., Miller, J.A., Rowe, C.D., Grantham, G.H., Siegfried, P., Armstrong, R.A., Kemp, J., Bacalau, J. (2013) Geology of the Monapo Klippe, NE Mozambique and its significance for assembly of central Gondwana, Precambrian Research, 233, 259-281.

McCourt, S., Armstrong, R.A., Jelsma, H., Mapeo, R.B.M. (2013) New U-Pb SHRIMP ages from the Lubango region, SW Angola: Insights into the Palaeoproterozoic evolution of the Angolan Shield, southern Congo Craton, Africa, Journal of the Geological Society, 170, 353-363.

Moreira, P., Fernández, R., Hervé, F., Fanning, C.M., Schalamuk, I.A. (2013) Detrital zircons U-Pb SHRIMP ages and provenance of La Modesta Formation, Patagonia Argentina, Journal of South American Earth Sciences, 47, 32-46.

Muñoz, M., Farías, M., Charrier, R., Fanning, C.M., Polvé, M., Deckart, K. (2013) Isotopic shifts in the cenozoic andean arc of central chile: Records of an evolving basement throughout cordilleran arc mountain building, *Geology*, 41, 931-934.

Peucat, J.-J., Jayananda, M., Chardon, D., Capdevila, R., Fanning, C.M., Paquette, J.-L. (2013) The lower crust of the Dharwar Craton, Southern India: Patchwork of Archean granulitic domains, *Precambrian Research*, 227, 4-28.

Rajesh, H.M., Chisonga, B.C., Shindo, K., Beukes, N.J., Armstrong, R.A. (2013) Petrographic, geochemical and SHRIMP U-Pb titanite age characterization of the Thabazimbi mafic sills: Extended time frame and a unifying petrogenetic model for the Bushveld Large Igneous Province, *Precambrian Research*, 230, 79-102.

Romano, R., Lana, C., Alkmim, F.F., Stevens, G., Armstrong, R. (2013) Stabilization of the southern portion of the São Francisco craton, SE Brazil, through a long-lived period of potassic magmatism, *Precambrian Research*, 224, 143-159.

Santos, M.N., Chemale, F., Dussin, I.A., Martins, M., Assis, T.A.R., Jelinek, A.R., Guadagnin, F., Armstrong, R. (2013) Sedimentological and paleoenvironmental constraints of the Statherian and Stenian Espinhaço rift system, Brazil, *Sedimentary Geology*, 290, 47-59.

Schmidt, A.S., Morton, A.C., Nichols, G.J., Fanning, C.M. (2013) Interplay of proximal and distal sources in Devonian-carboniferous sandstones of the Clair basin, west of Shetland, revealed by detrital zircon U-Pb ages, *Journal of the Geological Society, London*, 169, 691-702.

Suggate, S.M., Cottam, M.A., Hall, R., Sevastjanova, I., Forster, M.A., White, L.T., Armstrong, R.A., Carter, A., Mojares, E. (in press) South China continental margin signature for sandstones and granites from Palawan, Philippines, *Gondwana Research*.

Vennari, V.V., Lescano, M., Naipauer, M., Aguirre-Urreta, B., Concheyro, A., Schaltegger, U., Armstrong, R., Pimentel, M., Ramos, V.A. (in press) New constraints on the Jurassic-Cretaceous boundary in the High Andes using high-precision U-Pb data, *Gondwana Research*.

Vincent, S.J., Morton, A.C., Hyden, F., Fanning, M. (2013) Insights from petrography, mineralogy and U-Pb zircon geochronology into the provenance and reservoir potential of Cenozoic siliciclastic depositional systems supplying the northern margin of the Eastern Black Sea, *Marine and Petroleum Geology*, 45, 331-348.

Weinberg, R.F., Hasalová, P., Ward, L., Fanning, C.M. (2013) Interaction between deformation and magma extraction in migmatites: Examples from Kangaroo Island, South Australia, *Bulletin of the Geological Society of America*, 125, 1282-1300.

Xue, Y., Campbell, I., Ireland, T.R., Holden, P., Armstrong, R. (2013) No mass-independent sulfur isotope fractionation in auriferous fluids supports a magmatic origin for Archean gold deposits, *Geology*, 41, 791-794.

Yakymchuk, C., Siddoway, C.S., Fanning, C.M., Mcfadden, R., Korhonen, F.J., Brown, M. (2013) Anatectic reworking and differentiation of continental crust along the active margin of Gondwana: A zircon Hf-O perspective from West Antarctica, *Geological Society Special Publication*, 383, 169-210.

Zanetti, A., Mazzucchelli, M., Sinigoi, S., Giovanardi, T., Peressini, G., Fanning, M. (2013) SHRIMP U-Pb Zircon Triassic Intrusion Age of the Finero Mafic Complex (Ivrea-Verbano Zone, Western Alps) and its Geodynamic Implications, *Journal of Petrology*, 54, 2235-2265

IODP

Gallagher S., Exon N., Seton M., Ikehara M., Roest W., Hollis C. (2013) Detailed report on the Southwest Pacific IODP Workshop, Sydney Australia, October 9-11, 2012. Web publication of the Integrated Ocean Drilling Program: <http://www.iodp.org/workshops>.

Gallagher S.J., Exon N., Seton M., Ikehara M., Hollis C.J., Arculus R., D'Hondt S., Foster C., Gurnis M., Kennett J.P., McKay R., Malakoff A., Mori J., Takai K., Wallace L. (2013) Exploring new drilling prospects in the Southwest Pacific. *Scientific Drilling*, No. 16.

Clarke S., Hubble T., Airey D., Boyd R., Yu P., Webster J.D., Keene J., Exon N., Gardner J., Ward S.N. and Shipboard Party SS12/2008, 2014. Morphology of Australia's eastern continental slope and related tsunami hazard. S. Krastel et al. (eds.), *Submarine Mass Movements and Their Consequences. Advances in Natural and Technological Hazards Research* 37, 529-538.

Many other papers from Australian and New Zealand authors on ocean drilling results were published throughout the international literature, including papers in *Nature* and *Science*.

VISITING FELLOWS

Adams C.J., Bradshaw J.D., Ireland T.R. (2013) Provenance connections between late Neoproterozoic and early Paleozoic sedimentary basins of the Ross Sea region, Antarctica, southeast Australia and southern Zealandia, *Antarctic Science* (Published on-line 17 Jul 2013).

Binns R.A. (2013) Seafloor massive sulfide deposits and 'black smokers': The potential in Maluku and Papua, and guides for exploration, in Basuki N.I. (Ed.) *Papua and Maluku Mineral Resources*, *Proceedings MGEI Annual Convention*, 1-9.

Binns R.A. (in press) Bikpela – A large siliceous chimney from the PACMANUS hydrothermal field, Manus Basin, Papua New Guinea, in *Metallogeny and Mineralization of Intraoceanic Arcs II: Kermadec, Tofua, Manus, Mariana, Aeolian*, *Economic Geology*, 109.

Yeats C.J., Parr J.M., Binns R.A., Gemmell J.B., Scott S.D. (in press) The SuSu Knolls hydrothermal field, Eastern Manus Basin, Papua New Guinea: An active submarine high-sulfidation copper-gold system, in *Metallogeny and Mineralization of Intraoceanic Arcs II: Kermadec, Tofua, Manus, Mariana, Aeolian*, *Economic Geology*, 109.

Eggleton Tony (2013) It's global warming, stupid: Perceiving climate change. *Australian Quarterly* 84, 3-7.

Jones P.J., Olempska E. (2013) The ostracode suborder Eridostracina Adamczak, 1961, *Contributions to Palaeozoic Ostracod Classification No. 45*, *Neue Jahrbuch fur Geologie und Palaontologie, Abhandlungen*, 267, 341-352.

Mayer W. (2013) William Noel Benson (1885-1957): insights into the life and work of an eminent geologist, *Earth Sciences History*, 32, 55-85.

McDougall I. (2013) Retrospective on the plate tectonic revolution focusing on K/Ar dating, linear volcanic chains and the geomagnetic polarity time scale. *Earth Sciences History*, 32, 313-331.

McDougall I. (2013) *Perspectives on $^{40}\text{Ar}/^{39}\text{Ar}$ dating*, Geological Society, London, Special Publications, doi:10.1144/SP378.20.

McDougall I. (in press) K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dating techniques as applied to young volcanic rocks, particularly those associated with hominin localities, in *Treatise of Geochemistry*, 2nd edition, (Cerling, T.E., editor) Elsevier, Oxford, England.

Metcalfe I., Nicoll R.S., Willink R., Ladjavadi M., Grice K. (2013) Early Triassic (Induan-Olenekian) conodont biostratigraphy, global anoxia, carbon isotopic excursions and environmental perturbations: New data from Western Australian Gondwana, *Gondwana Research*, 23, 1136 – 1150.

Sansom I.J., Haines P.W., Plamen A., Nicoll R.S. (2013) A new pteraspidomorph from the Nibil Formation (Katian, Late Ordovician) of the Canning Basin, Western Australia, *Journal of Vertebrate Paleontology*, 33, 764–769.

NATIONAL AND INTERNATIONAL LINKS

COLLABORATION WITH AUSTRALIAN UNIVERSITIES, CSIRO & INDUSTRY

Earth Chemistry

Prof 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.

Prof Y. AMELIN with Prof R. Cas (Monash University) on geochronology and the origin of ores in the Archaean Yilgarn block, Western Australia.

Dr J.N. ÁVILA with Australian Scientific Instruments (ASI) on the development of analytical protocols for measurement of stable isotopes on the new SHRIMP SI.

Dr J.N. ÁVILA with Dr M. Lugaro (Monash University) on the timescale of presolar SiC grains.

Dr V.C. BENNETT with Dr A.P. Nutman (University of Wollongong) on geochemical and isotopic investigations of greater than 3.7 billion year old rocks from southwest Greenland to reveal early Earth chemical processes and environments.

Dr V.C. BENNETT with Dr S. Buchman (University of Wollongong) on isotopic investigations of eastern Australian eclogites.

Dr V.C. BENNETT with Dr M.J. van Kranendonk (University of New South Wales) on geochemical investigations of Archean rocks from the Pilbara region, Western Australia.

Dr J.J. BROCKS with Prof B. Rasmussen (Curtin University of Technology) on the thermal maturity of Archean organic matter.

Dr J.J. BROCKS with Prof P. De Deckker (RSES, ANU) on the reconstruction of sea surface temperatures over the past 300 years on Australia's East and South coast and on the lipid composition of Acantharians.

Dr J.J. BROCKS with Prof K. Grice and a cluster of researchers (Melbourne University, Curtin University, University of Western Australia and international universities) on Organic Geochemistry of Mineral Systems (CSIRO Flagship Cluster).

Dr J.J. BROCKS with Prof M. Kennedy (University of Adelaide) on geobiology and hydrocarbons of the McArthur Basin and on biogeochemistry of the Bitter Springs Excursion in the Amadeus Basin.

Dr J.J. BROCKS with Dr M. Prebble (ANU) and Ms J. Lattaud (ENS Lyon), a biomarker study on the archaeological and environmental history of Tekopeia, a remote Indonesian Island.

Dr J.J. BROCKS with Dr A. Carlo (ANU) on the search for beeswax in ancient archaeological artefacts.

Dr J.J. BROCKS with Ms A. Jarrett, Mr B. Bruisten (ANU) and Dr G. Logan (Geoscience Australia) on the biomarker record of sulfate oxidizing bacteria revisited.

Dr S.J. FALLON with Prof J. Hughes (Griffith University) on ageing the Australian lungfish.

Dr S.J. FALLON with Dr R. Thresher (CSIRO) on Climate from Deep Sea Corals.

Dr S.J. FALLON with Dr J. Lough and Dr K. Fabricius (Australian Institute of Marine Science) on climate records from tropical corals.

Dr S.J. FALLON with Dr J. Sanderman (CSIRO) on the history of Coorong Delta.

Dr S.J. FALLON with Dr L. Reed (Flinders Universtiy) on the vegetation history of Naracoorte Cave region.

Dr M. HONDA with A/Prof D. Phillips (The University of Melbourne) and Prof A. Chivas (The University of Wollongong) on cosmogenic noble gas studies in young basalts.

Dr M. HONDA with A/Prof D. Phillips (The University of Melbourne) and Profs S. O'Reilly and B. Griffins (Macquarie University) on noble gas studies in diamonds.

Dr M. HONDA with Dr M. Kendrick (The University of Melbourne) on combined studies of noble gas and halogen geochemistry on mantle-derived samples.

Prof T.R. IRELAND with Australian Scientific Instruments (ASI) on the commercialization of SHRIMP ion microprobes.

Prof T.R. IRELAND with Prof P. Vasconcelos (University of Queensland) on geochronology and geochemistry of regolith.

Prof T.R. IRELAND with Prof J. Aitchison and Prof G. Clarke (University of Sydney) on geochronology of India and Himalaya.

Prof T.R. IRELAND with Prof R. Large (University of Tasmania) on S isotope compositions of shales and economic deposits.

Prof T.R. IRELAND with Prof J. Lattanzio and Dr M. Lugaro (Monash University) on isotope compositions of stardust.

Prof T.R. IRELAND with Dr K. Liffman (CSIRO) on early solar system processes.

Prof T.R. IRELAND with Dr J. Walsh (CSIRO) on S isotopes.

Dr C.H. LINEWEAVER with Dr T. Davis (University of Queensland) on misconceptions about the big bang, energy conservation in cosmology and the relationship between entropy and gravity.

Dr D. RUBATTO with Dr L. Martin (University of Western Australia) on the measurement of oxygen isotopes in garnet.

Dr R. SALMERON with Prof M. Wardle (Macquarie University) on the structure and dynamics of star forming accretion disks.

Dr R. SALMERON with Dr K. Liffman (CSIRO and Swinburne University) on the early Solar System.

Ms K.M. STRZEPEK with Dr A. Revill and Dr R. Thresher (CSIRO) and Dr C. Smith (Latrobe University) on compound specific nitrogen isotope analysis.

Dr I.S. WILLIAMS with Australian Scientific Instruments Pty. Ltd. (Canberra) on SHRIMP development and marketing.

Dr I.S. WILLIAMS with Dr J.A. Trotter (University of Western Australia) and Prof I. Metcalfe (University of New England) on palaeoclimatology using marine bioapatite oxygen isotopes.

Dr I.S. WILLIAMS with Dr P.G. Lennox (University of New South Wales) on emplacement and deformation ages of the Wyangala Granite, Cowra, NSW.

Dr R. WOOD with Dr D. Wright and Dr L. Nejman (Griffith University) on chronology of Pod Hradem, a Middle to Upper Palaeolithic site in the Czech Republic.

Dr R. WOOD with Ms S. Wasef (Griffith University) on direct radiocarbon dating of Sacred Ibis bones from Ancient Egypt.

Dr R. WOOD with Ms J. Wright (Griffith University) on radiocarbon dating of a skeleton from northern Queensland.

Dr R. WOOD with Prof J. Balme (University of Western Australia) on radiocarbon dating of Pleistocene sites in the Kimberly.

Earth Environment

Dr N. ABRAM with Dr Steven Phipps and Prof Matthew England (University of New South Wales) on Antarctic climate modeling and processes.

Dr N. ABRAM with Dr Mark Curran and Dr Tessa Vance (Antarctic Climate and Ecosystems CRC) on Antarctic palaeoclimate reconstructions.

Prof P. De DECKKER with Dr Dan Wilkins (Antarctic Division) on The Holocene history and dating of crater lakes.

Prof P. De DECKKER with Dr Jessica Reeves (Ballarat University) on Ostracod taxonomy and ecology.

Prof P. De DECKKER with Prof Colin Murray Wallace (University of Wollongong) on The palaeoenvironmental reconstruction of the Lacepede Shelf offshore South Australia.

Prof P. De DECKKER with Prof Nigel Tapper (Monash University) on Airborne dust.

Dr S.M. EGGINS with Prof M. Byrne and Mr S. Doo (University of Sydney) and Dr Sarah Hamylton (University of Wollongong) on the Great Barrier Reef Foundation Project, 'Reef-scale impacts of changing climate on calcification by large benthic foraminifera on the Great Barrier Reef'.

Dr M.J. ELLWOOD with Dr Edward Butler (CISRO), Dr Andrew Bowie (ACE CRC) and Dr Christel Hassler (University of Technology Sydney) on Trace metals in Tasman Sea and SW Pacific waters.

Dr M.J. ELLWOOD with Prof William Maher (University of Canberra) on Mercury and arsenic cycling in organisms.

Dr M.K. GAGAN with Assoc. Prof R. Drysdale and Dr J. Hellstrom (University of Melbourne) on ARC *Discovery* grant DP1095673 (2010-2013): Multi-proxy fingerprinting, absolute dating, and large-scale modelling of Quaternary climate-volcano-environment impacts in southern Australasia.

Dr M.K. GAGAN with Dr H. McGregor and Prof C. Woodroffe (University of Wollongong) and Dr S. Phipps (University of New South Wales) on coral reconstructions of El Niño-Southern Oscillation variability in the central equatorial Pacific.

Dr M.K. GAGAN with Prof J.-x. Zhao (University of Queensland) on U-series dating of Indonesian speleothems.

Dr M.K. GAGAN is an Associate Investigator with the ARC Centre of Excellence for Climate System Science led by Prof A. Pitman (University of New South Wales).

Prof R. GRÜN 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) on the ARC grant DP110101415 Understanding the migrations of prehistoric populations through direct dating and isotopic tracking of their mobility patterns.

Prof R. GRÜN with Dr N. Stern (La Trobe University) on the environmental reconstruction of the Lake Mungo Lunette.

Prof R. GRÜN with Dr Gerrit van den Berg (University of Wollongong) on the dating of a range of Indonesian Sites

Prof R. GRÜN with Dr Z. Jacobs (University of Wollongong) on the dating of Italian middle Palaeolithic sites.

Dr D. HESLOP with Dr Raphael.Viscarra-Rossel (CSIRO Land and Water) on the magnetic mineralogy of Australian soils.

Dr D. HESLOP with Dr P. Hesse (Macquarie University) on the analysis of Australian dust in marine sediments.

Dr D.C. "Bear" McPHAIL with Dr John Moreau (University of Melbourne), Dr Frank Reith and Prof Joël Brugger (University of Adelaide), and Dr Anthony Dosseto (University of Wollongong) on the fractionation of uranium isotopes in the regolith.

Dr D.C. "Bear" McPHAIL with Dr Anthony Dosseto (University of Wollongong) and Prof Peter Hiscock (University of Sydney) on landscape evolution, human occupation history and groundwater in the Lake George catchment, NSW.

Dr D.C. "Bear" McPHAIL with Dr Wendy McLean and Ms. Liz Webb (Parsons Brinckerhoff, Sydney) on groundwater dynamics in the Lower Murrumbidgee catchment, NSW.

Mr G. NASH with CSIRO to demonstrate the assembly and operation of the ANU multicoring equipment.

Dr M.D. NORMAN with Drs. A. Nemchin, F. Jourdan, and M. Grange (Curtin University) and Prof M. Walter (University of New South Wales), and Dr P. Blevin (Geological Survey of New South Wales) on ages and compositions of molybdenite and cassiterite mineralisation.

Prof B.J. PILLANS with Dr G.D. van den Berg (University of Wollongong) on the Quaternary stratigraphy of Soa Basin, Flores and Walanae Basin, Sulawesi, Indonesia.

Prof B.J. PILLANS with Dr K. Mulvaney (Rio Tinto Iron Ore) on Aboriginal rock art, Burrup Peninsula, Western Australia

Prof E.J. ROHLING with Prof O. Hoegh-Guldberg (University of Queensland) on a study about consequences of global warming, and

Prof E.J. ROHLING with Dr J. Webster (University of Sydney) on a novel approach to sea-level studies.

Mr. N. SCROXTON with Dr J Hellstrom (University of Melbourne) on U/Th dating

Mr. N. SCROXTON with Dr Henk Heijnis and Patricia Gadd (ANSTO) on X-ray fluorescence scanning of stalagmites.

Dr R. Strzepak with Prof Philip Boyd, (University of Tasmania), Prof Bill Maher (University of Canberra), and Dr Leanne Armand (Macquarie University) on the multiplicative effects of climate change on marine phytoplankton ecophysiology.

Dr J. YU with Dr Laurie Menviel (UNSW) on deep South Atlantic carbonate system.

Earth Materials & Processes

Prof R. ARCULUS with Prof M. Coffin (University of Tasmania) on a forthcoming research voyage of Australia's Marine National Facility to Heard-Kerguelen.

Prof R. ARCULUS with Prof L. Danyushevsky and Dr T. Falloon (University of Tasmania) on the petrology or submarine volcanism and tectonism in the SW Pacific.

Prof R. ARCULUS with Prof S. Turner (Macquarie University) on isotopic geochemistry of submarine volcanic rocks.

Prof R. ARCULUS with Prof D. Gust (Queensland University of Technology) on the petrogenesis of the volcanic rocks of Mt Kilimanjaro.

Prof R. ARCULUS with Dr K. Knesel (University of Queensland) on the age dates of submarine volcanic rocks of the SW Pacific.

Prof R. ARCULUS with Dr C. Spandler (James Cook University) on the petrology of zoned Alaskan ultramafic intrusions.

Dr A. BENARD with Dr B. McInnes (CSIRO) on SHRIMP sulfur isotopes on arc mantle xenolith studies.

Dr A.J. BERRY with Dr M. Kusiak (Curtin University) on the mobilisation of trace elements in zircon with implications for the dating of metamorphic rocks.

Dr A.J. BERRY with Dr D. Paterson, Dr M.D. de Jonge, and Dr C. Glover (Australian Synchrotron), using synchrotron radiation to study the distribution and speciation of elements in minerals and melts.

Prof I.H. CAMPBELL and Dr Y. AMELIN with Prof R. Cass, Dr R Weinberg and Dr R. Squire (Monash University), Dr M. Wingate (Geological Survey of Western Australia) and Dr W. Bleeker (Geological Survey of Canada) on a Linkage supported project titled "Prospectively of late Archaean basaltic and gabbroic rocks associated with major gold and base-metal deposits".

Prof S.F. COX (as a member of the ARC Centre of Excellence in Ore Deposits, University of Tasmania), with staff at Beck Engineering, on aspects of the development of fracture-controlled flow regimes in intrusion-related hydrothermal ore systems.

Dr M. FORSTER and colleagues with Dr M. Roberts (Marengo Mining) on supervision of PhD student, Oleg KOUDESHAV, whose project is titled "Argon geochronology dating and tectonic events at Yandera".

Dr M. FORSTER with Dr P. Lennox (University of New South Wales) on argon geochronology of tectonic events on eastern Australia.

Dr M. FORSTER with Dr G. Batt (University of Western Australia) on argon geochronology of tectonic events of China.

Dr M. FORSTER with Prof J. Aitchison, Prof G. Clarke and PhD students (University of Sydney), AISRF research on the Himalaya orogeny.

Dr M. FORSTER with members of the TANG³O (Thermal and Noble Gas, Geochemistry and Geochronology Organisation) which includes ANU (Prof T.R. IRELAND), Melbourne University (Assoc Prof D. Phillips and Prof B. Kohn), Curtin University (Prof B. McInnes and Dr F. Jourdan) and the University of Queensland (Prof P. Vasconcelos).

Mr B.J. HANGER with Prof V. Kamenetsky (University of Tasmania) on garnet peridotite xenoliths studies.

Mr B.J. HANGER with Dr D. Paterson and Dr D. Howard (Australian Synchrotron) on XANES studies of garnet.

Mr B.J. HANGER with Prof M. Killburn (University of Western Australia) on NanoSIMS studies of zoned garnets.

Dr J. HERMANN with Dr C. Spandler (James Cook University, Townsville) on element recycling in subduction zones.

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

Dr J. HERMANN with Dr M. Kendrick (Melbourne University) on subduction recycling of noble gases.

Dr J. HERMANN with Dr G. Rosenbaum (University of Queensland) on teaching undergraduate field geology.

Dr P. KING with Dr A. Green and Dr J. Huntingdon (CSIRO) on infrared spectroscopy.

Dr P. KING with Dr C. Moore (University of Canberra) on regolith studies.

Prof G. LISTER developed links with Prof Jonathan Aitchison (University of Sydney) and Prof Mike Sandiford (University of Melbourne) in the context of a proposed Centre of Excellence in Asian Geoscience. Although the initial bid for an ARC Centre of Excellence did not succeed, efforts continue to develop this three way interaction.

Dr O. NEBEL with Prof J. Woodhead (Melbourne University) on the evolution of oceanic island basalt lavas.

Prof H. O'NEILL with Dr C. Spandler (James Cook University) on diffusion of trace elements in olivine and other minerals at high temperature.

Dr J.A. PADRON-NAVARTA with Dr J.M. González-Jiménez (GEMOC, Sydney) on sulphides in serpentinites.

Dr J.A. PADRON-NAVARTA with Dr M. Kendrick (Melbourne University) on subduction recycling of noble gases.

Dr G.M. YAXLEY with Prof V.S. Kamenetsky (University of Tasmania) on kimberlite petrogenesis and emplacement project; Redox studies of garnet-bearing xenoliths from the Obnazhennaya kimberlite, Siberia.

Dr G.M. YAXLEY with Prof V.S. Kamenetsky (University of Tasmania), Dr Geoff Nichols (formerly Macquarie University), Dr Roland Maas (University of Melbourne), Dr Elena Belousova (Macquarie University), Dr Anja Rosenthal (University of Bayreuth) and Dr Marc Norman (RSES) on a study of the first reported occurrence of kimberlite in Antarctica.

Earth Physics

Dr N. BALFOUR with Craig O'Neill (Macquarie University), Tim Rawling (University of Melbourne) and Anya Reading (University of Tasmania) on Seismometers in Schools.

Mr C.C. CHAPMAN and Dr A.McC. HOGG with Dr S.R. Rintoul (CSIRO Marine and Atmospheric Research) on variability in the Southern Ocean.

Dr D.R. DAVIES with the Earthbyte group (University of Sydney) to incorporate plate motion reconstructions into mantle convection models.

Dr D.R. DAVIES with Luis Moresi's group (Monash University) to develop improved computational models for geodynamics.

Dr S.M. DOWNES with Drs S. Marsland and P. Uotila (CSIRO Marine and Atmospheric Research) on the Southern Ocean multi model analysis for the Coordinated Ocean-Ice Reference Experiments Phase 2 (CORE-II) international effort.

Dr A.McC. HOGG and Dr M.L. WARD with Prof M.H. England and Dr P.A. Spence (University of New South Wales) on the development of a high resolution ocean model.

Dr G.O. HUGHES with Dr J. Pye (Research School of Engineering, ANU) on convective flows in solar thermal systems.

Dr C. KLOOTWIJK with Dr E. Tohver (University of Western Australia) on magnetostratigraphy of upper Permian rocks from the Sydney and Gunnedah Basins.

Dr S. MCCLUSKY with Dr C. Watson and Dr M. King (University of Tasmania) on crustal deformation studies.

Ms I. ROSSO and Dr A.McC. HOGG with Assoc. Prof P.G. Strutton (Institute for Marine and Antarctic Studies, University of Tasmania), Dr A.E. Kiss (School of Physical, Environmental and Mathematical Sciences, University of New South Wales at Australian Defence Force Academy) and Dr R.J. Matear (CSIRO Marine and Atmospheric Research) on transport of nutrients in the ocean.

Dr J-P. MONTILLET with Dr Kegen Yu (SNAP lab, The University of New South Wales) on Modelling stochastic processes in Geodetic time series.

Prof M.L. RODERICK with Dr R. Donohue, Mr T. VanNeil, Dr T. McVicar (CSIRO) on hydrologic impacts of climate change.

Prof M.L. RODERICK with Prof A. Pitman (ARC Centre of Excellence for Climate System Science) on land-atmosphere feedbacks.

Dr M. SALMON with NICTA on the Geothermal Data Fusion Project.

Dr M. SALMON with Nader Issa (University of Western Australia), helping with the installation of a Seismometer in Harvey.

Prof M. SAMBRIDGE with Dr V. Brando (CSIRO) on joint supervision of a Ph.D. student project on transdimensional inversion approaches to remote sensing of geospatial data.

Prof M. SAMBRIDGE, Dr N. BALFOUR and Dr M. SALMON with Dr T. Rawling (University of Melbourne) on the Australian Seismometers in Schools program, part of the AuScope Australian Geophysical Observing System (AGOS) Educational strand.

Prof M. SAMBRIDGE with Dr L. Gross (University of Queensland) on development of inversion software, part of the AuScope Australian Geophysical Observing System (AGOS) Inversion laboratory strand.

Ms K. SNOW, Dr S.M.DOWNES and Dr A.McC. HOGG with Dr B. Sloyan (CSIRO Marine and Atmospheric Research) on the dynamics of Antarctic Bottom Water formation and transport.

Dr H TKALČIĆ with Dr A. Reading (University of Tasmania) on different projects to study lithospheric structure of Australia.

Dr P. TREGONING with Dr C. Watson and Prof M. King (University of Tasmania) on sea level, Antarctic mass balance and crustal deformation studies.

Ms M. YOUNG with Dr A. Reading and Dr D. Bombardieri (University of Tasmania) to develop a 3D shear wave velocity model of the Tasmanian crust.

PRISE

Dr R.A. ARMSTRONG with Dr L. Shewan (University of Sydney) on studies of human mobility on Archaeological sites from Cambodia.

Dr R.A. ARMSTRONG with Dr M. Roberts (Marengo Mining Ltd) on the geochronology of the Yandera region, Papua New Guinea.

Dr R.A. ARMSTRONG with Dr M. Doyle (AngloGold-Ashanti) on geochronology of the Tropicana deposit, Western Australia.

IODP

The Australian IODP Office (AIO) at RSES is also the contact point for ANZIC – the Australian and New Zealand IODP Consortium. The Australian Research Council (ARC), fourteen Universities, three Government agencies, and a marine geoscience peak body (MARGO) provided funding for Australia's membership of IODP until September 30, 2013. From October 1, 2013, the contributors will be ARC, two Australian government agencies, fifteen Australian universities and New Zealand. Naturally, the office has collaborated with a great number of individuals in Universities, Government agencies and foreign agencies.

ANU Professors Ian Jackson, Richard Arculus and Neville Exon are on the Governing Council of ANZIC. Neville Exon and Michael Gagan are on the ANZIC Science Committee. Richard Arculus was a member of the key IODP Proposal Evaluation Committee until September.

Visiting Fellows

Mr R.V. BURNE with scientists from LITHICON and RSES on an intermediate MgSi phase, critical for the early organomineralisation of Lake Clifton thrombolites.

Dr K.A.W. CROOK and Dr E.A. FELTON with Dr D. Fink (Australian Nuclear Science and Technology Organization) on cosmogenic age dating of rocky coastal geomorphic features.

Dr K. A. W. CROOK with Dr John Molony and others from ANU's Emeritus Faculty, have re-evaluated and confirmed conclusively evidence that Portuguese fleets visited, mapped and laid claim to coastal and adjacent areas of eastern and north-western Australia 250 years before Captain James Cook's voyages.

Emeritus Prof R.A. EGGLETON with Emeritus Prof G Taylor (University of Canberra) on the bauxites of the southern Highlands and on silcrete.

Emeritus Prof I. McDOUGALL, with Prof P. Vasconcelos (University of Queensland) on the geochronology of the Omo-Turkana Basin in eastern Africa.

INTERNATIONAL COLLABORATION

Earth Chemistry

Prof Y. AMELIN with Dr R. Tucker (US Geological Survey) on geological evolution and mineralisation in Madagascar, Afghanistan and north-eastern US (New England).

Prof Y. AMELIN with Dr C. Stirling (Otago University) on detecting small uranium isotopic variations in nature and evaluating their origin and significance.

Prof Y. AMELIN with Dr A. Krot (University of Hawaii) on the origin of chondrites and their parent asteroids.

Prof Y. AMELIN with Prof S. Jacobsen (Harvard University) on chronology of the solar system's oldest solids.

Prof Y. AMELIN with Dr K. Kossert (Physikalisch-Technische Bundesanstalt, Germany) on determination of half-lives of short-lived isotopes.

Prof Y. AMELIN with Dr Qing-zhu Yin (University of California Davis) on the origin of chondrites and their parent asteroids.

Prof Y. AMELIN with Dr M. Schonbachler (University of Manchester) on the extinct radionuclide systematics of the early Solar System.

Prof Y. AMELIN with Dr T. Iizuka (University of Tokyo) on the extinct radionuclide systematics and chronology of the early Solar System.

Prof Y. AMELIN with Dr A. Irving (University of Washington) on the chronology and origin of differentiated meteorites.

Dr J.N. ÁVILA with Prof E. Zinner and Dr F. Gyngard (Washington University) on the study of presolar stardust grains.

Dr V.C. BENNETT with 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 K. Bermingham and Dr R. Walker (University of Maryland) on determining nucleosynthetic isotopic anomalies in ancient terrestrial rocks.

Dr V.C. BENNETT with Dr N Dauphas (University of Chicago) on integrated heavy stable isotope studies of Earth's oldest carbonates to reconstruct early atmosphere development and evolution.

Dr V.C. BENNETT and PhD student Alex McCOY-WEST with Dr R Walker and Dr I Puchtel (University of Maryland) on determining the age structure of the southern ocean basin through rhenium-osmium isotope analyses of mantle peridotites.

Dr J.J. BROCKS with Prof N. Butterfield (University of Cambridge) on the Palaeontology and organic geochemistry of Neoproterozoic successions in Europe.

Dr J.J. BROCKS with Mr J. Logemann and Prof J. Rullkötter (University of Oldenburg) and Dr J. Moreau (University of Melbourne) on intact polar lipids of halophilic bacteria and archaea.

Dr J.J. BROCKS with Mr B.J. Bruisten (ANU), Dr R. Schinteie (CSIRO Petroleum), Mr J. Colangelo-Lillis (University of Montreal), Dr L. Reuning and Prof R. Littke (RWTH Aachen University) on hydrothermal destruction of hydrocarbons in the Neoproterozoic Bitter Springs Formation, Amadeus Basin, central Australia.

Dr J.J. BROCKS with the Agouron Pilbara Drilling Project including Prof R. Summons and Ms K. French (MIT), Dr C. Hallmann (MPI Bremen), Prof S. George (Macquarie University), Prof G. Davidson Love (University of California, Riverside), Prof M. Van Kranendonk (UNSW), Prof R. Buick (University of Washington, Seattle), Prof J. Abelson (Agouron) and many others.

Dr J.J. BROCKS with Dr Schouten (NIOZ) and many others, Round Robin for the TEX₈₆ palaeotemperature proxy.

Dr J.J. BROCKS with Prof S. Porter (University of California, Santa Barbara) on the geobiology of the Cryogenian in the Grand Canyon.

Dr J.J. BROCKS with Prof E. Javaux (University of Liege) and Prof S. Poulton (University of Leeds) on microfossils, biomarkers and geochemistry of Mesoproterozoic successions in Northern Africa.

Dr J.J. BROCKS with Ms N. Gueneli (ANU) and Ms J. Rouillard (ENS Lyon) on the search for the oldest biomarkers on Earth.

Dr S.J. FALLON with Dr B. Roark (Texas A&M university), Dr T. Guilderson (Lawrence Livermore National Laboratory) and Dr F. Pariah (National Oceanic and Atmospheric Administration, USA) on climate records from North Pacific Deep Sea Corals.

Dr S.J. FALLON with Dr L. Skinner (University of Cambridge) on ocean overturning from deep sea sediment cores.

Dr M. HONDA with Dr J. Harris (University of Glasgow) and Dr D. Araújo (Universidade de Brasília) on noble gas studies in diamonds.

Prof T.R. IRELAND with Prof T. M. Harrison and Prof K. McKeegan (University of California, Los Angeles) on mass spectrometer technology.

Prof T.R. IRELAND with Prof E. Zinner and Dr F. Gyngard (Washington University in St Louis) on provenance of stardust.

Prof T.R. IRELAND with Prof A. Cooper (Otago University) on the geochronology of New Zealand sediments.

Prof T.R. IRELAND with Prof P. Phillipot (Institut de Physique du Globe de Paris, France) on S isotopes.

Prof T.R. IRELAND is a member of the Joint Science Team of the JAXA (Japan) Hayabusa 2 Mission.

Dr C.H. LINEWEAVER with Prof P.C.W. Davies (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 Dr Mark D. Vincent (University of Western Ontario) on a new astrobiological atavistic model of 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 (Howard University) on the thermal history of the Earth and life on billion year timescales.

Dr C.H. LINEWEAVER is developing collaborations with Prof Norm Sleep (Stanford University), Prof Eschel Ben Jacob (Tel Aviv University), Prof Phil Nicholson (Cornell University), Prof Lawrence Krauss (Arizona State University), Dr Carlo Maley (University of California, San Francisco) and Prof Thanu Padmanabhan (Intra-University Centre for Astronomy and Astrophysics, Pune India).

Dr D. RUBATTO with Prof P. Philippot and Ms C. Francois (Institut de Physique du Globe de Paris, France) on the metamorphic evolution Archean terranes in Pilbara and Barbeton.

Dr D. RUBATTO with Prof L. Baumgartner, Dr B. Putlitz, and Dr C. De Meyer (University of Lausanne, Switzerland) on calibration of standards for oxygen isotopic analysis and fluid migration within high pressure rocks.

Dr D. RUBATTO with Prof I. Buick (Stellenbosch University, South Africa) on the development of standards for SIMS isotopic analysis.

Dr D RUBATTO with Dr D. Harlov (Deutsches Geo Forschungs Zentrum, Potsdam, Germany) on the effect of recrystallization the oxygen isotopic composition of monazite, zircon, garnet and apatite.

Dr D. RUBATTO with Prof D. Whitney (University of Minnesota) on the geochemical and geochronological evolution of the blueschist belt in Turkey.

Dr D. RUBATTO with Prof M. Engi, Mr D. Regis and Ms B. Niederhauser (University of Bern, Switzerland) on the chronology of Alpine metamorphism.

Dr D. RUBATTO with Dr M. Beltrando (University of Turin) on the chronology of paleo-margins assembled within the Alpine orogeny.

Dr D. RUBATTO with Prof T. John (University of Muenster and Freie Univerität Berlin, Germany) on fluid circulation in Tianshan high pressure rocks.

Dr D. RUBATTO with Dr D. Zegezinov and Prof V. S. Shatsky (Russian Academy of Sciences Siberian Branch, Russia) on the oxygen isotopic composition of kimberlitic garnet.

Dr D. RUBATTO with Mr C.E. Ganade de Araujo and Prof U. Cordani (Universidade de Sao Paulo-USP/Servico Geologico do Brasil-SGB) on the chronology of eclogites in the Western Gondwana Orogeny.

Dr D. RUBATTO with Mr J. Wang and Prof J. Zhang (Peking University, China) on the chronology of melting and metamorphism in Tibet Himalaya.

Dr D. RUBATTO with Dr Antonio Acosta-Vigil (University of Granada) on the chronology of melting around the Ronda Peridotite, Spain.

Dr R. SALMERON with Prof A. Konigl (University of Chicago) on wind-driving protostellar disks.

Dr I.S. WILLIAMS and Prof R.W.R. RUTLAND with Dr A. Solli (Geological Survey of Norway) on the evolution of the Caledonian nappes of Norway.

Dr I.S. WILLIAMS with Dr E. Krzemińska (Polish Geological Institute – National Research Institute, Warsaw) on the evolution of the basement beneath the East European Platform in Poland.

Dr I.S. WILLIAMS with Dr S. Mikulski (Polish Geological Institute – National Research Institute, Warsaw) on the geochronology of metallic deposits in the Variscides of Southern Poland.

Dr I.S. WILLIAMS with Dr P. Fiannacca, Dr R. Cirrincione and Prof A. Pezzino (University of Catania, Sicily) on the chronology of thermal events in the Serre Massif, Calabria.

Dr I.S. WILLIAMS with Prof D. Liu, Dr Z. Ji and Dr G. Wu (Chinese Academy of Geological Sciences, Beijing) on tracing Permo-Triassic palaeoclimate in Tibet using marine bioapatite O isotopes.

Dr I.S. WILLIAMS with Dr M. Kusiak (Polish Academy of Science, Warsaw) on chronology of the composite Karkonosze pluton, Sudetes.

Dr I.S. WILLIAMS with Dr W. Müller (Royal Holloway University of London) on spatially-resolved oxygen isotope systematics of fossil teeth.

Dr R. WOOD with Prof T. Higham and Dr K. Douka (University of Oxford), Dr A. Arrizabalaga and Dr A. Villaluenga (University of the Basque Country), Drs J. Soler, N. Soler and J. Maroto (University of Girona), Drs M. de la Rasilla and D. Santamaria (University of Oviedo), Dr J. Jorda (University of Distance Education, Spain), Drs C. Barroso and M. Caparros (Zafarraya, Spain) on several projects involving dating the Middle to Upper Palaeolithic transition in Europe.

Earth Environment

Dr N. ABRAM with Dr Robert Mulvaney and Dr John Turner (British Antarctic Survey, Cambridge) and Prof. Eric Wolff (University of Cambridge) on polar ice core palaeoclimate reconstructions.

Dr N. ABRAM with Prof. W. Hantoro (Indonesian Institute of Sciences, Bandung) and Dr H. Rifai (Padang University, Indonesia) on tropical palaeoclimate studies using coral and cave samples.

Dr M. DAVIES with Dr John Stone (University of Washington, USA) on cosmogenic isotope analysis of ice-rafted debris.

Dr M. DAVIES with Dr Alan Mix (Oregon State University, USA) on radiocarbon-based reconstructions of Northeast Pacific Deep and Intermediate Water.

Dr M. DAVIES with Dr Joseph Stoner (Oregon State University, USA) and Dr Guillaume St. Onge (University of Quebec Rimouski, Canada) on geomagnetic paleointensity/cosmogenic isotope production.

Prof P. De DECKKER with Dr Sabine Schmidt (University of Bordeaux I), Dating marine sediments using a variety of radionuclides.

Prof P. De DECKKER with Professor Stefan Schouten (NIOZ, Holland) and his former PhD student Raquel Lopez (now British Geological Survey), Lipid biomarkers in deep-sea marine cores.

Prof P. De DECKKER with Dr Jan-Berend Stuut (NIOZ, Holland), Airborne dust and deep-sea sediments and their composition.

Prof P. De DECKKER with Dr Matthias Moros and Dr Kerstin Perner (Baltic Sea Research Institute), The faunal composition and isotopic composition of deep-sea core offshore South Australia.

Prof P. De DECKKER with Dr Tony Rathburn and his PhD student Ashley Burkett (Indiana State University), Deep-sea foraminifera from the Australian region.

Dr S.M. EGGINS with Assoc. Prof Bärbel Hönisch (Lamont Doherty Earth Observatory, University of Columbia, USA) and Prof Howard Spero (University of California Davis, USA) on the calibration of foraminifer shell chemistry based geochemical proxies for the reconstruction of past seawater temperature and carbonate system parameters.

Dr S.M. EGGINS and Mr L. KINSLEY with Mr. John Roy, of Photon-Machines Inc., Boseman, Montana, on the refinement of laser ablation sample cell technology for *in-situ* microanalysis by laser ablation ICP mass spectrometry.

Dr M.J. ELLWOOD collaborates with Prof Philip Boyd (NIWA, NZ), Dr Helen Bostok (NIWA, NZ), Dr Helen Neil (NIWA, NZ), Dr Scott Nodder (NIWA, NZ), Dr Cliff Law (NIWA, NZ), Prof Steve Wilhelm (University of Tennessee) and Prof David Hutchins (University of Southern California) on Trace element and nutrient cycling in the SW Pacific Ocean during present and during the past.

Dr M.K. GAGAN with Prof 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 (2010-2013): Multi-proxy fingerprinting, absolute dating, and large-scale modelling of Quaternary climate-volcano-environment impacts in southern Australasia.

Dr M.K. GAGAN with Prof W. Hantoro and Dr D. Natawidjaja (Indonesian Institute of Sciences), Prof C.-C. Shen (National Taiwan University), Prof K. Sieh (Earth Observatory of Singapore), Prof L. Edwards and Dr H. Cheng (University of Minnesota), and Dr G. Schmidt (NASA Goddard Institute for Space Studies) on ARC Discovery grant DP110101161 (2011-2015): Climate and natural hazards in Australasia: A comprehensive impact analysis of prehistoric droughts, great earthquakes, and the Toba super-eruption.

Dr M.K. GAGAN with Co-Chief Investigators Dr Jody Webster (University of Sydney) and 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 with Prof C. Falgueres, Dr J.J. Bahain and other staff members (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.

Prof R. GRÜN with Drs D. Grimaud-Hervé and M.H. Moncel (Département de Préhistoire du Musée National d'Histoire Naturelle, Paris) on the application of new isotopic systems on Neanderthal remains.

Prof R. GRÜN with Prof B. Maureille (Laboratoire d'Anthropologie des populations du Passé, Université Bordeaux 1) on similar applications on the sites of Agris, Les Predelles, La-Chapelle-aux-Saints, La Plage, Les Fieux, and Rescoundudou.

Prof R. GRÜN with Dr Patrice Coutaud (Université Bordeaux 1) on Sr analysis of human remains at the site of Tumulus des Sabres.

Prof R. GRÜN with Dr Vincent Mourre (Université de Toulouse-Le Mirail) on analyses of human remains at Grotte Nosetier.

Prof R. GRÜN with Dr S. Pratt (UPR 2147, CNRS, Paris) on the dating of the Grotte de la Chèvre.

Prof R. GRÜN is included in an NSF grant held by Dr Paola Villa (University of Colorado at Boulder) on the dating of Middle Palaeolithic sites in Italy.

Prof R. GRÜN with Prof Y. Rak, (Haifa University) on collection of hominid samples Skhul, Qafzeh, Tabun, Kebara and Amud, Israel and with Prof C.B. Stringer (Natural History Museum, London) on collection of hominid samples Broken Hill, Omo 1, Wadjak, Iwo Eleru. He also collaborates with many international scholars on the timing of modern human evolution.

Prof R. GRÜN with Dr J. Brink (University of Bloemfontein), Dr C.B. Bousman (Texas State University) and Prof M. Bateman (University of Sheffield) on the dating of a range of sites in South Africa, including the newly discovered human site of Cornelia.

Prof R. GRÜN with Prof G. Barker (University of Cambridge), Dr M. Lahr (University of Cambridge), Prof S. McBrearty (University of Connecticut) and Prof M. Musso (Università di Roma "La Sapienza") on dating work in Africa.

Prof R. GRÜN with the Institute of Geology, China Earthquake Administration, Beijing and the East China Normal University, Shanghai on 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 with Prof ZhongPing Lai (State Key Laboratory for Cryosphere Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Lanzhou) on environmental change in the Qaidam Basin.

Prof R. GRÜN with Dr A. Pike (University of Southampton) on uranium uptake of bones

Prof R. GRÜN with Prof T. de Torres (Escuela Tecnica Superior de Ingenieros de Minas de Madrid) on the calibration of amino acid racemisation in bones, and on cave bear evolution.

Dr D. HESLOP with Dr Tingping Ouyang (Guangzhou Institute of Geochemistry, Chinese Academy of Sciences) on the magnetization of sediments from the South China Sea.

Dr D. HESLOP with Ms Pengxiang Hu (Institute of Geology and Geophysics, Chinese Academy of Sciences) on the magnetic mineralogy of Australian soils.

Ms A. KIMBROUGH with Dr Wahyoe Hantoro (Indonesian Institute of Sciences, Bandung, Indonesia) on the reconstruction of the Australian-Indonesian Summer Monsoon.

Dr M.D. NORMAN with Prof M. Garcia (University of Hawai'i) on the origin and evolution of hotspot volcanism.

Dr M.D. NORMAN with Dr L. Nyquist (NASA Johnson Space Center) on the ages of lunar impact basins.

Dr M.D. NORMAN with Dr N. Zellner (Albion College, Michigan) on the compositions and ages of lunar volcanism and impacts.

Dr B.N. OPDYKE is a member of the International Ocean Drilling Program Project team for Expedition 342.

Prof B.J. PILLANS with Dr B Alloway (Victoria University of Wellington) on the Quaternary stratigraphy of Soa Basin, Flores, Indonesia.

Prof B.J PILLANS with Dr T. Barrows (Exeter University) on Southern Hemisphere Late Pleistocene glacial chronologies

Prof E.J. ROHLING with Dr G.L. Foster and Dr Ivan Haigh (University of Southampton, UK), Prof A. Payne and Drs. M. Siddall, D. Lunt, R. Pancost (University of Bristol, UK), Prof R. Gehrels (University of York, UK), Prof A. Long (University of Durham, UK), Profs. G. Henderson, C. Bronk-Ramsey and N. Barton (University of Oxford, UK), Drs. M. Tamisiea and S. Jevrejeva (NOC, Liverpool, UK), Dr A. Thomas (University of Edinburgh, UK), Prof E. Wolff (University of Cambridge, UK), Profs. J. Lowe and M. Menzies (Royal Holloway, UK), Prof D. Beerling (University of Sheffield, UK), Dr M. Rogerson. (University of Hull, UK), Dr J. Stanford (University of Wales, Swansea, UK), Profs. R. van de Wal, A. Sluijs, H. Dijkstra, L. Lourens (University of Utrecht, NL), Dr J. Cruz-Larrasoana (Institute of Earth Sciences Jaume Almera, Barcelona, Spain), Dr C. Bolton (University of Oviedo, Spain), Prof B. Wening (University of Cologne, D), Prof H. Paelike (MARUM, University of Bremen, D), Drs. P. Koehler, B. Rabe and A. Mackensen (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany), Prof S. Bernasconi (ETH, Zurich, Switzerland), Dr S. Maus (University of Bergen, Norway), Dr P. Dodd (Norwegian Polar Institute, Tromsø, Norway), Prof R. DeConto (University of Massachusetts, USA), Prof R. Anderson (Lamont–Doherty Earth Observatory, USA), Prof J. Hansen (Columbia University, USA), Profs. L. Edwards and H. Cheng (University of Minnesota, USA) on global change studies.

Mr. N. SCROXTON with Hai Cheng (Xi'an Jiatong University/University of Minnesota) on U/Th dating.

Dr R. STRZEPEK with Dr B. Nunn (University of Washington) on environmental proteomics.

Dr R. STRZEPEK with Dr A. Tagliabue (University of Liverpool, UK) on marine biogeochemical modeling.

Dr R. STRZEPEK with Dr A-C. Alderkamp (Stanford School of Earth Sciences, Stanford University, USA) on marine phytoplankton genomics.

Dr J. YU with Profs. Wally Broecker and Robert Anderson (Columbia University), Prof Henry Elderfield (Cambridge University), Prof Zhangdong Ji (Earth Environment Chinese Academy of Science), Prof Jun Tian (Tongji University) and Dr Sev Kender (British Antarctic Survey) on the reconstruction of deep water carbonate chemistry on different time scales.

Earth Materials & Processes

Prof R. ARCULUS with Dr J. Lupton (NOAA), Dr C. de Ronde (GNS), Prof M. Jackson (University California at Santa Barbara), and Prof K. Rubin (University of Hawaii) on submarine volcanic and hydrothermal rocks.

Prof R. ARCULUS with Prof M. Perfit (University of Florida) on reviews of submarine volcanism.

Prof R. ARCULUS with Dr O. Ishizuka (JAMSTEC) as Co-Chief of a forthcoming International Ocean Discovery Program Expedition 351 to the nascent Izu-Bonin Arc.

Prof R. ARCULUS with Prof D. Ionov (Universite de Montpellier) on peridotites associated with island arcs.

Dr A. BENARD with Prof A.B. Woodland and Dr K. Klimm (University of Frankfurt) on Mossbauer spectroscopy and sulfur speciation in the arc mantle.

Dr A. BENARD with Prof Dmitri A. Ionov (University of Montpellier) on studies of mantle xenoliths from far-East Russia.

Dr A. BENARD with Dr J. Labidi (Carnegie Institution) on multi-isotope and redox-specific sulfur studies in subduction zones.

Dr A.J. BERRY with Dr S.E. Ashbrook (University of St Andrews) on the crystal chemistry of hydrous wadsleyite.

Dr A.J. BERRY with Dr U. Faul (Massachusetts Institute of Technology) on fluorescence tomography of partially molten rocks.

Dr A.J. BERRY with Dr M.C. Rowe (University of Auckland) on the effect of degassing on the oxidation state of sulfur in volcanic glasses.

Dr A.J. BERRY with Dr D. Weiss (Imperial College London) on removing arsenic from drinking water using novel materials.

Dr A.J. BERRY with Dr J.F.W. Mosselmans (Diamond Light Source) and Dr P.F. Schofield (Natural History Museum, London) on the oxidation state of multivalent elements in silicate melts.

Miss H.A. COCKER with C. Leys (PT Eksplorasi Nusa Jaya) on the Grasberg porphyry Cu-Au deposit, Indonesia.

Prof S.F. COX with PhD students M Arndt and S Virgo and Professor Janos Urai (all at RWTH - University of Aachen, Germany) on using C/O isotope studies to explore aspects of fluid flow associated with the formation of calcite vein arrays in Oman.

Prof S.F. COX with PhD student J Klaver and Professor J Urai (RWTH - University of Aachen) on using Broad Ion Beam polishing techniques, in conjunction with scanning electron microscopy, to quantify the evolution of pore structures during compaction of quartz aggregates at high temperature hydrothermal conditions. The study is exploring evolution of fluid transport properties in simulated fault rock during interseismic healing.

Dr E.C. DAVID with Assoc Prof U.H. Faul (Massachusetts Institute of Technology) on seismic signature of water in olivine.

Dr E.C. DAVID with Prof R.W. Zimmerman (Imperial College London) on modelling of elastic properties of sedimentary rocks.

Dr E.C. DAVID with Dr Seiji Nakagawa (Lawrence Berkeley National Laboratory, USA) on resonant bar experiments.

Dr M. FORSTER with Prof R. Hall and Dr L. White (Royal Holloway University of London) on the tectonics and dating of geological events on Sulawesi, Indonesia.

Dr M. FORSTER with Dr M. Cottam and Dr S. Suggate (Royal Holloway University of London) on the tectonics and dating of geological events on northern Borneo, Malaysia, and the island of Palawan, Philippines.

Dr M. FORSTER with Prof E. Suparka (Institute Technical of Bandung (ITB)) on the tectonics and dating of geological events on the south arm and the south east arm of Sulawesi and central Java, Indonesia.

Dr M. FORSTER with Prof T. Ahmad (Kashmir University) on the tectonics and dating of geological events on in the NW Himalaya.

Dr M. FORSTER with Prof S.K. Bhowmik (Indian Institute of Technology, Kharagpur, India) on the east Himalaya syntaxis.

Dr M. FORSTER with Dr E. Catlos (University of Texas, USA) on the tectonics of western Turkey.

Dr M. FORSTER with Mr Musri and colleagues (University Hasanuddin, Sulawesi, Indonesia) on the tectonics of Indonesia.

Dr M. FORSTER with Dr J. Soesilo and colleagues (University of Pembangunan Nasional, Indonesia) involving the tectonics of Indonesia.

Dr J. HERMANN with Dr Q. Qing (Chinese Academy of Science, Beijing, China) on the clinopyroxene-melt trace element partitioning in high-Mg diorites.

Dr J. HERMANN with Dr Q. Liu (China University of Geosciences, Wuhan, China) on the melting of subducted crust during exhumation.

Dr J. HERMANN with Prof Y.F. Zheng (University of Science and Technology, Hefei, China) on fluids in subducted continental crust.

Dr J. HERMANN with Dr A. Korsakov (Novosibirsk, Russia) on coesite and diamond facies metamorphism in the Kokchetav Massif, Kazakhstan.

Dr J. HERMANN with Prof M. Engi (University of Berne, Switzerland) on Barrovian metamorphism in the Central Alps.

Dr J. HERMANN with Dr A. Acosta Vigil (University of Granada, Spain) on an experimental study of anatexis in metapelites.

Dr J. HERMANN with Dr M. Beltrando (University of Torino, Italy) on the formation and evolution of blueschist and eclogite facies rocks in the Western Alps.

Prof I. JACKSON with Prof D.R. Schmitt and Ms H. Schijns (University of Alberta, Canada), Dr U.H. Faul (Massachusetts Institute of Technology), Dr A.M. Walker (University of Bristol), Prof D.L. Kohlstedt and Dr M. Zimmermann (University of Minnesota, Minneapolis), Dr A. Barnhoorn (Technical University, Delft), Dr R.J.M. Farla (University of Bayreuth), Prof S. Karato (Yale University), Dr Y. Kono (Carnegie Institution of Washington), and Prof S.J.S. Morris (University of California, Berkeley) on the laboratory measurement and modelling of seismic properties.

Dr P. KING with A/Prof R. Gellert and Prof J.L. Campbell (University of Guelph, Canada), Dr M. Schmidt (Brock University, Canada), Prof M.D. Dyar (Mt. Holyoke College, USA), Prof E.M. Stolper and Dr M. Rice (Caltech, USA), Prof S. McLennan (SUNY Stony Brook, USA), Dr L. Thompson (University of New Brunswick, Canada), Dr A. Yen and Dr D. Blaney (NASA Jet Propulsion Laboratory, USA), Prof H. Newsom and Ms A. Ollila (University of New Mexico, USA) and Dr R.A. Yingst (Planetary Science Institute, USA) on Mars Science Laboratory science.

Dr P. KING with Assoc Prof J.F. Larsen (University of Alaska Fairbanks, USA), Prof M. S. Ramsey and Dr R. Lee (University of Pittsburgh, USA) and Prof T. Fischer and Dr J.M. de Moor (University of New Mexico) on understanding volcanic systems.

Dr P. KING with Prof T.K. Sham (University of Western Ontario, Canada), R. Gordon (University of Washington Seattle, USA); and Prof M.D. Dyar (Mt. Holyoke College MA, USA) on synchrotron science.

Prof G. LISTER with Prof R. Hall (Royal Holloway University of London) on the 4D SE Asia project.

Prof G. LISTER with Prof T. Ahmad (University of Kashmir), now in an AISRF funded project led by Prof Aitchison.

Dr J. MAVROGENES with Profs J. Blundy and S. Sparks (University of Bristol) on porphyry copper deposit formation.

Dr O NEBEL with Dr M. Wille (Tuebingen University, Germany) and Dr P.Z. Vroon (Vrije Universiteit Amsterdam, The Netherlands) on the stable isotope compositions of arc lavas.

Prof H. O'NEILL with Prof A. Putnis and Drs C. Putnis and H. King (Westfälische Wilhelms-Universität Münster) on surface modification in olivine following annealing.

Prof H. O'NEILL with Dr F. Jenner (Open University, UK) on the trace-element geochemistry of mid-ocean ridge basaltic glasses.

Dr J.A. PADRON-NAVARTA with Dr V. Lopez-Sanchez Vizcaino (University of Jaen, Spain), Dr M.T. Gomez-Pugnaire (University of Granada, Spain) and Dr C. Marchesi (CSIC, Spain) on the high-pressure metamorphism of serpentinite and water recycling in subduction zones.

Dr J.A. PADRON-NAVARTA with Dr C.J. Garrido (CSIC, Spain) and Dr K. Hidas (Universite Montpellier 2, France) on the deformation of the subcontinental lithosphere from Ronda peridotite in South Spain.

Dr G.M. YAXLEY with Prof G.P. Brey (University of Frankfurt) on a study of refractory spinel peridotites from the Kaapvaal Craton of southern Africa.

Dr G.M. YAXLEY with Prof A.B. Woodland (University of Frankfurt) and Prof A.J. Berry (RSES) on investigations of redox conditions in the cratonic mantle.

Dr G.M. YAXLEY with Prof M. Hirschmann (University of Minnesota) and Dr R. Rapp (RSES) on a project concerning the earth's deep carbon cycle, funded by the Deep Carbon Observatory of the Carnegie Institute at Washington.

Dr G.M. YAXLEY with Dr A. Rosenthal (Bayreuth University) on a high-pressure experimental investigation of the stability of phlogopite in peridotite with excess hydrous fluid.

Dr G.M. YAXLEY with Prof D.H. Green (University of Tasmania) and Dr A. Rosenthal (Bayreuth University) on a high-pressure experimental investigation of the phase and melting relations of hydrous peridotite.

Dr G.M. YAXLEY with Dr E.S. Kiseeva (Oxford University) and Prof V.S. Kamenetsky (University of Tasmania) on the nature of majorite substitutions in sub-lithospheric diamond inclusions and on evidence for partial melting and metasomatism of eclogite xenoliths from the Roberts Victor kimberlite.

Earth Physics

Dr N. BALFOUR with Dr J. Taber (IRIS Education and Outreach, Washington USA) and Mr P. Denton (British Geological Survey, UK) on educational seismology programs.

Mr. C.C. CHAPMAN with Dr R. Morrow (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), a component laboratory of the Centre national de la Recherche Scientifique (CNRS), Toulouse, France) on the variability of Southern Ocean currents.

Prof P. R. CUMMINS with Mr H. Damlamian (Applied Science and Technology Division of the Secretariat of the Pacific Community) on tsunami hazard and inundation mapping for Tongatapu, Tonga.

Prof P. R. CUMMINS with the Japan Marine Science and Technology Center

Prof P. R. CUMMINS with Dr J. Murjaya (Indonesian Agency for Meteorology, Climatology and Geophysics) on a study of the seismic wave amplification effects of the Jakarta Basin.

Prof P. R. CUMMINS with Dr S. Hidayati (Indonesian Geological Agency for Meteorology, Climatology and Geophysics) on seismic hazard assessment in Indonesia.

Prof P. R. CUMMINS with Prof S. Widyantoro (Bandung Institute Indonesian Agency for Meteorology, Climatology and Geophysics), Dr L. Briger (German Research Centre for Geosciences, Germany) and Dr T. Bodin (University of California, Berkeley) on a study of the crustal structure of central Java.

Prof P. R. CUMMINS with Dr B. Bautista (Philippine Institute of Volcanology and Seismology) on a study of seismic amplification in Baguio City, the Philippines.

Dr D.R. DAVIES with Dr S. Goes (Imperial College London) to improve our dynamical interpretation of seismic images.

Dr D.R. DAVIES with the AMCG Group (Imperial College London) for further development of Fluidity, the computational framework.

Dr D.R. DAVIES with L. Stixrude and C. Lithgow-Bertelloni (University College London) to incorporate thermodynamic constraints into models of mantle dynamics.

Dr S.M. DOWNES with Dr S.M. Griffies (NOAA/Geophysical Fluid Dynamics Laboratory, USA) and Dr R. Farneti (International Centre for Theoretical Physics, Italy) on the Southern Ocean multi model analysis for the Coordinated Ocean-Ice Reference Experiments Phase 2 (CORE-II) international effort.

Dr S.M. DOWNES with Dr C. de Ronde (Geological and Nuclear Science, NZ) on the spreading of hydrothermal plumes in the southwest Pacific Ocean.

Prof R.W. GRIFFITHS with Prof C. Kincaid (University of Rhode Island, USA), Dr K. Druken (Carnegie Institute, Washington) and D. Stegman (University of California, Berkeley, USA) on the dynamics of subduction zones and their interactions with mantle plumes.

Dr A.McC. HOGG and Dr M.L. WARD with Dr S. Griffies (Geophysical Fluid Dynamics Laboratory, USA) on the development of a high resolution ocean model.

Dr G. IAFFALDANO with Prof E. Calais (Ecole Normale Superieure Paris) on Numerical modelling of present-day rifting in Africa.

Dr G. IAFFALDANO with Prof C. DeMets (University of Wisconsin-Madison) on Bayesian noise-reduction in finite-rotation datasets of the Central and North Atlantic.

Dr G. IAFFALDANO with Dr T. Bodin (University of California, Berkeley) on Software for Bayesian noise-reduction in finite-rotation datasets.

Prof B.L.N. KENNETT with Dr T. Furumura (Earthquake Research Institute, University of Tokyo, Japan), Dr K. Chen (National Taiwan Normal University) and Dr T-K. Hong (Yonsei University Korea) on a variety of issues in seismic wave propagation, particularly guided waves phenomena.

Dr C. KLOOTWIJK with Dr H. Théveniau (Bureau de Recherches Géologiques et Minières, France) on paleomagnetism of the Upper Permian Newcastle Coal Measures, Sydney Basin.

Dr S. MCCLUSKY with Prof T.A. Herring, Dr R. Reilinger and Dr R.W. King (Massachusetts Institute of Technology, Cambridge, USA) on development of GAMIT/GLOBK GPS analysis software and Mediterranean/Mid East geodynamics studies.

Dr S. MCCLUSKY with Dr P.Vernant (Université Montpellier 2, France) on Western Mediterranean geodynamics.

Dr S. MCCLUSKY with Dr S. Ergintav, (Marmara Research Center, Gebze, Turkey) on earthquake hazards in Turkey.

Dr S. MCCLUSKY with Dr A. ArRajehi, (King Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia) on Red Sea tectonic studies.

Dr S. MCCLUSKY with Dr I. Meilano, (Institut Teknologi Bandung (ITB), Indonesia) on crustal deformation studies and earthquake hazards in Indonesia.

Dr J-P. MONTILLET with Dr M. Woolfson (The University of Nottingham) on a signal processing technique to decorrelate signals in GPS time series.

Dr J-P. MONTILLET with Dr M. Lainen (The University of Helsinki, Finland) on a toolbox for Markov chain Monte Carlo (MCMC) applications.

Dr A PURCELL with Dr A. Simms (University of California, Santa Barbara, USA) on the reconstruction of sea level change within the Gulf of Mexico.

Prof M.L. RODERICK with Dr S. Schymanski (Eidgenössische Technische Hochschule (ETH), Zurich, Switzerland) and Prof M. Sivapalan (University of Illinois at Urbana-Champaign) on the inclusion of vegetation in hydrologic models.

Dr M. SALMON with T. Stern (Victoria University of Wellington) on a North-western North Island project.

Prof M. SAMBRIDGE with Dr T. Bodin (University of Berkeley, USA) and Prof K. Gallagher (University of Rennes, France) on Bayesian methods of data inference.

Dr E. SAYGIN with Dr A. Fichtner (ETH), Dr L. Vanacore (University of Leeds, UK) and Prof T. Taymaz (Istanbul Technical University, Turkey) on seismic structure of Turkey.

Dr E. SAYGIN with Mr Suhardjono (Badan Meteorologi, Klimatologi, dan Geofisika, Indonesia) and Prof S. Widiyantoro (Institut Teknologi Bandung (ITB), Indonesia) on crustal structure of Indonesia and surrounding regions.

Ms K. SNOW with Dr B. Sutherland (University of Alberta, Canada) and Dr A. Hogg (University of Bristol, UK) on the properties and flows of particle laden currents.

Dr H TKALČIĆ with Dr S. Tanaka (Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan), Prof V. Cormier (University of Connecticut, USA), Prof J Rhee (Seoul National University, Korea) Prof M. Mattesini (Universidad Complutense de Madrid, Spain) on the Earth's core.

Dr H TKALČIĆ with Dr A. Fichtner (Utrecht University, The Netherlands) on earthquake sources.

Dr H TKALČIĆ with Dr Y. Chen (3D Array Technologies, USA) on lithospheric structure of northeast Asia.

Dr P. TREGONING collaborates with Dr S. Bettadpur (University of Texas at Austin, USA) on the analysis of GRACE data.

Ms M. YOUNG with Dr P. Arroucau (North Carolina Central University, USA), working on ambient seismic noise.

PRISE

Dr R.A. ARMSTRONG with Prof A. da Silva Filho and Assoc. Prof I. de Pinho Guimaraes (Federal University of Pernambuco, Brazil) on the geochronology and crustal growth history of the Borborema province, Brazil.

Dr R.A. ARMSTRONG with Prof R. Hall and Dr L. White (Royal Holloway University, London) on the geochronology of various areas in Indonesia.

Dr R.A. ARMSTRONG with Dr C. McFarlane (University of New Brunswick, Canada) on a sulphur isotope study.

Dr R.A. ARMSTRONG with Dr R. Schmitt (Universidade Federal do Rio de Janeiro) on the geochronology of Gondwana.

Dr R.A. ARMSTRONG with Dr G. de Kock (Council for Geoscience, South Africa) on the geochronology of the Damaran Belt, Namibia.

Dr R.A. ARMSTRONG with 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 and on the geochronology of the Limpopo Belt, Botswana and surrounding cratons.

A/Prof C.M. FANNING with Dr J. Goodge (University of Minnesota, Duluth) on the geochronology and provenance of sequences in the central Transantarctic Mountains, Antarctica.

A/Prof C.M. FANNING with Prof F. Hervé (Universidad de Chile), Dr M. Calderón (Geological Survey of Chile, SERNAGEOMIN) and Dr R.J. Pankhurst (British Geological Survey) on the geochronological and tectonic evolution of the central Chile basement rocks.

A/Prof C.M. FANNING with Dr C. Rapela (Uni La Plata) and Dr C. Casquet and Dr C. Galindo (Universidad Complutense de Madrid) on the geochronological and tectonic evolution of the Sierras Pampeanas, NW Argentina.

A/Prof C.M. FANNING with Dr C. Siddoway (Colorado College), Prof M. Brown and Mr C. Yakymchuk (University of Maryland) on the tectonic evolution of the Fosdick Mountains, Mary Byrd Land, Antarctica.

A/Prof C.M. FANNING with Dr F. Espinoza (Geological Survey of Chile, SERNAGEOMIN) on the age and isotopic characteristics of Cretaceous to Tertiary volcanism in northern Chile.

A/Prof C.M. Fanning and Dr D. Elliot (Ohio State University) on the geochronology and isotopic characteristics of Permo-Triassic detritus in the Transantarctic Mountains.

A/Prof C.M. Fanning with Dr J. Aleinikoff (U.S. Geological Survey) on the age of igneous and metamorphic rocks in the New England area, USA.

Dr B. FU with Prof M. Bröcker (Universität Münster, Germany) on O-Hf isotopic studies of zircons in pre-Cretaceous igneous rocks from the Cyclades, Greece.

Dr B. FU with Prof Z. Xu and H. Wang (Nanjing University, China) on determining the timing and origin of Cu(-Au) mineralisation and associated magmatism in eastern China.

Dr B. FU with A/Prof I.N. Bindeman (University of Oregon, USA) and D.L. Drew on U-Pb and O-Hf studies of zircons in rhyolites of the Picabo volcanic field, Idaho, USA.

IODP

Collaboration occurs with many scientists in America, Japan, Europe, New Zealand, India and Korea in the IODP context. We 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.

The relationship with New Zealand is very close and they are represented on the ANZIC Governing Council and Science Committee. Their scientists are part of the ANZIC quota for drilling expeditions and IODP panels.

Visiting Fellows

Mr R.V. BURNE with Dr J. Paul (Göttingen University) on the work of Kalkowsky and its impact on subsequent microbiolite research.

Dr K.A.W. CROOK with A/Prof A. SWITZER (Nanyang Technological University, Singapore) on cosmogenic age dating of rocky coastal geomorphic features.

Dr P.J. JONES with Dr E. Olempska (Institute of Paleobiology, Polish Academy of Sciences) on Palaeozoic ostracod classification.

Dr W. MAYER with the Muséum national d'Histoire naturelle (Paris) on the description and interpretation of the geological collections made by various French expeditions to Australia between 1801 and 1841.

Emeritus Prof I. McDOUGALL with Prof F. Brown (University of Utah) in relation to the geochronology of the Omo-Turkana Basin in eastern Africa.

Dr E. TRUSWELL with a number of researchers in the US on sedimentary sequences on the Antarctic margin.

Dr E. TRUSWELL with Dr C. Domack (Hamilton College, New York) on Cenozoic vegetation history of Antarctica.

COOPERATION WITH GOVERNMENT AND INDUSTRY

Earth Chemistry

Dr J.J. BROCKS with Ms N. Güneli and scientists from an international oil company on assessment of new Proterozoic oil source rocks.

Dr J.J. BROCKS with Mr B. Bruisten and scientists from an Australian oil exploration company on assessment of gas and oil generation potential of an Australian basin.

Dr S.J. FALLON with Dr A. McDougall (Department of Natural Resources & Water) and David Roberts (SeqWater) on the ageing of Australian lungfish.

Prof T.R. IRELAND with the Space Policy Unit of the Australian Government in regards to the Hayabusa Space Missions.

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), the National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan) and Geoscience Australia (Canberra).

Dr 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. He spent a week in Korea retuning the upgraded KBSI SHRIMP IIe/mc, followed by three weeks in Tsukuba, Japan, commissioning the new SHRIMP IIe/mc at the AIST and training its operators. He spent a month at the Beijing SHRIMP Centre recommissioning the CAGS SHRIMP II after its move to the Zhong-guan-cun Life Science Park, commissioning the newly-installed SHRIMP IIe/mc at the same location and training its operators. He undertook demonstration of light isotope analyses for prospective international customers. He visited the Polish Geological Institute – National Research Institute, Warsaw, to inspect facilities for the SHRIMP IIe/mc to be installed there in 2014, and spent a week on demonstration analyses for visiting researchers from the National Geophysical Research Institute, Hyderabad, India.

Dr I.S. WILLIAMS with Dr R.S. Nicoll (Geoscience Australia) 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 P. De DECKKER with Dr David Cohen (ANSTO), The composition of Australian aerosols.

Dr M.K. GAGAN with Dr H. Heijnis (ANSTO) on AINSE grant ALNGRA11165: A long-term low-latitude record of volcanic eruptions recorded in the sulphate record of Indonesian speleothems.

Dr M.K. GAGAN with Dr M. Fischer and Dr D. Fink (ANSTO) on coral reconstructions of El Niño-Southern Oscillation variability in the central equatorial Pacific.

Dr M.K. GAGAN with Dr P. Treble (ANSTO) on speleothem records of past climates in Australia.

Ms A. KIMBROUGH with Kell and Denson Stoneworks, Tumut NSW, Australia for speleothem sample preparation.

Dr D.C. "Bear" McPHAIL with Dr Wendy McLean and Ms. Liz Webb (Parsons Brinckerhoff, Sydney) on groundwater dynamics in the Lower Murrumbidgee catchment, NSW.

Dr D.C. "Bear" McPHAIL with Mr. Prem Kumar of the NSW Office of Water on groundwater in the Lower Murrumbidgee catchment, NSW.

Dr D.C. "Bear" McPHAIL with Dr Wendy McLean (Parsons Brinckerhoff, Sydney) and Dr Karina Meredith (ANSTO) on dating groundwater using ^{14}C .

Dr D.C. "Bear" McPHAIL with Wayne Gregory (Canberra Sand and Gravel) and Harry and Jim Osborne (land owners Lake George area) on landscape evolution and groundwater in Lake George.

Dr D.C. "Bear" McPHAIL with Ross Brodie, Laura Gow and other staff at Geoscience Australia about groundwater studies in the Menindee Lakes, NSW.

Dr D.C. "Bear" McPHAIL with the Minerals Tertiary Education Council (Minerals Geoscience Honours program of the Minerals Council of Australia).

Dr D.C. "Bear" McPHAIL with the Australian Institute of Mining and Metallurgy (AusIMM) for the Lachlan Branch and its professional and student members.

Dr M.D. NORMAN with Paula Cornejo (Antofagasta Minerals, Chile) and Geoscience Australia on the timing of mineralisation.

Prof B.J. PILLANS with Dr P. Morris (Geological Survey of Western Australia) on the geochronology of regolith/landform evolution in the Kalgoorlie region, WA.

Prof E.J. ROHLING with the Environment Agency and the UK Climate Impact Programme (UK).

Earth Materials & Processes

Prof R. ARCULUS with Nautilus Minerals and Blue Water Minerals Pty Ltd. on submarine volcanism, hydrothermalism and tectonism.

Dr A.J. BERRY with Dr A.C Harris (Newcrest Mining Limited), using synchrotron radiation to study the distribution and speciation of gold in arsenopyrite.

Prof I.H. CAMPBELL and PhD student H. COCKER with PT Eksplorasi Nusa Jaya, Indonesia on the platinum group element geochemistry of the suite of intrusions associated with the Grasberg copper-gold deposit in Papua.

Prof I.H. CAMPBELL and Hons student J. LOWCZAK with Newcrest Mining on the platinum group element geochemistry of the suite of intrusions associated with the Cadia copper-gold deposit in NSW.

Prof S.F. COX and Honours student A. CLARK with geologists at the Northparkes porphyry Cu-Au deposit in a study of vein development in mineralised vein systems.

Prof S.F. COX with geomechanics and numerical modelling specialists in Beck Engineering Ltd (in Sydney and Berlin), Modelling the influence of fluid-driven failure processes in controlling fluid pathways and localization of mineralisation in intrusion-related hydrothermal systems.

Dr M. FORSTER with Dr G. Fraser (Geoscience Australia) on $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of tectonic events within Australia.

Dr P. KING with Dr J. Hamilton, Dr S. Sommocal and Dr A. Cannerup (Lithicon) on new methods to characterize rocks.

Prof G. LISTER with AngloGold Ashanti, Newmont, Teck, Marengo Mining and Vale in support of the 4D Porphyry project. This collaboration led to a \$1.005M Linkage Project aimed to commence in 2014.

Dr O NEBEL with Dr T. Ivanic (Geological Survey of Western Australia) on the evolution of the Yilgarn cratonic mantle.

Earth Physics

Mr R. BENAVENTE and Prof P. CUMMINS with Geoscience Australia on the improvement of the Tsunami Warning System.

Prof B.L.N. KENNETT, with Dr E. Saygin (RSES) and Drs R. Blewett & T. Fomin (Geoscience Australia) produced an E-book titled 'Deep crustal reflection Profiling: Australia 1978-2011', published by ANU E-Press.

Dr M. SALMON with Geoscience Australia, providing information on the AuSREM model and negotiating the use of the Australian Seismometers in Schools data for earthquake location and analysis.

Dr M. SALMON with Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE), helping them connect to the new seismometers we have installed around South Australia.

Dr M. SALMON with WA Department of Mines and Petroleum, helping with the installation of a seismic instrument in Harvey.

Dr E. SAYGIN with Dr L. Hutton (Geological Survey of Queensland) on imaging seismic structure of Mt. Isa.

Dr H TKALČIĆ with Dr C Spaggiari and Dr K Gessner (Geological Survey of Western Australia) on lithospheric structure of the Albany Fraser Orogen, Western Australia.

Ms M. YOUNG with the Department of Primary Industries of the Geological Survey of Victoria, Geoscience Australia and Mineral Resources Tasmania in her work on a 3D shear wave velocity model of southeast Australia.

PRISE

Dr R.A. ARMSTRONG with Dr Hielke Jelsma (De Beers) on the geochronology of Angola, the DRC and Indian cratons.

Dr R.A. ARMSTRONG with Dr P. Blevin (NSW Department of Industry and Investment) on the geochronology and origin of granites from NSW.

Dr R.A. ARMSTRONG with Dr Andrew Cross and Dr Keith Sircombe (Geoscience Australia) on the geochronology and oxygen and Hf isotope studies of sediments and granites from a number of areas in Australia.

Dr B. FU with Dr T.P. Mernagh (Geoscience Australia) on fluid inclusion studies of the Maldon gold deposit, central Victoria.

IODP

CSIRO, Geoscience Australia, AIMS and ANSTO were members of ANZIC until September; CSIRO and Geoscience Australia (GA) continued after September.

Dr Chris Yeats of CSIRO is a member of the ANZIC Governing Council and a member of a high-level international IODP Planning Committee (*JOIDES Resolution* Facility Board).

Dr Andrew Heap of GA is on the future ANZIC Governing Council.

Dr Ben Clennell of CSIRO was the ANZIC representative on IODP's Site Characterisation Panel and continues in the new Science Evaluation Panel.

Dr Anna Kaksonen of CSIRO and Dr Janet Lough of AIMS were members of the ANZIC Science Committee until September.

Visiting Fellows

Mr R.V. BURNE with Dr A. Kendrick and Mr R. Chaple (WA Dept of Parks and Wildlife) on the consequences of World Heritage listing for the interaction between tourism and stromatolite conservation in Hamelin Pool.

Dr K. A. W. CROOK provides professional advice to Ministers of the Commonwealth & NSW Governments on topics within his competence.

Dr K. A. W. CROOK with Prof B. PILLANS and others in an ARC Linkage Project "Enigmatic Lake George - Changing environments, sustainable sand".

Dr P.J. JONES with Dr J.R. Laurie (Geoscience Australia) on Carboniferous ostracod biostratigraphy in northwestern Australia.

STAFF ACTIVITIES

CONFERENCES AND OUTSIDE STUDIES

Earth Chemistry

Prof Y. AMELIN, 'Cosmochemical perspective on the early evolution of the solar system' Workshop, Sapporo, Japan, 20-22 February, gave an invited oral presentation titled "Precision in meteorite chronology: the limits to growth".

Prof Y. AMELIN, 44th Lunar and planetary Science Conference, The Woodlands, USA, 18-22 March, gave one first-author oral presentation titled "Pb-isotopic dating of CAIs from CV chondrite NWA 4502" and five co-authored presentations. He also organised and co-convened a related workshop of the "Early Time" initiative (17 March).

Prof Y. AMELIN, visited Q-Z. Yin's laboratory at the University of California Davis, 23-30 March to work on Al-Mg isotopic dating of refractory inclusions from the carbonaceous chondrite NWA 4502.

Prof Y. AMELIN, Goldschmidt Conference, Florence, Italy, 25-30 August, organised a session, was first author on a poster presentation delivered by co-author, PhD student Ms M. HUYSKENS and co-authored five presentations, but did not attend the meeting.

Prof Y. AMELIN, William Smith Meeting, 'The first century of Isotope Geochronology: the legacy of Frederick Soddy and Arthur Holmes', London, UK, 25 – 27 June, followed by the EARTHTIME workshop on 28 June. Invited oral presentation, "U-Pb meteorite chronology: the limits to growth".

Prof Y. AMELIN, 76th Annual Meeting of the Meteoritical Society, Edmonton, Canada, 29 July-2 August was first-author on an oral presentation delivered by a co-author and co-authored other five presentations, but did not attend the meeting.

Prof Y. AMELIN, Sponsors meeting of the Linkage project on evolution and ore genesis in the Yilgarn block, WA, 12-15 November, gave an oral presentation titled "High precision U-Pb zircon dating: an update".

Prof Y. AMELIN, Andrew Gleadow retirement symposium and TANG³O workshop, Melbourne, 25-26 November, gave an oral presentation titled "Precision and accuracy of U-Pb dating over time".

Dr J.N. ÁVILA, visited the School of Mathematical Sciences, Monash University, to work with Dr M. Lugaro on the timescale of presolar SiC grains.

Dr V.C. BENNETT, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a keynote talk in the symposium 'Geochemical and geodynamical perspectives of continent formation through time' titled "An integrated Isotopic-Geologic View of Early Continental Crust Formation from the Oldest Rock Record". She organised and convened a session exploring 'What do we know about the Hadean after 30 years?' to commemorate the first discovery of Hadean age materials on the SHRIMP I.

Dr V.C. BENNETT conducted ARC-funded fieldwork in the Flinders ranges, South Australia in May.

Dr J.J. BROCKS, 'Imaging the past to imagine the future' - ICDP working and planning conference, GeoForschungsZentrum (GFZ) Postdam, Germany, 11-14 November.

Mr A. CHOPRA, 2013 Humboldt Colloquium, Sydney, 18 October, presented a talk titled "Creating the elemental composition of reference life".

Mr A. CHOPRA, RSES School Seminar, 7 August, presented a talk titled "Nobel Conversations" about the 2013 Lindau Nobel Laureates Meeting.

Mr A. CHOPRA, Seminar Series at the Institute for Immunology and Infectious Diseases at Murdoch University in Perth, 17 July, presented a talk entitled "What can life on Earth tell us about life in the Universe".

Dr S. FALLON, AMSA2013 Golden Jubilee Conference, Gold Coast, Queensland, 7-11 July, presented a paper titled "Using Radiocarbon in coral skeletons to reconstruct seep CO₂ input into seawater DIC at Milne Bay, PNG".

Dr M. HONDA, TANG30 (Thermochronology and Noble Gas Geochemistry and Geochronology Organization) workshop, Melbourne, 25-26 November, presented a talk on "Preliminary results from the HELIX-MC mass spectrometer: resolution of argon isobaric interferences".

Prof T. R. IRELAND visited Japan to attend a meeting of the Sample Allocation Committee, the Joint Science Team Meeting, and the First Symposium on samples returned from the JAXA Hayabusa sample return mission.

Mr P. KOEFOED, RSES Student Conference, 19 September, gave a talk titled "Meteorite from Mercury?".

Dr C.H. LINEWEAVER, National Physical Sciences and Oncology Meeting, Phoenix, USA, 18 April, gave a lecture titled "The Atavistic Model of Cancer".

Dr C.H. LINEWEAVER, 'Deep Time' conference, ANU, 4-5 June, gave a lecture titled "The concept of time in physics and biology" and participated in a panel discussion.

Dr C.H. LINEWEAVER, Gordon Conference on the Origin of Solar Systems, Mt Holyoke, USA, 23-28 June.

Dr C.H. LINEWEAVER, Australasian Evolution Society Meeting, Melbourne, 2 October, gave an invited plenary lecture "The planet of the apes fallacy, the origins of cancer and life on other planets".

Dr C.H. LINEWEAVER, Kepler Conference, California, 4-5 November, presented the Titius-Bode relation.

Dr C.H. LINEWEAVER, Warburg Effect Cancer Workshop, Phoenix, USA, 7 November, gave a presentation "The Atavistic Model of Cancer and the Warburg Effect".

Dr C.H. LINEWEAVER, Third Australian Exoplanet Conference, Melbourne, 6 December, gave a lecture "Exoplanetary System Architectures and Habitability".

Dr C.H. LINEWEAVER, Bayesian Reasoning and Maximum Entropy Conference, Canberra, 15-20 December, gave a presentation "Can the low entropy of the universe be a local fluctuation".

Dr D. RUBATTO, Goldschmidt conference, Florence, Italy, 25-30 August, presented an invited talk titled "Integration of U-Pb dating, trace elements and oxygen isotopes at the microscale".

Dr D. RUBATTO, International Eclogite Conference, Courmayeur, Italy, 2-8 September, presented a talk titled "In-situ oxygen analysis of zircon and garnet to investigate fluids in subduction" and co-guided an excursion titled "Multi-stage HP metamorphism and assembly of a rifted continental margin".

Dr R. SALMERON, Australian International Education Conference, Canberra, 8-11 October.

Dr R. SALMERON, International Astronomical Union Symposium 299, Victoria, Canada, 2-7 June, presented a poster titled: "Magnetocentrifugal jets and chondrule formation in weakly-ionised protostellar disks".

Ms K.M. STRZEPEK, Goldschmidt Conference, Florence, Italy, 25-30 August, oral presentation titled 'Deep-sea coral amino acids illuminate ecosystem processes on SE Australian seamounts'.

Ms K.M STRZEPEK, Applied Isotope Geochemistry Conference, Budapest, 22-27 September, first author on an oral presentation (delivered by A. Revill, CSIRO), titled 'Amino acids in deep sea coral: what compound specific isotopes reveal about the biogeochemistry of a western boundary current in a changing climate'

Ms K.M STRZEPEK, 12th Australasian Environmental Isotopes Conference, Perth, 10-12 July, contributed to the keynote presentation delivered by Dr Colin Smith titled "LC-IRMS application of Amino Acids in Archaeological Applications" and to the keynote presentation delivered by Dr Andrew T Revill titled "Compound specific stable isotopes as a tool for understanding marine biogeochemical processes and ecological interactions".

Dr I.S. WILLIAMS, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a talk titled "Analysing conodont $\delta^{18}\text{O}$ by SIMS".

Dr I.S. WILLIAMS, International Meeting on Precambrian Evolution and Deep Exploration of the Continental Lithosphere, Beijing, 7-9 October, was an invited guest speaker and presented a review talk titled "30 years of progress in applying microdating techniques to understanding Precambrian crustal evolution".

Dr R. WOOD, 7th World Archaeological Congress, Dead Sea, Jordan, 13-18 January, co-organised a session entitled "Recent advances in dating and chronology" in collaboration and presented a paper titled "Radiocarbon dating of El Castillo and the Middle to Upper Palaeolithic Transition of Northern Iberia".

Dr R. WOOD, 13th Bone Diagenesis Conference, Lyon, France, 22-25 October, presented a poster titled "Radiocarbon dating bone in warm, arid environments using ninhydrin".

Dr R. WOOD, Australian Archaeological Association Conference, Coffs Harbour, NSW, 1-4 December, presented a paper titled "Radiocarbon dating and the Middle to Upper Palaeolithic transition in Iberia" and a poster titled "Sample selection for radiocarbon dating" with Dr S. FALLON.

Earth Environment

Dr N.J. ABRAM, American Geophysical Union Fall Conference, San Francisco, USA, 9-12 December, presented an invited talk titled "Climate variability, warming and ice melt on the Antarctic Peninsula over the last millennium".

Dr N.J. ABRAM, Strategic Science in Antarctica, Hobart, 24-26 June, presented a plenary talk titled "Warming and ice melt on the Antarctic Peninsula".

Dr N.J. ABRAM, PAGES Open Science Meeting, Goa, India, 13-16 February, presented a talk titled "Reconstruction of tropical sea surface trends during the last millennium" and a poster titled "Warming and ice melt on the Antarctic Peninsula during the last millennium".

Dr N.J. ABRAM conducted field work as part of the Aurora Basin North ice core project, Antarctica, December 2013-January 2014.

Dr M. DAVIES, Fall 2013 American Geophysical Union Conference, San Francisco USA, 3-7 December, presented a paper titled "Drivers of foraminiferal and bulk sedimentary $^{10}\text{Be}/^9\text{Be}$ ratios in a marine sediment record offshore of sub-tropical Australia" and co-authored two other papers, "Porewater salinity and $\delta^{18}\text{O}$ reveal a kilometer-deep subsurface pathway for glacial meltwater into the Gulf of Alaska" and "From the Pacific to the Arctic: Paleoclimatic History of the Gulf of Alaska and the Bering Sea".

Dr M. DAVIES was an ANZIC shipboard participant on IODP Expedition 341: Southern Alaska Margin Tectonics, Climate, and Sedimentation during June-July and was a member of the Sub-sampling party for IODP Expedition 341, Texas A&M University, College Station TX during November.

Dr S.M. EGGINS, 17th American Geophysical Union Conference, San Francisco, USA, 8-13 December, presented a poster PP23B-1957 titled "What is the right temperature sensitivity for foraminiferal Mg/Ca paleothermometry in ancient oceans?"

Dr S.M. EGGINS visited the Lamont Doherty Earth Observatory of the University of Columbia, NY, USA from 22nd November to 6th December, where he presented a seminar "How does Mg/Ca seawater paleothermometry work?"

Dr S.M. EGGINS conducted field work (planktic foraminifer cultures) at the University of Southern California's Wrigley Institute for Environmental Studies, Santa Catalina, CA, USA, from the 1st July to 31st August.

Dr M.J. ELLWOOD, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a paper titled "Trace changes in the biogeochemical cycling of iron during the annual subtropical spring bloom east of New Zealand" and co-presented a paper titled "A 30ka Sponge-Diatom Silicon Isotope Record of Dissolved Silicon Concentration in Subantarctic Mode Water" with Mr J. Rosseau.

Dr M.J. ELLWOOD conducted fieldwork at One Tree Island in July and December.

Dr M.K. GAGAN led fieldwork with a team of 10 investigators to drill and collect speleothems in the Maros Limestone District, southwest Sulawesi, Indonesia from 8 June to 5 July.

Prof GRÜN, 7th International Bone Diagenesis Meeting, Lyon, France, 22-25 October, gave two invited talks on "Uranium series analysis of fossil bones and teeth" and "Maps of elemental distributions in modern and fossil human teeth'.

Dr D. HESLOP, Meeting of the Americas – American Geophysical Union, Cancun, Mexico, 14-17 May, presented a paper titled "Unmixing magnetic mineral assemblages to reconstruct environmental processes".

Dr D. HESLOP, American Geophysical Union Fall Meeting, San Francisco, U.S.A, 9-13 December, presented an invited paper titled "Magnetic Unmixing: From the Known to the Unknown" and a poster titled "A Simple Model of Sedimentary Magnetization Acquisition".

Ms A.K. KIMBROUGH, 19th National Conference of the Australian Meteorological and Oceanographic Society (AMOS), Melbourne, Australia, 11-13 February, presented a poster titled "Changes in the Australian-Indonesian Summer Monsoon throughout Glacial Terminations III and II".

Ms A.K. KIMBROUGH, conducted field work in South Sulawesi, Indonesia from 6 June – 10 July.

Ms A.K. KIMBROUGH, 12th International NCCR Climate Summer School "From Climate Reconstructions to Climate Predictions", Grindelwald, Switzerland, 1-6 September, presented a poster titled "Reconstructing changes in the Australian-Indonesian Summer Monsoon throughout Glacial Terminations III and II (265 to 75 ky BP)".

Ms A.K. KIMBROUGH, Student Conference 2013, Canberra, 19 September, presented a 5 min talk titled "Science, Cheese, and the Swiss Alps: How Grindelwald changed my mind about climate models".

Ms A.K. KIMBROUGH, International Union for Quaternary Research (INQUA) 2013 Early Career Researcher Inter-congress meeting, Wollongong, 2-6 December, presented a 12 min talk titled "Speleothem reconstructions of the Australian-Indonesian Summer Monsoon throughout Glacial Termination III (265 ky BP)".

Ms K. LONG, International Union for Quaternary Research (INQUA) Early career researcher conference, Wollongong, 2-6 December, presented her honours and continuing PhD research titled "An Ear to the Ground: Fish otolith geochemistry, environmental conditions and human occupation at Lake Mungo".

Ms K. LONG, completed an internship with Elise Dufour at the Museum National d'Histoire Naturelle (MNHN) in Paris between 15-26 April.

Dr D.C. "Bear" McPHAIL undertook fieldwork in the Lake George catchment, NSW during June and in the Lower Murrumbidgee catchment, NSW during October.

Dr D.C. "Bear" McPHAIL International Association of Hydrogeologists 40th Congress, Solving the Groundwater Challenges of the 21st Century, Perth, 15-20 September, co-authored a paper titled "A pathway-dependent model of silicon isotope fractionation during silicate weathering."

Mr G. NASH undertook fieldwork in the Jervis Bay - Saint Georges Basin area during May.

Dr M.D. NORMAN, 44th Lunar and Planetary science Conference, The Woodlands, Texas, USA, 18-22 March, presented a paper titled "Metal Particles in Apollo 17 Impact Melt Breccias: Textures and Highly Siderophile Element Compositions" and was a co-author on 3 other presentations.

Dr M.D. NORMAN, 76th Meteoritical Society Conference, Edmonton, Canada, 29 July – 2 August, presented a paper titled "U-Pb ages and compositions of Apollo 14 regolith glasses."

Prof B.J. PILLANS conducted fieldwork in Western Australia in August with Dr A. ABRAZHEVICH to collect samples for paleomagnetic dating of oxidized regolith.

Prof E.J. ROHLING, Paleo constraints on Sea level rise (PALSEA2) Meeting: "Estimating rates and sources of sea-level change during past warm periods", Rome, Italy, 21-25 October.

Prof A.P. ROBERTS, Meeting of the Americas – American Geophysical Union, Cancun, Mexico, 14-17 May, Invited speaker and co-convenor of the “Paleomagnetism and Rock Magnetism from Scientific Drilling” session.

Prof A.P. ROBERTS, Asia Oceania Geosciences Society, 10th Annual Meeting, Brisbane, 24-28 June, Invited speaker, (clash with meeting below, declined).

Prof A.P. ROBERTS, 3rd Beijing International Symposium on Paleomagnetism and Earth and Planetary Deep Interiors, Beijing, China, 27-30 June, Invited speaker.

Prof A.P. ROBERTS, International Association of Geomagnetism and Aeronomy (IAGA) Quadrennial Meeting, Merida, Mexico, 26-31 August, Invited speaker, (declined).

Prof A.P. ROBERTS, American Geophysical Union Fall Meeting, San Francisco, USA, 9-13 December, Invited speaker in three sessions: “Applications of Paleomagnetism to Tectonic and other Geologic Problems”, “Quaternary geomagnetic field behavior” and “Rock magnetism: beyond the state-of-the-art” and co-convenor of the Environmental Magnetism session.

Mr. N. SCROXTON, American Geophysical Union Fall Meeting, San Francisco, USA, 9-13 December, gave a poster presentation titled “Speleothem carbon isotopes in the tropics: a proxy for vegetation and what they reveal about the demise of *Homo floresiensis*”.

Mr. N. SCROXTON, PAGES 2nd Young Scientists Meeting and the 4th Open Science Meeting in Goa, India, 11-16 February, presented a talk at the Young Scientists Meeting and a poster at the Open Science Meeting. Both were titled “Fluctuations in the Indonesian Australian Monsoon: New Insights from the Flores Stalagmite Record”.

Mr. N. SCROXTON, Australia Oceania Geosciences Society Annual Meeting, Brisbane, 24-28 June, presented a talk titled “What does the Flores speleothem carbon isotope record tell us about the demise of *Homo floresiensis*”.

Earth Materials & Processes

Prof R. ARCULUS, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a keynote address titled “Subduction zones as probes of mantle composition”.

Prof R. ARCULUS, American Geophysical Union Fall Meeting, San Francisco, 9-13 December, presented a keynote address titled “New insights into arc-backarc systems; the Tonga-Kermadec example”.

Prof R. ARCULUS, Dr J. MAVROGENES and Mr T. WHAN conducted field work in the Alaskan inside passage during July.

Dr A. BENARD, Goldschmidt 2013 Conference, Florence, Italy, 25-30 August, presented a paper titled "Melt evolution from the mantle wedge to the crust: insights from South Kamchatka and West Bismarck arc xenoliths".

Dr A.J. BERRY, Specialist Group for Geochemistry, Mineralogy and Petrology (Geological Society of Australia) meeting at Mission Beach, 14-19 July, presented a keynote talk titled "Geological applications of synchrotron radiation: magmas, fluids, ores and minerals".

Dr A.J. BERRY, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a talk titled "The oxidation states of cerium and europium in silicate melts as a function of oxygen fugacity, composition and temperature".

Miss H.A. COCKER conducted field work at the Grasberg porphyry Cu-Au deposit, Indonesia, from 18-25 November.

Prof S.F. COX, International Applied Geochemistry Symposium, Rotorua, 18-21 November, presented a keynote lecture "Injection-driven swarm seismicity and permeability enhancement: implications for the formation of orogenic gold deposits" in a Society of Economic Geologists special session and another lecture based on the stable isotopic work of PhD student Paul Stenhouse.

Ms K. HAYWARD, 2013 Conference of the Geoscience Society of New Zealand, Christchurch, 24-27 November, presented a paper titled "Static Coulomb Stress Modelling in a complex earthquake sequence: Can it provide useful information for earthquake risk analysis?".

Dr E. C. DAVID, 5th Biot Conference, Vienna, Austria, 10-12th July, presented a paper titled "Model for frequency-dependence of elastic velocities in sedimentary rocks".

Dr M. FORSTER, Structural Geology and Tectonics Special Group conference (SGTSG), Waratah Bay, Victoria, 29 January - 4 February, presented a paper entitled "Tectonics at the Eurasian-India boundary: The history of a pebble".

Dr M. FORSTER, TANG³O (Thermochronology and Noble Gas, Geochronology and Geochemistry Organisation), 25-26 November, presented a paper titled "⁴⁰Ar/³⁹Ar geochronology and the diffusion of ³⁹Ar in phengite-muscovite intergrowths during step-heating experiments in vacuo".

Dr M. FORSTER was invited to Institute Technical of Bandung, Indonesia for collaboration with Prof Suparka, on the 4th to the 14th May.

Dr M. FORSTER conducted fieldwork in NW India with Prof J. Aitchison, Prof G. Clarke and several PhD students, from the 30th May to the 17th June.

Dr M. FORSTER conducted fieldwork on the south arm of Sulawesi with Mr Musri (PhD candidate from Institute Technical of Bandung, Indonesia), Dr Soseilo (University of Pembangunan Nasional, Java), 2 Indonesian students and 1 ANU PhD student, from the 15th to the 30th November.

Dr M. FORSTER visited Hasannudin University, Sulawesi to commence communications with Head of Geology Departmentt, Dean and Vice-Rector on future collaboration, November 2013.

Dr M. FORSTER conducted fieldwork on the high-pressure terranes of Greece from the 11th September to the 3rd October.

Mr B.J. HANGER, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a paper titled "Oxygen fugacity in the Kaapvaal cratonic lithosphere – evidence from Fe XANES measurements of Fe³⁺ in garnet from the Kimberley pipe".

Mr B.J. HANGER, Biennial Conference of the Specialist Group for Geochemistry, Mineralogy and Petrology, Geological Society of Australia, Mission Beach, Queensland, 14-19 July, presented a paper titled "XANES and Redox-Related Processes in the Cratonic Lithosphere".

Mr B.J. HANGER attended a short course on Oxygen Fugacity at Macquarie University, Sydney, 27-28 May.

Dr J. HERMANN, Specialist Group in Geochemistry Mineralogy and Petrology (SGGMP), Townsville, 14-19 July, presented a paper "The formation of intra-continental adakites and high-Mg diorites by partial melting of lower crust" and was co-author on 4 other contributions.

Dr J. HERMANN, Goldschmidt conference, Florence, Italy, 26-30 August, presented a paper "Experimental constraints on carbon recycling in subducted sediments and altered oceanic crust" and a paper "Biotite with high Nb/Ta is an important host for Nb in the lower crust" and was co-author on 6 other contributions.

Dr J. HERMANN, 10th International Eclogite Conference, Courmayeur, Italy, 1-8 September, presented a paper "Nature and composition of fluids in deeply subducted rocks" and was co-author on 2 other contributions.

Prof I. JACKSON, 3rd Global CoE International Symposium on Deep Earth Mineralogy in conjunction with TANDEM 2013, Matsuyama, Japan (March), gave a keynote presentation in the session "Rheology of Minerals and Rocks".

Prof I. JACKSON, 10th Annual Meeting of the Asia Oceania Geosciences Society, Brisbane, 24-28 June, gave an oral presentation titled "Elastically Accommodated Grain-Boundary Sliding: New Insights from Experiment and Modelling".

Prof I. JACKSON, General Assembly of the International Association of Seismology and Physics of the Earth's Interior, Gothenburg, Sweden, 22-26 July, gave two oral presentations titled "Dislocation damping and anisotropy of seismic-wave attenuation" and "Elastically accommodated grain-boundary sliding and its role in seismic wave attenuation".

Prof I. JACKSON, Fall Annual Meeting of the American Geophysical Union, San Francisco, 9-13 December, gave an oral presentation titled "The Onset of Anelastic Behaviour in Fine-Grained Olivine at High Temperature".

Dr P. KING, The Australian Astrobiology Meeting, Sydney, NSW, 30 June – 2 July gave an invited talk titled “Results from the Mars Science Laboratory Curiosity Rover”.

Dr P. KING Specialist Group in Geochemistry, Mineralogy and Petrology Conference, Mission Beach Qld, 15 – 18 July, gave an invited talk titled “New methods to probe the full thermal history of volcanic rocks”.

Dr P. KING, Lunar and Planetary Science Conference, The Woodlands TX USA, 18-22 March, co-authored twelve papers.

Dr P. KING, Geological Society of America, Denver CO USA, 27-30 October, co-authored three papers.

Dr P. KING, Goldschmidt Conference, Florence, Italy, 25-30 August, co-authored two papers.

Dr P. KING spent three days doing field work in the Bega Batholith, NSW, attended the Mars Science Laboratory team meeting at Caltech, California, spent three days working with a colleague at Mt. Holyoke College, Massachusetts, USA, a week working with colleagues at the University of Guelph, Ontario, Canada and two days at CSIRO North Ryde.

Mr Y. LI, 23rd International Geophysical Conference & Exhibition, Melbourne, 11-14 August, gave an oral presentation titled “An exploratory study of the seismic properties of thermally cracked, fluid-saturated aggregates of sintered glass beads”.

Mr Y. LI conducted laboratory based experiments in the rock physics lab at the University of Alberta (Canada) from 14 October to 6 December under the supervision of Prof Douglas Schmitt as his Ph.D. project co-supervisor.

Mr Y. LI, 2013 American Geophysical Union Conference, San Francisco, USA, 9-13 December, presented a poster titled “Properties of sintered glass-bead media”.

Prof H. O’NEILL, Goldschmidt Conference, Florence, Italy, 25-30 August, presented a talk titled “The Effects of Silicate Melt Composition and Sulfur on the Solubilities of PGEs in Silicate Melts” and co-authored six other papers.

Prof H. O’NEILL, “Origin of the Moon” Royal Society meeting, London, 23-24 September, gave an invited talk on “Composition of earth & Moon”.

Prof H. O’NEILL and Mr Paolo SOSSI undertook fieldwork to examine and sample the peridotites of Corsica during September.

Prof H. O’NEILL conducted experiments using synchrotron X-rays at the European Synchrotron Research Facility, Grenoble, UK in July and at the Australian Synchrotron in December.

Prof H. O’NEILL undertook fieldwork to examine and collect samples from the volcanoes of Java during a two-week visit in April.

Dr J.A. PADRON-NAVARTA, Goldschmidt2013 Conference, Florence, Italy, 20-25 August, presented a talk "Hydrogen diffusion in Ti-bearing forsterite" and a poster "A potential geothermometer for antigorite serpentinite" and was co-author on 2 other contributions.

Dr J.A. PADRON-NAVARTA, American Geophysical Union Fall Meeting, San Francisco, 9-13 December, presented an invited talk "Spatiotemporal evolution of dehydration reactions in subduction zones" and a poster "Complex hydrogen diffusion in forsterite" and was co-author on 2 other contributions.

Dr G.M. YAXLEY, Specialist Group on Geochemistry, Mineralogy and Petrology of the Geological Society of Australia biennial conference, Mission Beach, Qld, 14-19 July, presented a paper on "High-pressure experimental constraints on the fate of carbonate in altered oceanic crust during subduction to the Transition Zone and Lower Mantle".

Dr G.M. YAXLEY participated in a field trip to the Ulten-Nonsberg district in the eastern Italian Alps, 21-23 August, to examine and collect peridotites.

Dr G.M. YAXLEY, Goldschmidt Conference, Florence, Italy, August 25-30, presented a key-note talk called "Xenoliths, XANES and redox-related processes in the cratonic lithosphere".

Earth Physics

S. ALLGEYER, ModSim (Modelling and Simulation Society of Australia and New Zealand), Adelaide, 2-6 December, co-authored a paper titled "Are the physics we use to model deep-ocean tsunami adequate?".

S. ALLGEYER, Math for Planet Earth 2013, Melbourne, 9-11 July, co-authored a paper titled "Are the physics we use to model deep-ocean tsunami adequate".

S. ALLGEYER, Asia and Oceania Geological Society 2013, Brisbane, 23-28 June, co-authored two papers titled "Modelling the Tsunami Free Oscillations in the Marquesas (French Polynesia)" and "Investigating Tsunami Secondary Effects in the Propagation and Inversion of the TransPacific Tsunamis".

Dr N. BALFOUR, GEOPRISMS Meeting, Wellington, 15-17 April.

Dr N. BALFOUR, Antelope Users Group Meeting, Brisbane, 22-23 June, presented a talk on "AuSIS: The Australian Seismometers in Schools Network".

Dr N. BALFOUR, IAHS-IAPSO-IASPEI Joint Assembly, Gothenburg, Sweden, 22-26 July, gave an invited presentation titled "The Australian Seismometers in Schools Network (AuSIS): A multipurpose network primarily aimed at promoting careers in geoscience".

Dr N. BALFOUR, AuScope Symposium, Canberra, 30 July, gave an invited presentation titled "The Australian Seismometers in Schools Network: Benefits of community engagement in real geoscience experiments".

Dr N. BALFOUR, Australian Earthquake Engineers Society Meeting and the Australian Seismologists Meeting, Hobart, 15-17 November, gave a presentation on "The Australian Seismometers in Schools Network (AuSIS): A multipurpose network for earth shaking education, monitoring and research".

Mr R. BENAVENTE and Prof P. CUMMINS, Asia Oceania Geosciences Society Annual Meeting, Brisbane, Australia, 24-28 June, presented a paper titled "Rapid First Order Slip Distribution Estimation for Megathrust Earthquakes Using the W-Phase".

Mr R. BENAVENTE and Prof P. CUMMINS, Mathematics of Planet Earth 2013 Conference, Melbourne, Australia, 8-12 July, presented a paper titled "The Seismic W-phase and Earthquake Rupture Model Estimation".

Mr. C. CHAPMAN, The Australian Meteorological and Oceanographic Society Annual Conference, Melbourne, 11-13 February, presented a paper titled "Jet Jumping: Variability of Southern Ocean Jets near Topography".

Mr. C. CHAPMAN, Australian Mathematical Sciences Institute's winter school, "The Mathematics of Planet Earth", Brisbane, 24 June – 5 July, gave a presentation titled "Why studying the Southern Ocean is Hard".

Mr. C. CHAPMAN, The Australian Mathematical Sciences Institute's student conference, Sydney, 19-20 September, presented a paper "Detecting oceanic jets using wavelets and higher order statistics".

Dr D.R. DAVIES, Asia and Oceania Geological Society 2013, Brisbane, 23-28 June, delivered a keynote seminar titled "Reconciling dynamic and seismic models of Earth's lower mantle – the dominant role of thermal heterogeneity".

Dr S.M. DOWNES, Dialogue between Contourite and Oceanography Processes, Hull, United Kingdom, 27-30 January, presented a paper titled "Tracing Southwest Pacific Bottom Water using potential vorticity and Helium-3".

Dr S.M. DOWNES, 8th Session CLIVAR/CliC/SCAR Southern Ocean Panel, Hobart, 21-22 February, gave an invited presentation titled "Southern Ocean parameterized eddy metrics in CMIP5".

Dr S.M. DOWNES, WGOMD/SOP Workshop on Sea Level Rise, Ocean/Ice Shelf Interactions and Ice Sheets, Hobart, Australia, 18-20 February, gave an invited talk titled "Model representation of Southern Ocean bottom water mass formation and circulation".

Dr S.M. DOWNES, Twelfth Informal ACCESS Model Evaluation Workshop, Melbourne, Australia, 11 April, co-organised, chaired and presented a talk titled "Southern Ocean circulation in CMIP5 models."

Dr B. GAYEN, 'Ocean Turbulence' meeting, Santa Fe Center for Nonlinear Science, 3-7 June, presented a poster titled "The mechanical energy budget of horizontal convection at large Rayleigh numbers".

Dr B. GAYEN, American Physical Society - Division of Fluid Mechanics meeting, Pittsburgh, November, presented a paper titled "Adding available potential energy to the mechanical energy budget of Rayleigh-Bénard convection" and the Andreas Acrivos Award lecture titled "Turbulence and internal waves in tidal flow over topography".

Mr E. GOWAN, European Geosciences Union (EGU) General Assembly 2013, Vienna, Austria, 7-12 April, gave a talk titled "Modelling the Laurentide Ice Sheet using improved ice margin chronologies and glacio-isostatic observations".

Mr E. GOWAN, American Geophysical Union Fall Meeting, San Francisco, United States, 9-13 December, gave a talk titled "Model of the western Laurentide Ice Sheet from glacio-isostatic adjustment analysis and revised margin locations".

Prof R.W. GRIFFITHS, 'Ocean Turbulence' meeting, Santa Fe Center for Nonlinear Science, 3-7 June, presented an invited paper titled "Where is mixing in the oceans important?"

Prof R.W. GRIFFITHS, American Physical Society - Division of Fluid Mechanics meeting, Pittsburgh, 24-26 November, presented a paper titled "Adding available potential energy to the mechanical energy budget of Rayleigh-Bénard convection".

Prof R.W. GRIFFITHS visited the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India, 12-14 December to present a research lecture titled "Turbulent convection: flow transitions and mechanical energy budgets" and to present a Silver Jubilee Public Lecture titled "Balancing the budget: What drives the global circulation of the oceans?".

Dr A.McC. HOGG, The Australian Meteorological and Oceanographic Society Annual Conference, Melbourne, 11-13 February, presented a paper titled "The Transient Response of the Southern Ocean to Climate Change".

Dr A.McC. HOGG, CLIVAR's Southern Ocean Panel Meeting, Hobart, 21-22 February, presented a paper titled "Eddy physics in the Southern Ocean – Impacts on the MOC & ACC".

Dr A.McC. HOGG, The Theo Murphy International Scientific Meeting: New models and observations of the Southern Ocean, its role in global climate and the carbon cycle, Buckinghamshire, UK, July, presented an invited talk titled "Circulation in the Southern Ocean: A conspiracy between wind, buoyancy, eddies and geometry".

Dr G.O. HUGHES, Ocean Turbulence, Santa Fe, USA, 3-7 June, presented a paper titled "Energy requirements of the global ocean circulation".

Dr G.O. HUGHES, IAHS-IAPSO-IASPEI Joint Assembly, Gothenburg, Sweden, 22-26 July, presented a paper titled "Diapycnal transport processes in the ocean overturning circulation".

Dr G.O. HUGHES, European Turbulence Conference 14, Lyon, 1-4 September, presented a paper titled "Available potential energy in Rayleigh-Bénard convection".

Dr G.O. HUGHES, Buoyancy Effects and Turbulent Mixing in Fluids, Cambridge, September, presented a paper titled "Mixing and available potential energy in convective flows".

Dr G. IAFFALDANO, American Geophysical Union Fall Meeting, San Francisco USA, 9 – 13 December.

Dr G. IAFFALDANO, CCFS lithosphere dynamics workshop, Perth, WA, 4 – 6 November, presented an invited keynote lecture titled "Observational constraints on global quantitative models of the coupled plates/mantle system".

Prof B.L.N. KENNETT, International Geological Congress, Brisbane, 5-10 August, gave a Keynote Lecture in the symposium "Lithosphere structure from ambient noise and other seismology".

Prof B.L.N. KENNETT, QUEST meeting, Brittany, France, 19-25 May, gave an invited lecture on "Ambient Noise Studies in Australia and Indonesia".

Prof B.L.N. KENNETT, Workshop on Lithospheric Dynamics, Perth, WA 4-6 November, gave a keynote lecture on the seismological structure of the lithosphere beneath Australia.

Prof B.L.N. KENNETT American Geophysical Union Fall Meeting, San Francisco USA, 9 – 13 December, presented a paper on a new method of energy projection for determining the evolution of the seismic source in 3-d, with an associated poster co-authored with Drs A. Gorbatov & S. Spiliopoulos (Geoscience Australia), and a second poster with R. CHOPPING on the Curie depth under Australia

Mr Y. LEONARD, attended the Introductory Academic Program – Research class (ANU Academic and Learning Centre), Three Minutes Thesis Showcase (ANU Research Skill and Training) and a Workshop in Science Communication (Australian National Centre for the Public Awareness of Science)

MR Y. LEONARD undertook fieldwork from 21 September to 9 November to collect continuous GPS data from Indonesian Geospatial Agency (BIG) and National Land Agency (BPN) in Jakarta, and GPS Campaign on East of Nusa Tenggara (Flores Island).

Dr L. LESCARMONTIER, American Geophysical Union Fall Meeting, San Francisco, USA, 9-13 December, co-authored a paper on "Tides-modulated Icequakes in the Mertz Glacier grounding area, East Antarctica".

Dr L. LESCARMONTIER, IGS conference, Beijing, China B. presented a co-authored paper titled "Dynamics of the Mertz Glacier and its ice tongue, East Antarctica implications of its calving and changes at various time scales".

Dr L. LESCARMONTIER, Journée REFMAR, Paris, France, 17-21 June, presented a co-authored paper titled "Micro-Sismicité Induite Par La Marée Dans La Région Du Glacier Mertz, Terre Adélie, Est-Antarctique".

Dr L. LESCARMONTIER undertook field work in Enderby Land, East Antarctica from 5 October to 31 December to set up a couple of autonomous GPS stations to measure the Post-Glacial Rebound in the region.

Dr J-P.MONTILLET, ModSim (Modelling and Simulation Society of Australia and New Zealand), Adelaide, 2–6 December, gave an oral presentation titled "Levy stable distribution to model stochastic processes in GPS time series".

Mr S. PACHHAI visited the Department of Earth and Planetary Science, Harvard University, USA, 7-20 April. He worked with Professor Miakii Ishii on rotational dynamics of the Earth's inner core. The visit was funded by a Mervyn and Kaitlin Paterson travel fellowship 2012.

Mr S. PACHHAI visited the Institute of Geophysics and Planetary Physics, University of California, San Diego, 21-28 August. He worked with Professor Guy Masters to apply the Neighbourhood Algorithm to study the Earth's inner core structure using normal mode data.

Prof M.L. RODERICK, American Geophysical Union Fall Meeting, San Francisco, USA, 9-13 December, presented a paper titled "Incorporating the Vegetation Response to Changing Atmospheric CO₂ into the Budyko Framework".

Ms I. ROSSO, The Australian Meteorological and Oceanographic Society Annual Conference, Melbourne, 11-13 February, presented a paper titled "The Vertical Transport in the Ocean due to Meso and Sub-mesoscales: Impacts in the Kerguelen Region".

Ms I. ROSSO, 19th Conference on Atmospheric and Oceanic Fluid Dynamics, Newport, USA, 17-21 June, presented a poster titled "The Vertical Transport in the Ocean due to Sub-mesoscale structures: Impacts in the Kerguelen Region".

Dr J.A. SAENZ, 'Ocean Turbulence' meeting, Santa Fe Center for Nonlinear Science, 3-7 June, presented a poster titled "Power input from buoyancy and wind in the mechanical energy budget of the ocean circulation".

Dr M. SALMON CONASTA 62 – Australian Science Teachers Association Conference, Melbourne, 7 – 10th July, presented workshop entitled "On Shaky Ground: Introduction to seismology using hands on activities".

Dr E. SAYGIN, Asia and Oceania Geological Society 2013, Brisbane, 23-28 June and gave a talk titled "The Crustal Structure of Indonesia from Seismic Noise Tomography".

Dr E. SAYGIN, 3rd International Symposium on Earthquake and Disaster Mitigation Schedule, Yogyakarta, Indonesia, 17-18 December, gave a talk titled "The Crustal Structure of Indonesia from Seismic Noise Tomography".

Dr E. SAYGIN conducted seismic experiments in Jakarta, Indonesia in October, November and December.

Prof M. SAMBRIDGE, European Geoscience Union meeting, Vienna, 7-12 April, gave a presentation titled "Parallel Tempering for sampling and optimization in seismic inverse problems".

Prof M. SAMBRIDGE, 2013 MaxENT conference (33rd International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering), Canberra, 15-20 December.

Ms. K. SNOW, the Australian Meteorological and Oceanographic Society Annual Conference, Melbourne, 11-13 February, presented a paper titled "Modelling Antarctic Bottom Water Overflows in Global Climate Model".

Ms. K. SNOW, CLIVAR's Southern Ocean Panel Meeting, Hobart, 21-22 February, presented a paper titled "Modelling Antarctic Bottom Water Overflows in Global Climate Model".

Ms. K. SNOW, 55th Woods Hole Oceanographic Institute Geophysical Fluid Dynamics Summer Program, Woods Hole, USA, 19-23 August gave an oral presentation titled "Particle driven flows down an incline into a linear stratification".

Dr H TKALČIĆ, European Geosciences Union, Vienna, April, gave a talk titled "Geodynamics of the Earth's inner core from seismology".

Dr P. TREGONING, Using GRACE Data for Water Cycle Analysis and Climate Modelling Workshop, Pasadena, California, USA, 15-17 July.

Dr P. TREGONING, American Geophysical Union Fall Meeting, 6-13 December, presented a paper titled "Innovative analysis constraints in the ANU GRACE solutions" and was a co-author on another oral presentation "Model of the western Laurentide Ice Sheet from glacio-isostatic adjustment analysis and revised margin locations".

DR P. TREGONING, European Geophysical Union, Vienna, 7-12 April, was a co-author on one oral presentation titled "Modelling the Laurentide Ice Sheet using improved ice margin chronologies and glacio-isostatic observations" and two poster presentations titled "Firn compaction modelling of the Antarctic ice sheet" and "Effect of neglecting high frequency non-linear motions induced by non-tidal ocean loading on estimating the geocenter motion from a geodetic network".

PRISE

Dr R.A. ARMSTRONG (with collaborators) conducted archaeological research at the Australian Synchrotron, Melbourne, 4-6 March.

A/Prof C.M. FANNING, GEOSUR conference, Viña del Mar, Chile, 23-27 November.

A/Prof C.M. FANNING conducted fieldwork in northern Chile from 29 November – 7 December.

Visiting Fellows

Dr R.A. BINNS, Indonesian Society of Economic Geologist Annual Conference, Denpasar, Indonesia, 30 November - 3 December, presented an invited keynote paper titled "Seafloor Massive Sulfides and black smokers: The potential in Maluku and Papua".

Dr R.A. BINNS, Australian Institute of Geoscientists meeting, Orange, NSW, 11-14 September and an associated field trip to the Copper Hill prospect near Molong NSW.

Dr K.A.W. CROOK, Sapphire Coast Marine Discovery Centre's Marine Science Forum, Eden, 4-5 May.

Dr W. MAYER, 24th International Congress of the History of Science, Technology and Medicine, Manchester, England, 22-28 July, presented a talk titled "Early European impressions of the Australian landscape and geology in art and in literature".

Emeritus Prof I. McDOUGALL, invited to the Soddy-Holmes symposium of the Geological Society of London in June, at which he presented a keynote address.

EDITORIAL RESPONSIBILITIES

Earth Chemistry

Prof Y. AMELIN, Associate Editor, *Geochimica et Cosmochimica Acta*.

Prof Y. AMELIN, Member of the editorial board, *Chemical Geology*.

Dr V C BENNETT, with Dr S Wilde and Dr T Iizuka was guest editor of a special issue of the *American Journal of Science*: "Assessing the Geologic Record of the First Billion Years" which was published in November.

Dr J.J. BROCKS, Associate Editor, *Geochimica et Cosmochimica Acta*.

Dr J.J. BROCKS, Associate Editor, PALAIOS, a Journal of the Society of Sedimentary Geology.

Dr J.J. BROCKS, Editorial Board, Geobiology.

Dr J.J. BROCKS, Editorial Board, GeoResJ, a new Elsevier journal

Dr M. HONDA, Associate Editor, Geochemical Journal.

Prof T. R. IRELAND, Associate Editor, Geochimica et Cosmochimica Acta.

Dr C.H. LINEWEAVER refereed 19 articles for Astrobiology, International Journal of Astrobiology, Astrophysical Journal, Monthly Notices of the Royal Astron. Society, Astronomy and Astrophysics, Earth System Dynamics, International Journal of Theoretical Physics, Astrophysics and Space Sciences, Physica Scripta, Physics of Life Reviews, Bioinformatics, Life, Entropy, Medical Hypotheses

Dr C.H. LINEWEAVER, Member of the Editorial Board, Astrobiology

Dr D. RUBATTO, Associate Editor, Lithos.

Dr D. RUBATTO, Editorial Board, Chemical Geology

Dr D. RUBATTO, Editorial Review Board, Journal of Metamorphic Geology.

Dr R. SALMERON, Reviewer for Australian Journal of Earth Sciences, Plasma Physics and Controlled Fusion, Astrophysical Journal, Monthly Notices of the Royal Astronomical Society, Astrophysics & Space Science.

Earth Environment

Dr N.J. ABRAM, Editor, Climate of the Past.

Dr M. DAVIES, Editorial meeting for IODP Expedition 341 Proceedings Volume at Texas A&M University, USA – Physical properties specialist.

Prof P. De DECKKER is on the editorial board of Palaeoclimatology, Palaeoecology, Palaeogeography, as well as Marine Micropaleontology, plus Journal of Paleolimnology.

Dr M.J. ELLWOOD is an associate editor for Marine and Freshwater Research.

Prof R. GRÜN is the Editor-in-Chief of Quaternary Geochronology, associate editor of the Journal of Archaeological and Anthropological Sciences and member of the Editorial Boards of Quaternary Science Reviews and Radiation Measurements.

Dr D. HESLOP, Associate Editor, Geochemistry, Geophysics, Geosystems.

Dr M.D. NORMAN, Executive Editor, *Geochimica et Cosmochimica Acta*, and Associate Editor, *Australian Journal of Earth Sciences*.

Prof B.J. PILLANS, Editorial Board, *Quaternary Science Reviews*.

Prof E.J. ROHLING, Editor, *Reviews of Geophysics*.

Prof A.P. ROBERTS, Guest Editor, special volume, *Global and Planetary Change* (Elsevier) and member of the Editorial Board, *Frontiers of Earth Science in China* (Springer).

Dr R. STRZEPEK, Manuscript reviewer for *Nature Geoscience*, *European Journal of Phycology*, *Global Change Biology*, and *Limnology and Oceanography* and proposal reviewer for National Science Foundation and Netherlands Organisation for Scientific Research Earth, and Life Sciences.

Dr J. YU, Reviewer for *Nature*, *Proceedings of the National Academy of Sciences*, *Earth and Planetary Science Letters*, *Geochimica et Cosmochimica Acta*, *Geology*, *Chemical Geology* and *Geochemistry*, *Geophysics*, *Geosystems*.

Earth Materials & Processes

Prof S.F. COX, Member Editorial Advisory Boards, *Journal of Structural Geology* and *Geofluids*.

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*.

Dr P. KING, Associate Editor, *Geochimica et Cosmochimica Acta*.

Dr P. KING, Contributing Editor, *A Life in Science*, *Elements*.

Prof G. LISTER, Associate Editor, *Journal of Geophysical Research*, *Solid Earth*.

Dr O NEBEL, Editorial Board, *The Journal of Mineralogy and Geochemistry* (*Neues Jahrbuch für Mineralogie*).

Prof H. O'NEILL, Editorial Board, *Chemical Geology*

Earth Physics

Dr N. BALFOUR reviewed papers for *Geophysical Journal International*, *Geophysical Research Letters* and *Bulletin of the Seismological Society of America*.

Dr P.R. CUMMINS, Editor, Geological Society of London Special Publication: Geohazards in Indonesia: Earth Science for Disaster Risk Reduction.

Dr S.M. DOWNES, Chief Guest Editor, Deep-Sea Research II special issue: Southern Ocean Dynamics and Biogeochemistry in a changing climate.

Prof R.W. GRIFFITHS, Associate Editor, Journal of Fluid Mechanics, Cambridge University Press.

Dr G. IAFFALDANO, Associate Editor of Annals of Geophysics and Geosphere

Prof B.L.N. KENNETT, Editor, Earth Planets and Space (Japan), Member of the Advisory Editorial boards for Physics of the Earth and Planetary Interiors and Earth and Planetary Science Letters.

Dr J-P. MONTILLET, Reviewer for the Journal of Geodynamics, GPS solutions, IET signal processing and Signal Processing (Elsevier – short communications).

Prof M.L. RODERICK, Associate Editor, Water Resources Research (American Geophysical Union) and Hydrology and Earth System Sciences (European Geosciences Union).

Dr M. SALMON provided peer reviews for Tectonophysics and Seismological Research Letters.

Dr P. TREGONING, Editor, Journal of Geophysical Research, Solid-Earth.

PRISE

Dr R.A. ARMSTRONG, Editorial Board, Journal of African Earth Sciences.

IODP

Prof N. EXON was involved in writing and editing various IODP documents, including the ANZIC Annual Report and reports relating to the Southwest Pacific IODP Workshop held in Sydney in 2012 including one in Scientific Drilling. A major new responsibility for him is collating and editing a major final report for the first phase of ANZIC in IODP (2008-2013).

Ms C. BEASLEY took the lead in designing the new ANZIC web site together with web designer Voodoo Creative. The new site went live in January 2013.

Visiting Fellows

Dr K. A. W. CROOK, Foundation Member of the Editorial Board, and an Editor-in-Chief Emeritus of *Sedimentary Geology*. He continues to serve as a reviewer on request.

Dr W. MAYER, Editor of INHIGEO publications (International Commission for the History of Geological Sciences). In this capacity he has edited and published the INHIGEO Annual Record 2013, No. 45, 144 p.

OUTREACH AND WORKSHOPS

Earth Chemistry

Dr J.J. BROCKS, scientific adviser for a major Japanese national television science program.

Dr J.J. BROCKS, TV interviews about early life on Earth and Mars in the outback of Northern Territory and on ANU campus for a major Japanese national television science program.

Dr J.J. BROCKS, Organization of the pilot of an intercollege 'Lab Visiting' program to bring young academics at ANU together and foster interdisciplinary research (a NECTAR initiative).

Dr J.J. BROCKS gave a talk titled "Toxic purple oceans" at Tallinn University of Technology, Estonia on 9 November.

Mr A. CHOPRA was interviewed by SBS Radio (Hindi) on numerous occasions about topics including the search and analysis of the 4.4 billion year old Martian meteorite "Black Beauty", the life and times of the revolutionary scientist Johannes Kepler, the results from the Kepler Telescope mission, cosmonauts at the International Space Station who went for a spacewalk with the 2014 Winter Olympics torch, the question whether there is ever a possibility of finding life on Mars and Venus, Earth's age and how scientists got to this number, the correlation between bushfires and climate change, Voyager 1 spacecraft reaching the edge of the Solar system's heliopause, Prof Dan Shechtman (who won the Nobel Prize for Chemistry in 2011) and the 2013 Nobel Prizes for Medicine, Physics and Chemistry.

Mr A. CHOPRA was invited to present a feature story on his research on ABC Radio National's The Science Show hosted by Robyn Williams, 4 May.

Mr A. CHOPRA presented an invited public lecture titled "My 14 billion year search for E.T." at Questacon's 100°C — Stories of 100 Canberra Scientists series during the Centenary of Canberra celebrations, 4 May.

Mr A. CHOPRA was an invited presenter at the 2013 ANU 3 Minute Thesis Showcase, 15 May and an invited judge for 3 Minute Thesis - ANU College of Engineering and Computer Science, 30 July.

Mr A. CHOPRA was an invited judge 2013 Summer Scholar Program – 3 Minute Project at ANU, 16 January; a panellist at the “Why do a graduate degree?” event for Honours students at ANU, 16 April; and an invited presenter at the 2013 ANU Summer Scholar's Welcome, 28 November.

Mr A. CHOPRA organised a public telescope observing at the ANU campus for the 2013 Partial Solar Eclipse on 10 May.

Mr A. CHOPRA assisted with other RSES staff and students at the 2013 ANU Open Day.

Mr A. CHOPRA contributed articles to the RSES student blog OnCirculation and Astrobiology Magazine's Pale Blue Blog.

Mr A. CHOPRA presented a guest lecture to Year 9 Science students at Melrose High School, Canberra on the search for extra-terrestrial life and to Year 9 students at Rossmoyne Senior High School in Perth, WA on astrobiology and planetary science research.

Mr A. CHOPRA, 2013 ANU Public Lecture hosted by the ANU Black Hole Society in Canberra, 31 July, presented a talk entitled “What can life on Earth tell us about life in the Universe”.

Dr C.H. LINEWEAVER gave a presentation "Origin and Fate of the Universe" at the International Space University, University of Southern Australia, 25 January.

Dr C.H. LINEWEAVER gave a lecture "Cool Factoids" to National Youth Science Forum elite Year 11 and 12 students, ANU, 17 January.

Dr C.H. LINEWEAVER gave a lecture "Astrobiology" to ACT science teachers, RSES, 31 January.

Dr C.H. LINEWEAVER attended the "Thermodynamic Paths to Metabolism" workshop, 5-8 May, Arizona State University, USA.

Dr C.H. LINEWEAVER attended the Post-Kepler Exoplanet Meeting in honour of David Latham, Harvard University Center for Astrophysics, 19-21 May.

Dr C.H. LINEWEAVER attended the invitation only Science Foo Camp, Googleplex, Mountain View California. With Paul Davies, he presented their new atavistic model of cancer, 21-23 June.

Dr C.H. LINEWEAVER attended the Australian Centre for Astrobiology Meeting at the University of New South Wales, Sydney 30 June – 7 July.

Dr C.H. LINEWEAVER attended the Astronomical Society of Australia annual meeting, Monash University, 7-12 July where he gave the Harley Wood Lecture, "The Birth, Life and Death of our Planetand of the Universe".

Dr C.H. LINEWEAVER attended the Warburg Effect Cancer Workshop at Arizona State University, USA, 6-8 November.

Dr C.H. LINEWEAVER attended the Australasian Evolution Society Meeting, Geelong Botanic Gardens, Melbourne, 29 September – 2 October.

Dr C.H. LINEWEAVER gave a guest lecture on "The Big Bang" at Melrose High School to Advanced Science Students, 18 November.

Dr C.H. LINEWEAVER gave a public lecture "The Origins of Sex and Death" sponsored by the Gender Institute, Hedley Bull Theatre, ANU, 20 November.

Dr C.H. LINEWEAVER was interviewed and appeared in ABC TV Science Show Catalyst about the Voyager spacecraft leaving the Solar System on 20 June and in a segment "Custom Universe - finetuned for us?" on 29 August. He also appeared in ABC TV Science Show Catalyst Online Edition, Moon Special, Extended Interviews on the origin of Life and the surface of the Moon.

Dr C.H. LINEWEAVER was interviewed on ABC TV news about Asteroid 2012DA14 passing close to Earth, 15 February; about the Chelyabinsk meteorite, 16 February; explained a partial eclipse of the Sun, 25 April; about the NASA Maven spacecraft, 19 November.

Dr C.H. LINEWEAVER was interviewed on Channel 7 TV news about the Chelyabinsk meteorite, 16 February; on Channel 10 TV news about the Chelyabinsk meteorite, 16 February and on Channel 10 TV, Wake Up! morning show about NASA's MAVEN spacecraft, November 20; comet ISON Sun grazing comet, 26 November; the International Space Station space walk with snorkels, 23 December.

Dr C.H. LINEWEAVER hosted an interview of Steve Benner about the chemical origin of life for ANU TV, recorded 24 May.

Dr C.H. LINEWEAVER was interviewed on Canberra Local radio program Fuzzy Logic about extrasolar planetary systems and the complexity of the universe, 22 September; on Coonabarabran local radio as part of the Siding Spring Observatory Star Party about his public lecture "How Many Kevin Rudds are in the Universe?" on 5 October.

Dr C.H. LINEWEAVER was interviewed on ABC radio Queensland Regional Drive program about Chelyabinsk meteorite, 18 February; on ABC Radio World Today "Just Sound Bytes", 28 February; ABC National Radio program "Sundays with James O'Loughlin" about Entropy broadcast 13 October.

Dr C.H. LINEWEAVER was interviewed on Radio National about the Chelyabinsk meteorite, 18 February; on Radio National's Future Tense program about asteroid mining, broadcast 19&20 February; on Radio National about the United Nations and asteroid mining, 29 October; about the MAVEN spacecraft launch to Mars, November 20; about ISON, MAVEN, GAIA and China's Chang'e 3 mission to the Moon, 2 December.

Dr C.H. LINEWEAVER gave an invited guest lecture "Are We Alone?" at the Indian Institute of Technology in Mumbai, India as part of Techfest 2013, 5 January.

Dr C.H. LINEWEAVER gave a presentation "The Clock is Ticking: How Long Do We Have?" and participated in a panel discussion in Burton and Garran Hall, ANU, on the future of life on Earth, 13 March.

Dr C.H. LINEWEAVER was an invited participant in the "In the Beginning...Origins Conference" about the relationship between religion and science organized by the Melbourne City Bible Forum. Dr Lineweaver participated in the lunchtime panel discussion on 30 August and gave a lecture on the age of the Universe, 1 September.

Dr C.H. LINEWEAVER was an invited participant in TEDxCanberra, a full day of public talks, where he gave the talk "Science, humility and the fallacy of the Planet of the Apes" 7 September.

Dr C.H. LINEWEAVER gave a lecture "Are We Living in a Black Hole?" for the ANU Black Hole Society, ANU, 24 September.

Dr D. RUBATTO presented two lectures at the international PhD School on "Zircon: a key mineral for dating and tracking geological processes" in Pavia, Italy, 8-13 September.

Dr R. SALMERON gave a talk "Magnetic activity of young stars" at Mathematics across the Disciplines, 5 November.

Ms K.M STRZEPEK presented on behalf of the ANU's Equity and Diversity Unit for the 'Queen B' workshop for girls from Goulburn High School (Yrs 10-12)

Ms K.M STRZEPEK received a certificate for participation in the Science Communication Workshop held by the Centre for the Public Awareness of Science, ANU.

Ms K.M. STRZEPEK planned the week and supervised a work experience student (N. Craze) from St Gregory's College, Campbelltown.

Dr I.S. WILLIAMS hosted visits to the SHRIMP laboratory by students attending the National Youth Science Forum on 17 and 31 January and 17 April.

Dr I.S. WILLIAMS hosted a tour of the SHRIMP laboratory by high school students visiting RSES in October as part of the ACT Science Experience.

Dr I.S. WILLIAMS supervised Masters student Ms H. James (Archaeology) in the O isotope analysis component of her research.

Earth Environment

Dr N.J. ABRAM spoke at the RSES 40th year reunion on “Earth Sciences in a changing climate” and performed the role of RSES Communications and Outreach co-ordinator.

Dr N.J. ABRAM gave a seminar at University of Sydney, 5 June, titled “Warming and ice melt on the Antarctic Peninsula”.

Dr N.J. ABRAM represented the ANU College of Sciences at North Sydney Girls High School careers day.

Dr N.J. ABRAM gave talks to high school students visiting RSES from Melrose High School about paleoclimate research, to year 3 and 4 students at Turner School about fossils and to Southern Cross travel club on Antarctic research.

Dr N.J. ABRAM was interviewed by ABC Breakfast TV show, ABC AM Radio, and various other international outlets about an Antarctic Peninsula ice core palaeoclimate record published in Nature Geoscience, 15 April 2013. The ANU and BAS Media releases generated worldwide coverage of the research.

Dr N.J. ABRAM was a presenter at the “Who Are Scientists” event, held at Kioloa Campus, October 2013 for year 9 students at 3 disadvantaged high schools. This was organized as part of the ANU Student Equity program.

Dr S.M. EGGINS was interviewed by ABC radio 666 on 2 October about coral calcification experiments being conducted in aquaria at the ANU. The audio broadcast and images of the ANU mesocosm and experiments were published online at www.abc.net.au/local/photos/2013/10/02/3860771.htm

Dr S.M. EGGINS was interviewed by ABC radio South East NSW about foraminifer collection and culture experiments being undertaken in Twofold Bay on the Far South Coast of NSW. The interview was broadcast in the week prior to the Sapphire Coast Marine Discovery Centre’s annual ‘Marine Science Forum’.

Dr S.M. EGGINS and PhD candidate Ms K.D. HOLLAND presented a talk entitled ‘Why put the acid on Twofold Bay’s planktonic foraminifera?’ at the Sapphire Coast Marine Discovery Centre’s annual ‘Marine Science Forum’ on the 5 May.

Dr M.J. ELLWOOD gave a talk at Science Week, CSIRO Discovery Centre, titled “Ocean Acidification: the Ocean’s response to increases in atmospheric carbon dioxide”.

Dr M.K. GAGAN presented an invited research seminar at the Earth Observatory of Singapore, Nanyang Technological University, Singapore on 8 May titled "Geochemical histories of the big-three earth hazards in southern Australasia: Great earthquakes, climate change and volcanic catastrophes".

Ms. K. LONG was interviewed on radio program 'Nutshell' about her PhD research into using fish otoliths from Lake Mungo as palaeoenvironmental proxies. Approximately 20 minute interview with Emma Erikson, 2XXFM, broadcast at 8:30am 30 July.

Dr D.C. "Bear" McPHAIL presented invited seminars on groundwater in the Lower Murrumbidgee to Geological Society of Australia (Canberra), International Association of Hydrogeologists (Canberra), Flinders University and the University of Canberra.

Dr D.C. "Bear" McPHAIL led the Honours Student Challenge between ANU and University of Wollongong students, Moss Vale, NSW in September 2013.

Dr B. N. OPDYKE has a monthly radio spot with 2XX community radio to discuss climate change issues.

Prof B.J. PILLANS, Chair, Steering Committee of the National Rock Garden Trust.

Prof E.J. ROHLING provided a 50-minute keynote "Understanding Sustainability" (with emphasis on global climate change), with extensive follow-up discussions, at the Biennial Curriculum Conference of the Australian Curriculum Studies Association, 24-27 September in Darwin.

Mr. N. SCROXTON was an Editor for the student run blog OnCirculation.

Mr. N. SCROXTON gave an outreach talk to Year 8 Science students at Melrose High School, ACT.

Mr. N. SCROXTON wrote an article for the Geochemical Society's Magazine: Elements titled: "Maximising an early-career researcher's exposure at conferences: Poster or Oral Presentation" Elements Magazine, vol. 9(4), p309.

Earth Materials & Processes

Prof S.F. COX provided 1.5 days of field excursions in the Canberra - Lake George area for students of Orana School.

Prof S.F. COX provided a lecture to geoscientists at Newmont's Waihi gold operations in New Zealand in November 2013.

Dr E.C. DAVID presented a paper titled "An exploratory study of the seismic properties of thermally cracked, fluid-saturated aggregates of sintered glass beads", by Y. Li, M. Olin, A. Clark, I. Jackson, and E. C. David at the EAGE Workshop on seismic attenuation, Singapore (28-30th October).

Dr M. FORSTER supervised a PhD student, Mr Musri, for Institute Technical of Bandung, Indonesia, both on Sulawesi for structural geology fieldwork and at ANU for microscopy and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology.

Dr M. FORSTER supervised a Post-Doctoral fellow (Dr L. White) from Royal Holloway University of London, SEARG, for $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology at ANU for argon geochronology.

Dr M. FORSTER supervised a Year 10 student, Ewout Rohling, from Stromlo High School for his formal Work Experience Program.

Dr J. HERMANN participated in several tours for High School students from Canberra and the region and organised four two-hour workshops for 10 school teachers from Canberra high schools.

Dr P. KING gave outreach talks at: Arawang Primary School, Waramanga and Canberra Girls' Grammar School, Deakin. She organized activities for an RSES table at Geoscience Australia's Open Day and gave a talk about the Earth Sciences program to prospective students at the ANU Open Day.

Dr P. KING had articles in The Canberra Times (27 September), an interview with ABC radio 702 (Sydney) on 27 September and an article in GeoEdLink (Australian Geoscience Council newsletter, March).

Dr P. King gave an invited talk for an ANU Science Teaching and Learning Centre workshop.

Dr P. KING was a contributing editor for the Elements column "A Life in Science" and wrote two articles, "Travelling for Work – Lessons from the Curiosity Rover", Elements, April 2013, 156-157 and "Changing Research Direction in the Middle of an Academic Career", Elements, December 2013, 476.

Dr P KING co-supervised Mr J. M. de Moor, University of New Mexico who obtained his PhD in 2013.

Prof G. LISTER has run industry workshops as part of the 4D porphyry project.

Dr G. YAXLEY, with Dr A.J. BERRY and Mr B. HANGER conducted collaborative work at the Australian Synchrotron in 2012 that was featured in the June 2013 edition of the Australian Synchrotron's on-line magazine, Lightspeed.

Earth Physics

Drs N. BALFOUR, M. SALMON and Prof M. SAMBRIDGE, together with Dr U. PROSKE have been building the Australian Seismometers in Schools network of 40 seismic stations in high schools across the nation. Throughout the year, this has involved visits to each school to install an instrument, give presentations and engage in media related activities.

Dr N. BALFOUR gave demonstrations of seismology for National Youth Science Forum student and staff visitors.

Dr N. BALFOUR gave a seminar to a class of students at Melrose High School and helped mentor for students as part of an ACE Science project. She also visited 14 schools around Australia including in VIC, NSW, NT and QLD and gave presentations to students and staff.

Dr N. BALFOUR gave a seminar at the University of Auckland titled "AuSIS: The Australian Seismometers in Schools Network".

Dr D.R. DAVIES delivered invited departmental seminars at The University of Sydney, Macquarie University, Monash University and Imperial College London.

Dr S. M. DOWNES gave a talk titled "Climate Models and Future Prediction for Australia" at the ANU Research School of Earth Sciences as part of a lecture series on climate change science to ACT high school teachers on 29 May.

Dr S.M. DOWNES gave a talk titled "Climate Change and Oceans" at the ANU Research School of Engineering for the Science without Borders students (course: Big Engineering Ideas to Save the Planet) on 26 Oct.

Dr A.McC. HOGG gave a talk at Merici College, Canberra, titled "Oceans and Climate" on 7 March.

Dr A.McC. HOGG, Video released by ANU media office, picked up by ABC online news, with in excess of 6000 views.

Dr A.McC. HOGG gave a talk titled "The Ocean's Role in Climate" at an ANU Climate Change Institute public event focussed on the release of the IPCC's Fifth Assessment Report on 9 Oct.

Dr A.McC. HOGG presented an overview of IPCC's Fifth Annual Report findings to a public forum on "Oil and the Yasuní ITT" held at ANU.

Prof B.L.N. KENNETT gave a number of radio interviews on issues related to earthquakes and tsunamis.

Dr M. SALMON organised National Youth Science Forum student and teacher visits to the RSES laboratories on 17 and 31 January and 17 April and presented a Seismology laboratory tour and talk to Science Experience Students on 2 October.

Dr M. SALMON partnered with Garran Primary School as part of the Scientists in Schools program.

Dr M. SALMON mentored Charlotte Anderson as part of the ACE Science Program at Melrose High School.

Dr M. SALMON gave talks to teachers and students at Rosebud Secondary College, Hawkesdale College, Keysborough Secondary College (Melbourne), Mt Clear College (Ballarat), Moamma Anglican Grammar, Cummins Area School, Jamestown Community School, Renmark High School, Roxby Downs Area School, Marden Senior College (Adelaide), St Luke's College (Karratha), John Paul College (Kalgoorlie), Kulin District High School, Mazenod College (Perth), Georgiana Malloy Anglican School (Busselton), St Mary Star of the Sea Catholic School (Carnarvon), and St Anne's Primary School (Harvey)

Dr M. SALMON was interviewed on television about the Australian Seismometers in Schools Project. Approximately 4 minute interview with Charlotte Hamlyn, ABC – 7:30 WA, broadcast at 7:30 pm 27 Sept.

Dr M. SALMON wrote articles about the AuSIS program in: Echo News 28/09/2013 – Mazenod College, Perth, Kalgoorlie Miner 24/9/2013, Pilbara Echo 18/9/2013, Port Lincoln Times 20/8/2013, Roxby Downs Sun 22/8/2013, The Murray Pioneer 27/8/2013, Northern Argus 4/9/2013, Riverine Herald, 16/05/2013.

Dr M. SALMON wrote a Preview article "The Australian Seismometers in Schools Network – Engaging students and communities in earth science around the nation", Issue 166, 31-32

Prof M. SAMBRIDGE gave presentations on seismology at Darwin High School and Nhulunbuy High school, NT during August and at Ulladulla High school, N.S.W. during September as part of the national outreach program Australian seismometers in Schools.

Prof M. SAMBRIDGE attended the Nhulunbuy Science fair in August to present on Seismology and geophysics.

Dr G. IAFFALDANO gave invited seminars at Monash University and Macquarie University.

Dr H TKALČIĆ was an invited faculty instructor in seismology for Incorporated Research Institutions For Seismology Advanced Studies Institute course held in January 2013 in Kuwait City, Kuwait.

Dr H TKALČIĆ gave an invited seminar at School of Earth and Space Exploration, Arizona State University, AZ, USA.

Dr H TKALČIĆ was a guest in SBS and ABC radio talk shows and his work on the Earth's inner core rotation featured on Croatian National Radio-Television, Canberra Times and other international and domestic newspapers.

Dr P. TREGONING was interviewed by MiningIQ (June 2013) and by LiveScience (23 May 2013) regarding continental-scale deformation of Australia caused by great earthquakes.

IODP

Prof N. EXON was an author of the 2012 Southwest Pacific IODP Workshop reports for Scientific Drilling and the IODP website.

Prof N. EXON has been involved in an outreach activity with consultant Grahame Cook, visiting key Government departments, both before and after the Federal election, to discuss IODP and its importance to them. Awareness of IODP is increasing.

Ms C. BEASLEY has played an important role in the planning of the Marine Geoscience Masterclass for 20 high quality undergraduate students from Australia and New Zealand, held in Perth in December, 2013, and funded by AIO. The Masterclass was hosted by CSIRO, the University of Western Australia, Curtin University, and the private company Advanced Geomechanics, and was regarded as a great success in enthusing students for this career possibility.

ANZIC contributed to Questacon's 'Deep Oceans' exhibit in 2013. During the JOIDES Resolution Expedition 341 on the Southern Alaskan Margin, Questacon hosted two sessions with high school groups, linking with 5 schools per session and a graduate group WISE (Women in Engineering and Science). Catherine noted that everyone she spoke to was interested in running this sort of activity again. In addition to the Questacon-hosted activities, New Zealand's Education Officer, Carol Larson presented Expedition 341 shipboard activities to New Zealand school and university students, plus a group from Rochedale High School in Brisbane.

Visiting Fellows

Mr R.V. Burne provided advice to the WA Department of Environment and Conservation, Parks and Visitor Services on the management and conservation of the Shark Bay World Heritage area and to FRAGYLE, Western Australia on the management and conservation of the RAMSAR listed Yalgorup Lakes National Park.

Mr R.V. Burne provided advice to the U.K. Nature Conservancy on the origin and development of the North Cornish coastline.

Dr K.A.W. CROOK is a member of the Board of Management of the Eden Killer Whale Museum, Eden NSW. During 2013 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 G. YOUNG, RSES.

Dr K. A. W. CROOK is a member of the Eden Foreshore Committee, in which

capacity he provides professional advice to Bega Valley Shire Council on coastal processes affecting foreshore management.

Emeritus Prof R.A. EGGLETON presented an Ockham's Razor talk on the ABC.

Emeritus Prof R.A. EGGLETON, Authorship of the section on climate change for the Australian Geography Curriculum Year 10. Cambridge University Press, in press.

Emeritus Prof R.A. EGGLETON gave a one hour talk about geology to Year 8 Science students at Canberra High School.

Dr E. TRUSWELL designed and presented a course of 6 lectures for U3A entitled Art and Science in the early exploration of Antarctica.

Dr E. TRUSWELL presented a public lecture at Kirstenbosch Botanic Gardens, Cape Town, South Africa in September 2013, relating geology and genetics in comparing the history of contemporary South African and Australian floras.

Dr E. TRUSWELL submitted an article on the distinctive gymnosperm *Welwitschia* (Gnetales), including its fossil record, to *Fronde*, the newsletter of the Australian National Botanic Gardens.

TEACHING ACTIVITIES

Earth Chemistry

Prof Y. AMELIN presented a lecture in the course PHYS8205: Nuclear Fuel Cycle.

Dr J.J. BROCKS, Convenor of EMSC3027: Palaeoclimatology, teaching the carbon cycle and the evolution of life and environment on early Earth.

Mr A. CHOPRA tutored PHYS 1201: Physics 2.

Prof T. R. IRELAND coordinates EMSC3022: Planetary Science and supports the EMSC3001 Field Camp held in Mt Isa.

Dr C.H. LINEWEAVER co-taught the course EMSC3022: Planetary Science and gave a guest Lecture on entropy as part of PHYS2020: Thermal and Statistical Physics.

Dr D. RUBATTO coordinated and co-taught the EMSC2015: Chemistry of Planet Earth.

Dr R. SALMERON taught MATH2306: Partial Differential Equations and Applications and PHYS2020: Thermal and Statistical Physics

Dr I.S. WILLIAMS gave 10 undergraduate lectures on isotope geochemistry as part of EMSC2015: Geochemistry of the Earth.

Dr I.S. WILLIAMS supervised undergraduate student Mr B. Young in his special research topic on constraining the age of Devonian fish and plant fossils.

Dr R. WOOD taught 2 lectures in ARCH1111: Archaeology: Finding treasure and history; 2 lectures in ARCH8032: Introduction to Archaeological Science; and 1 lecture in BIAN6510: Scientific Dating and Isotope Analysis for Archaeology and Anthropology.

Earth Environment

Dr N.J. ABRAM co-taught EMSC3027: Paleoclimatology and Climate Change.

Dr N.J. ABRAM gave guest lectures for the undergraduate courses EMSC1008: EARTH: The Chemistry and Physics of our Planet and EMSC2021: Climate System Science.

Dr M. DAVIES substitute lectured on trace fossils in EMSC2019: Geobiology and Evolution of Life on Earth, August 2013.

Prof P. De DECKKER taught the course EMSC2019: Geobiology and Evolution of Life on Earth and also ran a special seminar unit called 'Advanced Palaeontology' during which time he guided some 18 undergraduate students during a week-long excursion to numerous fossil sites and lakes in western Victoria and South Australia. During the excursion, he was assisted by Dr P. KING.

Dr S.M. EGGINS co-taught the 3rd year course EMSC3023: Marine Biogeochemistry, the 1st year course EMSC1006: Blue Planet with Dr P. KING and Prof R. GRIFFITHS and the Honours year short-course 'Quantitative Analysis in Research'.

Dr M.J. ELLWOOD coordinated and taught the third year course EMSC3023: Marine Biogeochemistry and taught the third year course EMSC3019: Coral Reef.

Dr M.K. Gagan delivered 12 lectures, 6 practicals and examined a 4-week section on palaeoclimatology for the course EMSC1008: EARTH: The Chemistry and Physics of our Planet.

Prof R. GRÜN taught a 6 unit course "Scientific dating techniques and isotope analysis for archaeology and palaeoanthropology" (BIAN 3010/6510) at the Department of Archaeology and Anthropology, ANU.

Dr D. HESLOP taught the course "Practical Statistics for Geoscientists" to Honours and Ph.D. students.

Ms A.K. KIMBROUGH, demonstrator for the paleoclimate section of the course EMSC 1008: EARTH: The Chemistry and Physics of our Planet.

Dr D.C. "Bear" McPHAIL convened and taught EMSC3025: Groundwater, 2nd semester and taught lectures and practical in EMSC2014: Sedimentology and Stratigraphy in the 1st semester.

Dr D.C. "Bear" McPHAIL coordinated the Minerals Tertiary Education Council Honours course, Regolith Geoscience and Mineral Exploration, held in April.

Dr B. N. OPDYKE taught EMSC2014: Sedimentology and Stratigraphy, the field components of EMSC2012: Introduction to Structural Geology and EMSC3019: Coral Reef field studies.

Prof B. PILLANS taught in ENVS3026: Geomorphology: landscape evolution under changing climate and EMSC3007: Economic Geology.

Prof E.J. ROHLING taught part of EMSC3027: Palaeoclimatology

Mr. N. SCROXTON demonstrated classes for EMSC2012: Introduction to Structural and Field Geology.

Dr J. YU taught EMSC3027: Palaeoclimatology.

Earth Materials & Processes

Prof R. ARCULUS taught part of EMSC3024: Magmatism and Metamorphism.

Dr A.J. BERRY convened and co-taught the course EMSC1008: Earth: the chemistry and physics of our Planet.

Dr A.J. BERRY facilitated the establishment of a geology undergraduate year abroad/exchange program between ANU and Imperial College London. The first student from Imperial started studying at ANU in second semester this year.

Prof I.H. Campbell co-ordinated and taught part of EMSC3007: Economic Geology.

Miss H.A. COCKER taught the lab component and gave two lectures of EMSC3007: Economic Geology.

Prof S.F. COX taught EMSC2012: Introduction to Structural and Field Geology, and EMSC3002: Structural Geology and Tectonics. He also contributed to a field trip for EMSC1008: The Chemistry and Physics of Our Planet and provided a series of lectures and a laboratory class for EMSC3007: Economic Geology.

Mr B.J. HANGER demonstrated for the course EMSC2017: Rocks and Minerals.

Dr J. HERMANN was convener of the course EMSC3024: Magmatism and Metamorphism and taught 18 hours of lectures, 20 hours of practicum and one day of excursion. He was also convener of the course EMSC3050: Special Topics in Earth Sciences and of EMSC3024: Field Geology and taught 11 full days of the field course.

Dr P. KING convened the course EMSC1006: The Blue Planet: An Introduction to Earth Systems Science. She also gave a guest lecture in the EMSC3022: Planetary Science course and had a minor role in co-convening the Honours course. She accompanied the Advanced Paleontology students on a 10-day field trip.

Dr P. KING led a successful ANU Vice Chancellor's Teaching Enhancement Grant: "Promoting deep learning in the cross-college introductory Earth Systems class using new online and research-led approaches: Creating a springboard for a future Office of Learning and Teaching grant application" by P. King & S. Eggins, (RSES), C. Fulton (RSB), & J. Lindesay & C. Fraser (FSES).

Dr P. King attended the 2nd Australian Geoscience Teaching Meeting in Townsville and presented a talk titled "Promoting deep learning in an introductory Earth Systems class at the Australian National University".

Prof G. LISTER assisted Prof S. COX in the course EMSC3002: Structural Geology and Tectonics.

Dr O NEBEL taught the Volcanic Hazard course as part of the Natural Hazard and Disaster Master program and the Crustal Formation course as part of the Nuclear Fuel Cycle Master program.

Prof H. O'NEILL gave part of the course EMSC2015: Chemistry of the Earth and Oceans.

Dr J.A. PADRON-NAVARTA taught 2 hours of lectures and 6 hours of practicum in the course EMSC3024: Magmatism and Metamorphism.

Dr G.M. YAXLEY taught the course EMSC2017: Rocks and Minerals and an EMSC3050: Individual Research Project.

Earth Physics

Prof P.R. CUMMINS delivered guest lectures in EMSC8707: Understanding Geological Hazards.

Prof P.R. CUMMINS delivered guest lectures in EMSC8706: Introduction to Natural Hazards.

Dr G. IAFFALDANO co-taught EMSC1008: EARTH: The Chemistry and Physics of our Planet, PHYS3070: Physics of the Earth and EMSC8016: Plate Tectonics and Mantle Dynamics.

Drs R.C. KERR, A.McC. HOGG and Prof R.W. GRIFFITHS taught the course PHYS3034: Physics of Fluid Flow.

Prof M.L. RODERICK, Drs A.McC. HOGG and S.M. DOWNES taught EMSC2021: Fundamentals of Climate System Science.

Prof M. SAMBRIDGE gave a guest lecture and tutorial on Geophysical inversion as part of the course PHYS3070: Physics of the Earth.

Dr E. SAYGIN delivered lectures on earthquakes in the Master of Natural Hazards & Disasters program.

Dr H TKALČIĆ coordinated and taught the course PHYS3070: Physics of the Earth.

Dr P. TREGONING was the Masters Convener at RSES.

HONOURS SUPERVISION

Honours Students (Geology)

* Mid Year start 2012/2013; # Mid Year start 2013/2014

Eloise Aitken#, (Prof D. Ellis & Dr S. Beavis), Surface water and groundwater of the Pambula floodplain.

William Bonney, (Prof B. Opdyke), Late Eocene climate dynamics from stable isotopes.

Sarah Buckerfield, (Prof S.F. Cox), Assessing hydraulic connectivity between the Walloon Coal Measures and Condamine Alluvium using geochemical data.

Diana Cato-Smith#, (Dr E. Papp), Electrical geophysical sand and gravel exploration at Lake George, New South Wales.

Wing Chan, (Dr S.M. Eggins), The effect of diurnal carbonate chemistry variability on coral calcification.

Andrew Clark, (Prof S.F. Cox), Vein formation at Endeavour 48 porphyry Cu-Au deposit, Eastern Australia.

Luke Cousins, (Dr M.D. Norman), The ages, chemical compositions and petrography of Apollo 11 lunar regolith glasses.

Kirsty Cummin#, (Dr P. King), Al-in-hornblende barometry of the I-type granites of the Bega Batholith, Lachlan Fold Belt.

John Daly#, (Dr D.C. "Bear" McPhail), The movement of water and solutes in upper lake sediments: Lake George, NSW.

Jessica Lowczak, (Prof I. Campbell), PGE geochemistry of the Forest Reef Volcanics, Cadia-Neville region, southeastern Australia: Implications for Cu-Au mineralization.

Alexander Moody, (Dr J. Mavrogenes, Prof R. Arculus & Dr R. Henley), Formation temperatures, sulfide and sulfate compositions of the Grasberg Cu-Au porphyry.

Jennifer Prichard, (Dr M.D. Norman), The geochemistry and geochronology of cassiterite from the New England orogeny.

Adam Rucinski-Stanek, (Prof J. Hermann), REE abundances in accessory minerals formed within subduction zones.

Anushka Sandanam, (Dr S.M. Eggins), pH regulation in the reef coral *Acropora formosa*: an in-vivo confocal fluorescence imaging study.

Gerhard Schoning* , (Dr D.C. "Bear" McPhail), Understanding inter-aquifer leakage processes in the Menindee Lakes area in far western NSW.

Morgan Williams, (Dr D. Rubatto), Exhumation of a crust-mantle contact: the geochemical record.

Hanling Yeow*, (Dr M. Honda), Geochemistry of diamonds and geochronology using the U/Th-He method.

Honours Physics of the Earth

Penelope Deacon (part time), (Dr G. Hughes), The effects of nonlinear mixing on the mechanical energy budget of a buoyant plume.

Emma Howard, (Dr A.McC. Hogg), Sources of momentum in the Southern Ocean.

Richard Skelton, (Prof I. Jackson), High pressure elasticity of omphacite from first principles simulations.

Masters Students

Master of Natural Hazards (7512)

Isabella Brom

Estelle Campbell

Sangay Chophel

Guillermo Cid Ortiz

Trevor Cox

Daniel Irawan

Gladys Le Masson

Anna Newton-Walters

Sharon Sarol
Florentino Sison
Vini Talai
Simon Walker
Ian Wirawan
Kiri Yapp

OTHER MATTERS

Earth Chemistry

Prof Y. AMELIN oversaw development of software and final stages of hardware upgrade of the MAT261 mass spectrometer. The instrument is now returned to regular usage.

Dr V.C. BENNETT served as the Secretary of the Volcanology, Geochemistry and Petrology (VGP) section of the American Geophysical Union and was the Fall AGU meeting organiser.

Dr V.C. BENNETT was on the Program Committee and was the Early Earth Theme Coordinator for the 2013 Goldschmidt Conference, Florence, Italy.

Dr V.C. BENNETT served as a member of the ANU Major Equipment Committee.

Dr J.J. BROCKS, Founding Member and Custodian of NECTAR, a group supporting early career academics at ANU.

Dr J.J. BROCKS, member of the Academic Steering Committee of the mass spectrometer facility at the Research School of Biology, ANU.

Dr J.J. BROCKS, Postgraduate Convenor (RSES).

Mr A. CHOPRA was invited to represent ANU at the Postgraduate & MBA Expo in Perth & Melbourne, September.

Dr C.H. LINEWEAVER is an elected member of the International Astronomical Union Commission 51 on Bioastronomy

Dr C.H. LINEWEAVER is a member of the NASA National Astrobiology Institute Focus Group on "Thermodynamics, Disequilibrium and Evolution".

Dr C.H. LINEWEAVER refereed a full proposal for the Chilean government's Iniciativa Científica Milenio (ICM) Science Nuclei competition and a \$4 million proposal for the Templeton Foundation.

Dr C.H. LINEWEAVER helped organise the National Institutes of Health, Physical Sciences and Oncology National Meeting, Arizona State University, USA and the Third Australian Exoplanet Conference, Swinburne University.

Dr C.H. LINEWEAVER moderated a panel discussion on the Origins of Cancer as part of the National Institutes of Health, Physical Sciences and Oncology National Meeting, Arizona State University, USA.

Dr D. RUBATTO, is the Australian representative on the Eclogite Conference Committee.

Dr R. SALMERON, Member of the National Committee for Astronomy (NCA) Decadal Plan Working Group, the Astronomy eResearch Advisory Committee, Astronomy Australia Ltd., the Giant Magellan Telescope Integral-Field Spectrograph (GMTIFS) Science Team, the Australian Mathematical Society and Astronomical Society of Australia (ASA) and the Inaugural Executive Committee, Astronomical Society of Australia Chapter on Women in Astronomy.

Dr R. SALMERON was a grant assessor for the Australian Research Council (ARC)

Ms K. M. STRZEPEK continued to contribute to the student run earth sciences blog: OnCirculation

Earth Environment

Dr N.J. ABRAM was a working group member of the PAGE Oceans2k synthesis project and a steering committee member of the PAGES Aus2k phase2 working group.

Prof P. De DECKKER is President of the scientific committee of the Grand Observatoire Observatoire du Pacifique Sud [GOPS] and is a member of the Lakes Advisory Committee for the Corangamite Shire Council in western Victoria.

Dr S.M. EGGINS served as a member of the board of the ANU Climate Change Institute and is an active member of the South Coast Marine Discovery Centre's research advisory network.

Dr M.J. ELLWOOD was involved with the 1st year enrolment desk for Science.

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. He also served on the ANZIC Science Steering Committee for the Australian Integrated Ocean Drilling Program (IODP) and is a member of the Australasian INTIMATE Project (INTegration of Ice, MARine and TERrestrial records of the Last Glacial Maximum and Termination), which is a core program of the INQUA Palaeoclimate Commission.

Dr D.C. "Bear" McPHAIL served as the ANU representative on the Steering

Committee of the Minerals Tertiary Education Council (Minerals Council of Australia) and as Student Liaison on the Lachlan Branch Committee of the Australian Institute of Mining and Metallurgy.

Dr M.D. NORMAN served on the Board of Directors of the Geochemical Society.

Dr B. N. OPDYKE organized a session for the 2013 Goldschmidt Conference held in Florence, Italy.

Prof B.J. PILLANS, Executive Committee, Geological Society of Australia, Co-Chair, Working Group on Lower/Middle Pleistocene Boundary, International Commission on Stratigraphy and Vice-Chair, Subcommission on Quaternary Stratigraphy, International Commission on Stratigraphy.

Prof E.J. ROHLING served on the coastal institute development and director appointment panel for Institute of Basic Science, S. Korea (Aug. 3-7)

Prof A.P. ROBERTS was a member of the JOIDES Resolution Facility Board, International Ocean Discovery Program (IODP) and was a Guest Professor at the Center for Advanced Marine Core Research, Kochi University, Japan

Earth Materials & Processes

Prof R. ARCULUS served as a member of the Steering Committee of the Marine National Facility, and the Proposal Evaluation Panel of the Integrated Ocean Drilling Program.

Dr A.J. BERRY, Chair of the X-ray Absorption Spectroscopy Beamline Advisory Panel, Australian Synchrotron.

Dr A.J. BERRY, Member of the X-ray Fluorescence Microscopy Beamline Advisory Panel, Australian Synchrotron.

Dr A.J. BERRY, Member of the User Advisory Committee, Australian Synchrotron.

Dr A.J. BERRY (with collaborators) was awarded beamtime at the Australian Synchrotron (4 awards, 12 days), Diamond Light Source, UK (4 awards, 13 days), and the European Synchrotron Radiation Facility, France (1 award, 6 days).

Prof I.H. CAMPBELL served as Secretary General of the Commission for the Evolution of the Solid Earth, a sub-commission of the International Mineralogical Association.

Miss H.A. COCKER completed the Principles of Tutoring and Demonstrating course (ANU Academic Professional Development Program).

Prof S.F. COX served on the organising committee for the conference of the Geological Society of Australia's Specialist Group in Tectonics and Structural Geology, to be held in Thredbo in February 2014.

Prof S.F. COX served on the Earth and Environmental Science advisory panel of the ACT year 11-12 Board of Studies.

Dr M. FORSTER is on the organizing committee for the 2014 Structural Geology and Tectonics Special Group Conference (SGTSG) to be held at Thredbo village.

Prof I. JACKSON served as Executive Committee member and 1st Vice-President, International Association for Seismology and Physics of the Earth's Interior.

Dr P. KING installed new equipment in the newly renovated infrared spectroscopy laboratory.

Prof G. LISTER is the Chair of the Specialist Group for Tectonics and Structural Geology of the Geological Society of Australia, organising the biannual meeting of the society in Thredbo in February 2014.

Prof H. O'NEILL is chair of the Specialist Group for Geochemistry, Mineralogy and Petrology (SGGMP) of the Geological Society of Australia.

Dr G.M. YAXLEY attended a Deep Carbon observatory meeting at the National Academy of Sciences, Washington DC in March and presented a poster. He also attended the CHIKYU+10 Integrated Ocean Drilling Program meeting in Tokyo in April as part of an Australian delegation.

Dr G.M. YAXLEY presented a RSES seminar on October 24, titled "Xenoliths, XANES and redox-related processes in the cratonic lithosphere".

Earth Physics

Prof P.R. CUMMINS served as secretary of the IASPEI/IAVCEI/IAPSO Joint Tsunami Commission.

Dr Y. DOSSMAN, Ms K. SNOW and Ms I. ROSSO attended the Scientific Writing Workshop run by the Centre of Excellence in Climate System Science, Melbourne, 2-4 October.

Prof R.W. GRIFFITHS served as a member of the Sectional Committee 4 for Earth, Ocean and Atmospheric Sciences, Australian Academy of Science.

Dr G. IAFFALDANO serves on the Early and Mid-Career Researcher Forum of the Australian Academy of Science.

Prof B.L.N. KENNETT is Director of ANSIR which continues as a National Research Facility in Earth Sounding, 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 2013 for broadband instruments in North Island, New Zealand and around

Bass Strait, and short-period experiments in NSW, Southern Queensland, and the Albany Fraser belt in Western Australia.

Prof B.L.N. KENNETT has resumed his earlier role as Coordinator of Earth Imaging for AuScope with responsibilities for both the Australian Geophysical Observing System (AGOS) and NCRIS.

Prof B.L.N. KENNETT, Chair National Committee for Earth Sciences and Chair of Working Party on National Geotransects; also Chief National Delegate to the International Union of Geological Science at the IGC Meeting in Brisbane in August.

Dr C. KLOOTWIJK ported 24 paleomagnetic processing and analysis programs from UNIX to PC. The programs represent the backbone of the PALSYS paleomagnetic/rockmagnetic data processing and analysis system of the former BMR/AGSO/GA paleomagnetism group. Included are a substantially rewritten version of DMAND, a powerful interactive graphics analysis program newly based on the DISLIN graphic environment, and an extensive application manual originally written by Dr J. Giddings of BMR/AGSO/GA and a former visiting fellow at the Department of Geology.

Dr M. SALMON, Coordinator for ANSIR portable seismic equipment.

Prof M. SAMBRIDGE was program leader for the AuScope-Australian Geophysical Observing System (AGOS) components, The inversion laboratory, and Australian Seismometers in Schools Education program.

Prof M. SAMBRIDGE served as IASPEI representative to the Committee on Mathematical Geophysics.

Prof M. SAMBRIDGE served as on the Executive board of AuScope – Australian Geophysical Observing system (AGOS) an organization for deploying national research infrastructure in the Earth Sciences.

Dr H TKALČIĆ is an academic manager of the Seismic and Infrasonic facility in Warramunga, Northern Territory.

Dr H TKALČIĆ is a coordinator for the PhB program in the Earth and Marine Sciences.

Dr P. TREGONING, National Delegate, International Association for Geodesy.

IODP

Prof R. ARCULUS and N. EXON took the lead in building a new ANU-led bid from the ANZIC group for an ARC/LIEF grant to cover Australia's membership of IODP in the five years from October 2013. The end result of this bid was the granting of all the funding requested, but only for two years (2014 and 2015). This means that another funding bid will be needed in 2015.

Prof N. EXON is one of the two geoscience representatives on the Technical Advisory Group set up by CSIRO to provide advice on the scientific equipment for the new Australian Research Vessel The Investigator, which is being built in Singapore and will be carrying out research in our waters in 2014.

Prof N. EXON is on the Board of the Australian Association for Maritime Affairs (AAMA), and was on its organising committee for an afternoon seminar – Ports and the Environment - held at the Exhibition Centre in Sydney in October. This brought together managers, industry representatives and marine scientists to discuss the problems faced at our major ports.

Prof N. EXON administered a number of ANZIC grants for post-cruise studies.

Prof N. EXON helped organize AAMA's afternoon seminar – Ports and the Environment - in Sydney in October.

Visiting Fellows

Dr E. TRUSWELL serves on the Council of the National Youth Science Forum (NYSF) which provides exposure to scientific research at national and international levels for some 450 Year 12 students each year.

Dr E. TRUSWELL served on the selection committee, Dorothy Hill Award, Australian Academy of Science.

Dr E. TRUSWELL serves on the Australian National Committee for the International Geoscience Co-operation program (IGCP) which is part of the UNESCO International Geosciences program.

Dr E. TRUSWELL serves on the committee of the Independent Scholars Association of Australia.