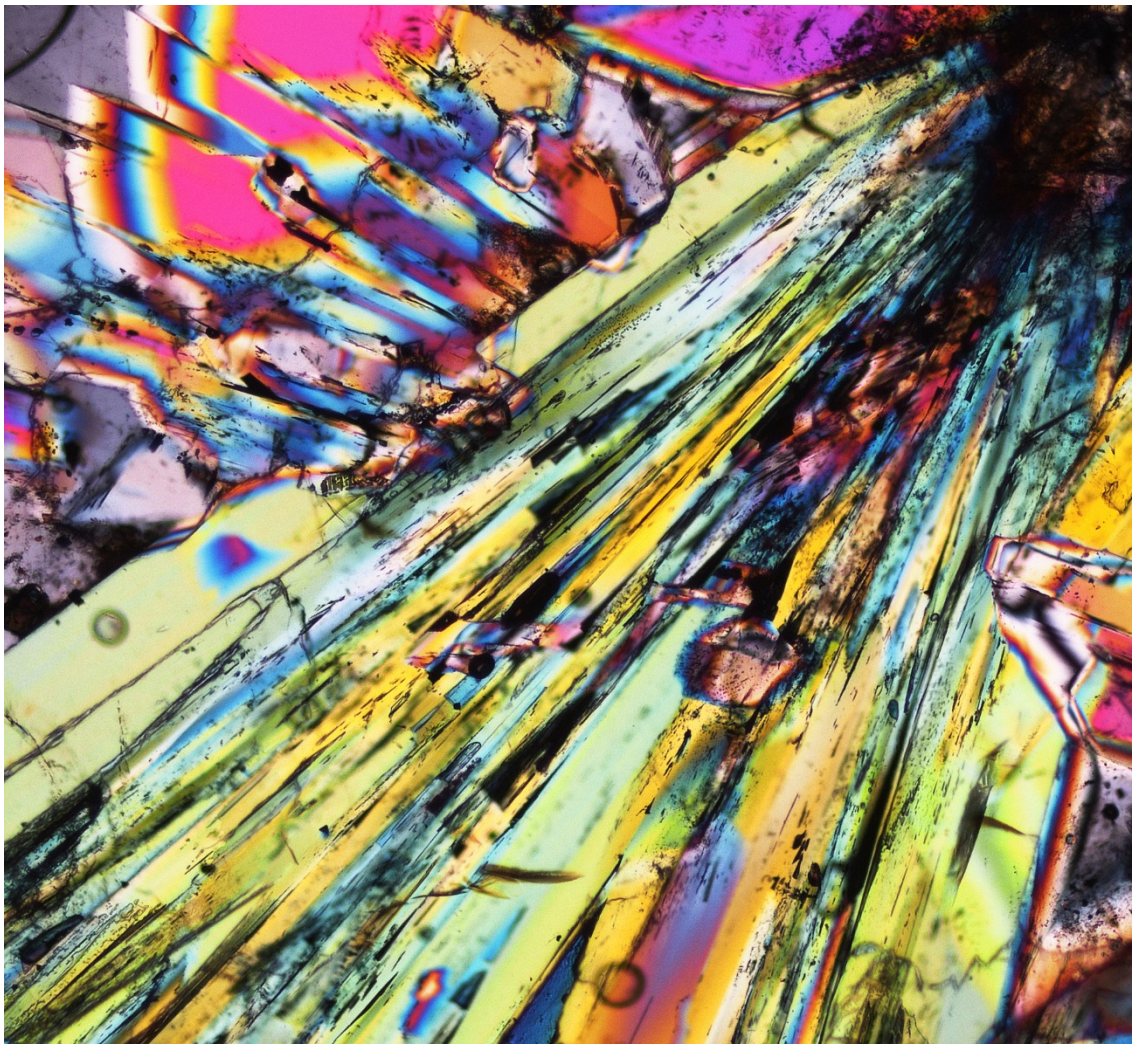
Research School of Earth Sciences Annual Report 2016



Polarised optical microscope image of a thick section of laumontite: a zeolite mineral from the Nolans Bore rare earth element ore deposit, Northern Territory. Photo Credit: Michael Anenburg

Australian National University

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DIRECTOR'S REVIEW OF 2016

2016 has been a year focused on capacity building. This began with a concerted effort to increase success in Commonwealth competitive grant funding schemes and followed with the launch of the School's "Frontier Research Theme" initiative to drive new areas of high impact research. A review of the School undergraduate education curriculum has also been ongoing throughout much of the year as have efforts to grow the new Masters of Earth Science (Advanced) program. At the same time the School has worked hard to create new professional development opportunities for both its academic and professional staff, and to implement a range of strategies to address equity issues and thereby enhance our ability to recruit and retain the best possible staff. A full review of the School was undertaken in late 2016 to gain an external assessment on the School's current performance and operations and to seek feedback on the planned future directions of the School.

This year saw a welcome return to higher success rates with Australian Research Council (ARC) funding, particularly the increase in funded ARC Discovery grants which underpin much of the School's fundamental research activities. This was topped off with the award of an ARC Future Fellowship to Associate Professor Nerilie Abram, ARC DECRA (early career) fellowships to Dr Adele Morrison, Dr Lauren Waszek and Dr Guilherme Mallmann, and the announcement of the 'renewal' ARC Centre of Excellence for *Climate System Science* with seven years funding of a new Centre of Excellence in 'Climate Extremes' beginning from 2017, among other successes.

The School welcomed two new hires in Seismology, Dr Caroline Eakin and Associate Professor Meghan Miller. These reflect a strong reinvestment by the School in seismology and a broadening and strengthening of its focus on plate boundaries and tectonics in and around the Australian region.

Multiple new "Frontier Research Themes" were spun up under the following banners

- 21st Century Resources
- Data Science
- Ice and climate
- C-cycle and mitigation
- Natural Hazards
- Planetary evolution and habitability

Each theme has been tasked with building research networks across and beyond the School as a basis for pursuing new research and funding opportunities that target some of the most significant challenges facing the geosciences. These themes build on the success of the frontier research "Climate Extremes". Both the "21st Century Resources" and "Ice and Climate" hosted national symposia in the School in late 2016 that invited researchers from academia, government and industry. These symposia and other activities in these and other 'Frontier Research Themes' have lead to a number of new initiatives and submissions for grant funding, and are creating significant new multidisciplinary research opportunities around existing research strengths of the School.

Research highlights for the year were many and include among other high profile publications and developments:

Humans have caused climate change for 180 years

The international PAGES 2k Consortium synthesis of palaeoclimate records spanning the last 500 years, led by RSES researcher Dr Nerilie Abram, revealed human activity has been causing global warming for the past 180 years and human-induced climate change is not just a 20th century phenomenon. This research revealed warming during the early stages of the Industrial Revolution that is detectable in the Arctic and tropical oceans from the 1830s. This was much earlier than anticipated, and has implications for assessing the extent that humans and greenhouse gas emissions have caused the climate to move away from its pre-industrial state.

Life thriving on early Earth

The discovery of 3.7 billion year old fossil stromatolites (mounds of carbonate constructed by communities of microbes) by Associate Professor Vickie Bennett in collaboration with University of Wollongong researchers. This finding provides evidence of life on Earth very early in our planet's history and predates the previously oldest known fossils by 220 million years. It indicates diverse microbial life had emerged and was thriving within the first few hundred million years of Earth's existence, in keeping with biologists' predictions surrounding the great antiquity of life's genetic code. Moreover, the results show that in addition to life existing as single cells for much of Earth's history, it had also rapidly organised into complex communities and ecosystems.

Consortium for Ocean-Sea Ice Modelling in Australia (COSIMA)

ANU researchers led the establishment of the Consortium for Ocean-Sea Ice Modelling in Australia (COSIMA), a partnership with the Bureau of Meteorology and CSIRO. The consortium has capitalised on rapid development of ANU expertise in ocean modelling, enabled by strategic appointments at RSES and the resources provided by ANU investment in the National Computational Infrastructure. This investment has created the capacity to develop ultra-high resolution global ocean model configurations and software that will underpin Australian ocean modelling efforts into the future. The large scale and complexity of the computational model development is equivalent to the major physical research infrastructure, and will underpin Australian oceanographic research and ocean forecasting (of the circulation, waves and sea ice) in the coming decades. Improved ocean models are vital for accurate ocean forecasting, climate prediction and research into ocean circulation.

A number of RSES academics were awarded significant national and international honours during the year. These include the prestigious Ganesha Widya Jasa Adiutama Award of the Bandung Institute of Technology in Indonesia to Professor Phil Cummins, the Australian Academy of Science's Jaeger Medal to Emeritus Professor Ross Griffiths, the Priestley Medal of the Australian Meteorological and Oceanographic Society to

Associate Professor Andy Hogg, and Professor Trevor Ireland's election to Fellow of the American Geophysical Union, among others.

The School graduated fourteen PhD students and two MPhil students, in addition to thirteen Honours (4th year) students. PhD candidate Kathryn Hayward is congratulated for being awarded an Australian Bicentennial Scholarship by the Australian Bicentennial Scholarships and Fellowships Trust of King's College, London. Two of the School's graduating Honours students, Aero LePlastrier and Ellen Cliff, were awarded University Medals for their outstanding achievements, and Ellen Cliff has been subsequently awarded a Rhodes Scholarship.

A major review of the School's Education program has been stewarded by Associate Professor David Heslop has been ongoing through 2016. It has identified key weakness in the existing program and proposed a new structure that develops clearer pathways for students through three majors focused around the research strengths of the School in geophysics, geology and geochemistry, and environmental and climate science. Effort will continue in 2017 to design and implement the new curriculum.

In late 2016 the School was subject to a full review of its research, education, research training, governance, and research and administrative support. The preliminary report received from the review committee, chaired by Professor Janet Hergt of the University of Melbourne, identified a range of achievements and strengths of the School and pinpointed key areas in need of development to better position the School for future success. The School is looking forward to taking on the challenges and aligning and shaping a new vision and mission around that of the University as outlined by Vice Chancellor Professor Brian Schmidt.

The research, education, research training, and engagement activities of the School have been ably supported by the commitment and expertise of its professional staff. These staff along with all the students and academic staff of the School are thanked for their dedication to the School, its excellence and our shared success.

STAFF AND STUDENT LISTS

ACADEMIC STAFF

Director

S.M. Eggins, BSc UNSW, PhD Tasmania

Associate Directors

Geochemistry	G.M. Yaxley, BSc PhD Tasmania
Geophysics	P. Tregoning, BSurv PhD UNSW
Ocean and Climate Geoscience	E. Rohling, BSc, MSc, PhD Utrecht
Higher Degree Research	J.J. Brocks, Dip Freiburg, PhD Sydney
Education	D. Heslop, BSc Durham, PhD Liverpool, Dr habil. Bremen
Special Projects	V.C. Bennett, BSc PhD UCLA

Distinguished Professors

B.L.N. Kennett, MA PhD ScD Cambridge, FAA, FRS (to 6/05/2016)

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

Professors

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

S.F. Cox, BSc Tasmania, PhD Monash

P.R. Cummins, BA Physics, PhD UC Berkeley

S.M. Eggins, BSc UNSW, PhD Tasmania

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

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 (Wellington)

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

E. Rohling, BSc, MSc, PhD Utrecht

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

I.S. Williams, BSc PhD ANU

Senior Fellows

N.J. Abram, BSC Advanced (Hons) Sydney, PhD ANU

Y. Amelin, MSc PhD Leningrad State

R.A. Armstrong, BSc MSc Natal, PhD Witwatersrand (to 18/11/16)

V.C. Bennett, BSc PhD UCLA

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

J.J. Brocks, Dip Freiburg, PhD Sydney

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

C.M. Fanning, BSc Adelaide (to 4/11/16)

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

D.C. Heslop, BSc Durham, PhD Liverpool, Dr habil Bremen

A.M. Hogg, BSc ANU, PhD UWA

M. Honda, MSc PhD Tokyo

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

P.L. King, BSc (Hons) ANU, PhD Arizona State

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

S.C. McClusky, BSurv PhD NSW

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

P. Tregoning, BSurv PhD UNSW

G.M. Yaxley, BSc PhD Tasmania

Fellows

D.R. Davies, MSc PhD Cardiff, UK

S.J. Fallon, BA MS San Diego, PhD ANU

M.A. Forster, BSc MSc PhD Monash

M.A. Kendrick, BSc Edinburgh, PhD Manchester

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

A. Valentine, BA MSc Cambridge, DPhil Oxford

J. Yu, BSc MSc Nanjing University, PhD Cambridge

Research Fellows

J. Avila, BSc MSc UFRGS, PhD ANU

N. Balfour, BSc (Hons) MSc Victoria (Wellington), PhD Victoria (Canada) (to 29/01/2016)

O. Branson, BSc (Hons) Bristol, MSc Southampton, PhD Cambridge (from 20/09/2016)

A. Burnham, MSci MA Cambridge, PhD Imperial College London

J. Dettmer, Dipl. Geophys. Hamburg, PhD Victoria (Canada) (to 24/08/2016)

C. Eakin, MSc Imperial College London, PhD Yale (from 20/06/2016)

B. Gayen, PhD UC San Diego, USA

P. Hu, PhD ANU & Chinese Academy of Sciences (to 24/12/2016)

C. Le Losq, MSc, PhD IPGP, France

S. Lewis, PhD ANU (to 30/01/2016)

G. Mallmann, BSc MSc UFRGS, Brazil, PhD ANU

J. Pownall, MEarthSci Oxford, PhD Royal Holloway University of London

A. Purcell, BSc (Hons), PhD ANU

E. Saygin, BEng Istanbul Technical, PhD ANU (to 1/02/2016)

C. Shakespeare, B.Sc (Hons) ANU, PhD Cambridge

K. Stewart, PhD ANU

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

Postdoctoral Fellows

S. Allgeyer, PhD Paris Diderot, France

E. David, BSc, MSc École Normale Supérieure, Paris, PhD Imperial College London (to 10/01/2016)

K. Grant, BSc Southampton, MSc JCU, PhD Southampton

B. Hejrani, BSc Kurdistan, MSc Tehran, PhD Aarhus, Denmark

F. Hibbert, PhD St Andrews, UK

S. Kim, BSc, MSc, PhD Seoul National

A. Koulali, PhD Rabat Agdal, Morocco

C. Krause, BSc (Hons) Macquarie (to 9/01/2016)

J. Mallela, BSc(Hons) Leeds, MSc Heriot-Watt, PhD West Indies

G. Marino, MSc (cum laude) 'Federico II' of Naples; PhD Utrecht

J. Pfeffer, MSc Joseph Fourier, Grenoble, France, PhD Strasbourg (from 4/10/2016)

C. Sippl, Dipl.-Geophys. Munich, PhD FU Berlin (to 10/09/2016)

P. Tollan, MSci Bristol, PhD Durham (to 16/08/2016)

D. Yin, PhD Tsinghua, Beijing (from 4/10/2016)

Emeritus Academics

R.J. Arculus, BSc PhD Durham, FAIMM

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. DeDeckker, BA MSc (Hons) Macquarie, PhD DSc Adelaide

R.A. Eggleton, BSc (Hons) Adelaide, PhD Wisconsin, DSc Adelaide

D.J. Ellis, MSc Melbourne, PhD Tasmania

J.D. Fitzgerald, BSc James Cook, PhD Monash

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

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

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

B.L.N. Kennett, MA PhD ScD Cambridge, FAA, FRS (from 7/05/2016)

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

I. McDougall, BSc Tasmania, PhD ANU, FAA

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

M.D. Norman, MSc Tennessee, PhD Rice

M.S. Paterson, BSc Adelaide, PhD Cambridge, FAA

R.W.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

Honorary Academics

R.A. Armstrong, BSc MSc Natal, PhD Witwatersrand (from 19/11/16)

C.M. Fanning, BSc Adelaide (from 5/11/16)

A. Gerson, PhD Strathclyde, Scotland (from 1/02/2016)

Visiting Fellows

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

L. Bean, BSc Sydney, DipEd Sydney Teachers College, GradDip ANU

R.V. Burne, BSc Wales, D.Phil Oxford

L. Chang, BSc Peking, PhD Southampton

G.F. Davies, MSc Monash, PhD CalTech

P. de Caritat, PhD ANU

F.R. Fontaine, DEUG (Hons) Reunion, MSc PhD Montellier II

J. Foster, BSc Sydney, MSc, PhD ANU

G.M. Gibson, BSc Edinburgh, PhD Otago

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

R. Henley, BSc (Hons) London, PhD Manchester

A.L. Jacques, BSc (Hons) Western Australia, PhD Tasmania

P.J. Jones, BSc. London, MSc. ANU, PhD London

F.E.M. Lilley, BSc (Hons) Sydney, MSc, PhD University of Western Ontario

P. Liu, PhD Chinese Academy of Sciences (to 14/08/2016)

Q. Liu, PhD Chinese Academy of Sciences (to 29/02/2016)

T.P. Mernagh, PhD Newcastle

B. Montaron, PhD Pierre et Marie Curie, France (from 23/05/2016)

J. Rogers, BSc. UK, BA ANU, BSc (Hons) ANU, PhD ANU

D.L. Strusz, B.Sc (Hons), PhD Sydney

E. Truswell, BSc (Hons) Western Australia, PhD Cambridge

PROFESSIONAL STAFF

School Manager

G.F.M. Pearson, BA, BTh, MBA, FAIM

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

D. Pradhan, (to 25/5/2016)

Philanthropic Development Manager

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

PRISE Business Officer and School Projects Officer (to 4/11/2016)

Senior Administration Officer (from 5/11/2016)

B.J. Armstrong, BSc UNISA (South Africa)

Building and Facilities Officer

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

Receptionist

T. Asher

Student Administrator HDR

M. Coldrick

Student Administrator Coursework and Honours

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

Cluster Administrators

M. Hapel - Geophysics

J. Magro – Geochemistry

R. Petch – Ocean and Climate Geoscience

IODP Administrator

C. Beasley

Electronics Group Manager

A. Latimore, BEng University of Canberra

Electronics Group

D. Cassar, AdvDipEng CIT

D. Cummins, AdvDipEng CIT

T. Redman, AssocDip(Elect Eng) CIT

H. Sasaki, AssocDip CIT

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)

C. Were, AdDipMechEng CIT, Cert III Engineering (Mechanical) Trade

G. Woodward, Cert-Fitting and Machining Trade

School Laboratory Manager

J. Cali, BAppSc QIT

Research Officers

A. Arcidiaco, BAppSc GradDip SAInst

J. Byrne, BSc (Hons) ANU, PhD Monash

A. Heerdegen, BSc (Hons) Massey, PhD ANU

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 Rensselar Polytechnic Institute

L. Rodriguez Sanz, BSc Venezuela, MEnvStudies, PhD Autonomous (Barcelona)

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

Research Assistants

B. Kallenberg, (to 7/12/2016)

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

Technical Officers

D. Clark, Cert III Metal Fabrication AdvDipEng CIT

J. Cowley, BSc ANU

R. Esmay

B. Fu, BSc Chungchun, MSc Nanjing, PhD Vrije

H. Gao, BSc Wuhan University, MSc Zhongshan University (to 4/11/2016)

J. Hope, BSc JCUNQ

L. Kinsley, BSc GradDipSc ANU

H. Kokkonen, Certificate in Lapidary ACT TAFE, BAppSc Canberra College of Advanced Education

P. Lanc

Q. Li, BEng Beingjing Electronic Science and Technology Institute, MEng UNISA

L. McMorrow, AssocDipSc NTU

H. Miller, AdDipMechEng CIT

G. Nash, BSc Hons ANU

S. Paxton, AssocDip AppliedGeoscience CIT , FGAA

A. Purelli, (from 20/04/2015)

S. Rayapaty, BEng Jawaharlal Nehru Technological University, MIT University of Canberra

A. Rummery

D. Scott, AssocDipMechEng CIT

H. Scott-Gagan, BSc Sydney

D. Thomson, Cert-Fitting and Machining Trade

B. Tranter, Cert II Auto Radiator Services John Batman Institute TAFE, Auto Climate Control/Air conditioning Casey Institute of TAFE (to 10/03/2016)

U. Troitzsch, Diplom Technische Universität Darmstadt, PhD ANU

D. Vasegh, AssocDeg Khajeh Nasireddin Toosi University of Technology (Iran)

X. Zhang, PhD LaTrobe

X. Zhao, BSc Jilin University, PhD Southampton

S. Zink, BSc Hanover, Diploma(MSc) Hanover

POST-GRADUATE STUDENTS

PhD Candidates

Amies, Jessica
Andrew, Sarah
Anenburg, Michael
Bean, Lynne
Bobrovskiy, Ilya
Bruisten, Benjamin
Carr, Patrick
Castillo Gonzalez, Paula
Chen, Bei
Chen, Mimi
Chopping, Richard
Cipta, Athanasius
Cline II, Christopher
Cocker, Helen
Connolly, Clare
Crisp, Laura
Dai, Yuhao
De Leon, Andrea
Ducommun-Dit-Verron, Joelle
Ellis, Bethany
Emetc, Veronika
Eriks, Nicole
Fang, Fang
Farmer, Nicholas
Gauthiez-Putallaz, Laure
Gibson, Angus
Goodarzi, Patrick
Gray, Sharon
Haber, Thomas
Hao, Hongda
Harazin, Kathleen
Hawkins, Rhys
Haynes, Marcus
Hayward, Kathryn
Holland, Katherine
Hu, Yuzhi Daisy
James, Hannah
Johnson, Emma
Jones, Timothy
Kallenberg, Bianca
Kimbrough, Alena
Kirby, Rachel
Koefoed, Piers
Koudashev, Oleg
Lakey, Shayne
Liu, Li
Loiselle, Liane
Long, Kelsie
Lowczak, Jessica
Manceau, Rose
Mare, Eleanor
Martin, Hayden
Masoumi, Salim
McConachie, Shannon
McConnochie, Craig
Miller, Laura
Mondal, Mainak
Mustac, Marija
Naguit, Muriel
Nand, Vikashni
Nash, Graham
O'Neill, Cameron
Owens, Ryan
Pejic, Tanja
Penny, Tiah
Pham, Thanh Son
Pranantyo, Ignatius Ryan
Prichard, Jennifer
Qian, Yao
Rajabi, Sareh
Renggli, Christian
Samanta, Moneesha
Schoneveld, Louise
Scicchitano ,Maria
Sebastian, Nita
Short, Michael
Sieber, Melanie
Skelton, Richard
Smith, Tegan
Sommer, Johanna
Stephenson, Joanne
Stone, Laura
Tambiah, Charles
Tian, Siyuan
Timmerman, Suzette
Tolley, James
Tyler, Perinne
Tynan, Sarah
Valetich, Matthew
Vreugdenhil ,Catherine
Ward, Josephine
Whan, Tarun
Williams, Morgan
Wu, Jiade
Wurtzel, Jennifer
Zannat, Umma Jamila
Zhou, Yifei

Brenner, Alan (withdrew September 2016)
David, Anthony (withdrew May 2016)
Doull, Matthew Jason (discontinued February 2016)
Papuc, Andreea (discontinued September 2016)
Stott, Rachel (withdrew January 2016)

MPhil Candidates

Baeza, Leonardo
Sohail, Taimoor
Leonard, Yosafat
Thorne, Jane (withdrew September 2016)

Master of Earth Sciences (Advanced)

Chen, Xiaoyu
Flanigan, Michaela
Hurt, Lynton (completed)
Joshi, Niranjan (completed)
Liyanage, Tharika (completed)
Merriman, Prudence
Shi, Lin
Singh, Dylan (completed)
Tuveng, Karina
Yin, Fan
Zhang, Xinyue (completed)

UNDERGRADUATE EDUCATION

Honours completions

Thirteen students completed Honours in 2016.

Earth & Marine Science Program

Semester 1	Course description	Convenor, Teaching staff	Number of students
EMSC1006/4006/6107	Blue Planet	**P. King, N.Engerer (FSES)**, S. Eggins, J.Lindesay (FSES), S. Haberle (SCHL)	122
EMSC2012/4012/6031	Introduction to Structural & Field Geology	**S. Cox,** K.Hayward	16
EMSC2014/4014/6014	Sedimentology & Stratigraphy	**B. Opdyke**	36
EMSC2017/2017/6017	Rocks and Minerals	**G. Yaxley**	27
EMSC3002/4002/6030	Structural Geology & Tectonics	**S. Cox**	14
EMSC3023/4023/6023	Marine Biogeochemistry	**M. Ellwood, S. Eggins,** S. Fallon	24
EMSC3024/4024/6024	Magmatism & Metamorphism	**G. Lister,** B. Hanger	16
EMSC3032/4032/6032	Melting Polar Ice Sheets	**P. Tregoning**	17

EMSC4706/8706	Natural Hazards	**P. Cummins**	21
Winter			
EMSC3001	Field Geology	**K. Hayward**	7
Semester 2			
EMSC1008	Earth	**A. Berry,** M. Gagan, C. Eakin	64
EMSC2015/4015/6015	Chemistry of the Earth	**I. Williams,** M. Kendrick	24
EMSC2019/4019/6019	Geobiology	**J. Brocks,** L.Bean	35
EMSC2021/4021/6021	Climate System Science	**A. Hogg,** M. Roderick	33
EMSC3007	Economic Geology	**J. Mavrogenes**	12
EMSC3022	Planetary Science	**C. Lineweaver,** T. Ireland	49
EMSC3025/4025/6025	Groundwater	**B. Hanger**	34
EMSC3027/4027/6027	Palaeoclimatology	**J. Yu,** G. Marino, N. Abram, E. Rohling	19
Spring			
EMSC3019	Coral Reef Field Studies	**M. Ellwood,** S. Fallon, J. Mallela	21
Special topics	Research project (6 units)	N. Abram, J. Brocks, S. Cox, S. Fallon, M. Forster, P. King, C. Lineweaver, G. Lister, J. Mavrogenes, S. McClusky, B. Pillans, P. Tregoning, I. Williams, G. Yaxley	13

Physics Program

	Course description	Convenor, Teaching staff	Number of students
PHYS3034/4034	Physics of Fluid Flows	**R. Kerr,** A.Hogg, B. Gayen, K. Stewart	20
PHYS3070	Physics of the Earth	**H.Tkalčić,** D.R. Davies	14

Archaeology Program

	Course description	Convenor, Teaching staff	Number of students
ARCH1111	Archaeology Uncovered	**D. Wright (RSHA),** incl. R. Wood	50
ARCH8032	Introduction to Archaeological Science	**P. Piper (RSHA),** incl. R. Wood	10

Fenner School of Society & Environment Program

	Course description	Convenor, Teaching staff	Number of students
ENVS3026	Geomorphology: Landscape evolution under changing climate	**J. Field (FSES),** B. Pillans	15

THESES AND AWARDS

PhD theses completed (Supervisor in parentheses)

Benavente, Roberto "Rapid finite fault inversion for megathrust earthquakes" (Phil Cummins)

Gueneli, Nur "Late Mesoproterozoic microbial communities" (Jochen Brocks)

Hoffmann, Janosch Fabian "Ice height change in east Antarctica derived from satellite laser altimetry" (Paul Tregoning)

Jollands, Michael "Experimental studies of diffusion in olivine" (Joerg Hermann)

Krause, Claire "Reconstructing the Australasian monsoon over the last 40,000 years using speleothems and palaeoclimate modelling" (Michael Gagan)

Li, Yang "A broadband laboratory study of the seismic properties of cracked and fluid-saturated synthetic glass materials" (Ian Jackson)

McAlpine, Sarlae "A petrological study of peridotite & pyroxenite xenoliths from the West Bismarck Arc and the Tabar-Lihir-Tanga-Feni Arc, Papua New Guinea" (Richard Arculus)

Meyerink, Scott "Effects of iron limitation on silicon metabolism and silicon isotopic discrimination in Southern Ocean diatoms" (Michael Ellwood)

Moore, Michael "Empirical modelling of site-specific errors in GPS observations" (Simon McClusky)

O'Kane, Tomas "4D tectonic reconstruction" (Gordon Lister)

Sapah, Marian "Characterization and chronology of refractory inclusions (CAIs) in the CV3 chondrite NWA 4502" (Trevor Ireland)

Snow, Kate "Antarctic bottom waters response to varying surface fluxes" (Andrew Hogg)

Vasilyev, Prokopiy "The oxidation state of deeply subducted, altered oceanic crust: an experimental study and the evidence from natural samples" (Gregory Yaxley)

Willmes, Malte "Strontium isotope tracing of prehistoric human mobility in France" (Rainer Grün)

MPhil thesis completed (Supervisor in parentheses)

Burne, Robert The role and significance of authigenic magnesium silicates in the organomineralisation of microbialites in the Yalgorup Lakes, Western Australia (Michael Gagan)

Higgins, Andrew Consequences of sulfate reduction in floodplain wetlands (Sara Beavis)

STAFF HONOURS & AWARDS

NAME	AWARD	AWARDING BODY
A/Prof. V.C. Bennett	Plenary Speaker, Goldschmidt Conference, Yokohama, Japan	Geochemical Society
Prof. P.R. Cummins	Ganesha Widya Jasa Adiutama Award	Bandung Institute of Technology (Indonesia)
Em. Prof. R.W. Griffiths	Visiting Professorship award	INPG, Universite Grenoble-Alpe, France
	Jaeger Medal	Australian Academy of Science
A/Prof. A. Hogg	Priestley Medal	Australian Meteorological and Oceanographic Society
Prof. T.R. Ireland	Fellow	American Geophysical Union
A/Prof. P.L. King	NASA Group Award to the MSL (Mars Science Laboratory) APXS (alpha particle X-ray spectrometer) Instrument Development and Science Team	NASA
Prof. B. Pillans	Fellow	Geological Society of Australia
Dr C. Shakespeare	Keith Runcorn thesis prize, Runner Up	Royal Astronomical Society
A/Prof. H. Tkalčić	Excellence in Research Achievement Award	AuScope
Dr A. Valentine	'Outstanding Reviewer' citation	Geophysical Journal International/Oxford University Press
Dr R. Wood	ECR women in research citation award for Archaeological Science	Clarivate Analytics (formerly the Intellectual Property & Science business of Thomson Reuters)
Dr Lesley Wyborn	Fellow	Geological Society of America

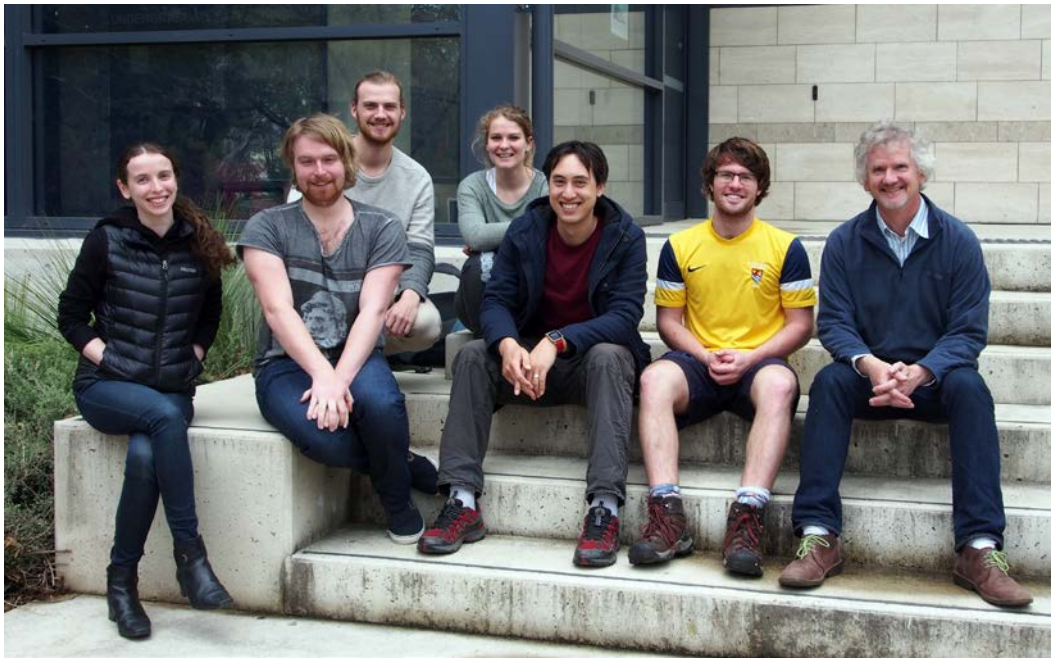
STUDENT HONOURS & AWARDS

Higher Degree Research

Allan White Scholarship	Laura Miller
DA Brown Travel Fellowship	Siyuan Tian
Jaeger Scholarship	Kathryn Hayward
Mervyn & Katalin Paterson Fellowship	Melanie Sieber
Ringwood Scholarship	Suzette Timmermann
Sue Kesson Scholarship	Laura Crisp
Australian Bicentennial Scholarship, awarded by the Australian Bicentennial Fellowships Trust, King's College, London	Kathryn Hayward

Coursework

A L Hales Honours Scholarship	Manon Dalaison
ARC Centre of Excellence Climate System Science Scholarship	Max Rintoul (RSES) and Joss Kirk (FSES)
Scholarship in Regolith Science	Zach Lamont (FSES)
ANU University Medal	Ellen Cliff and Aero Leplastrier
Victorian Space Science Education Centre: Australian Space Science Prize for best Honours thesis in Geology and Planetary Geology	Shannon McConachie



Some of our 2016 Honours students with Honours convenor Bradley Opdyke.
Photo credit: Bradley Pillans

RESEARCH ACTIVITIES

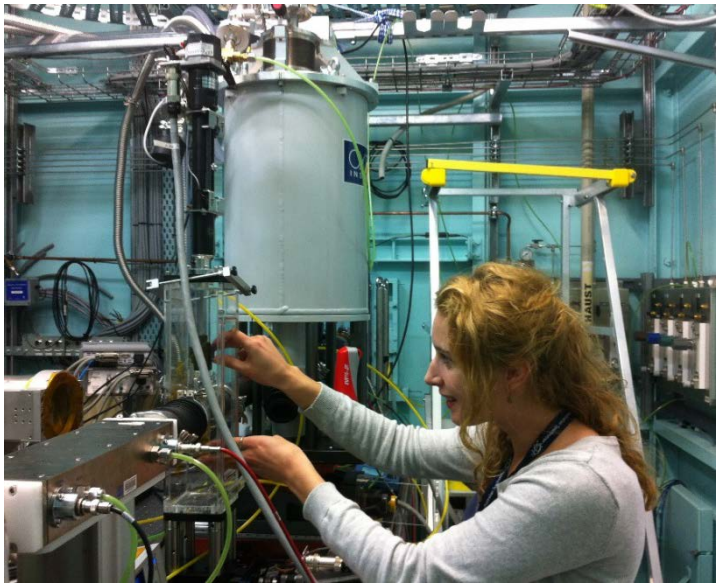
EXPERIMENTAL PETROLOGY

Group leader: Andrew Berry

In 2016 the Experimental Petrology group comprised four members of continuing academic staff (Andrew Berry, John Mavrogenes, Hugh O'Neill, and Gregory Yaxley), three postdoctoral fellows (Antony Burnham, Charles Le Losq, and Guil Mallmann), three technical staff, and 23 PhD students. We welcomed the arrival of Guil Mallmann (ARC DECRA) and two new PhD students, Laura Miller, working on the "Geochemical behaviour of As and Sb during planetary differentiation" and Nick Farmer, studying the "Mechanisms of H substitution in orthopyroxene and clinopyroxene and their influence on mantle melting", both of whom completed their undergraduate degrees at Imperial College London. We said goodbye to Prokopiy Vasilyev, who was awarded a PhD on an "Experimental study of the fate of subducted carbon" and moved to a postdoctoral position at Curtin University.

Two new piston-cylinders, that were constructed entirely in-house, have been commissioned and two more are nearing completion. These devices allow both temperature and pressure to be programmed and computer controlled. This expands the number of operational piston-cylinders in the group to nine. We have also placed an order for a JEOL JXA-8530F HyperProbe (funded by a LIEF grant in 2015) to replace our ageing Cameca SX100. The new microprobe, which has a field-emission electron gun, will arrive in 2017 and will provide superior spatial resolution to a conventional instrument.

We were awarded two new ARC Discovery Grants in 2016: $315,000 to Andrew Berry (with Ian Campbell) on "The copper-gold fertility of mountain belts" and $476,000 to Hugh O'Neill (with Richard Arculus) on "Melting in the Earth and the origin of basalts". Hugh O'Neill and Andrew Berry also continued to be supported by ARC Laureate and Future Fellowships, respectively. The group was also successful with the award of beamtime for three experiments at the Australian Synchrotron ("Coordination and valence state of Ge and Ga in silicate glasses quenched from high pressure melts", "In situ XANES of U and Th in silicate liquids at high pressure and temperature", and "The high temperature geochemistry of Antimony") and two experiments at the Advanced Photon Source, USA ("The effect of pressure on the Ti-in-zircon geothermometer", and "The redox state of pre-shield stage magmas at Hawaii").



PhD student Laura Miller at the Australian Synchrotron.

The research highlight of the year was a 45 page monograph by Hugh O'Neill on a new approach for the parameterisation of REE patterns (The smoothness and shapes of chondrite-normalised rare earth element patterns in basalts, Journal of Petrology, 57, 1463-1508).

A new initiative for the group is applied research in the areas of critical metals and mine tailings. To facilitate this activity and foster links with industry RSES has appointed Andrea Gerson, formerly of the University of South Australia, as an Honorary Professor. We are heavily involved in the Resources "Frontier Theme" of RSES and the organisation of a symposium on "21st Century Resources" (http://tectonics.anu.edu.au/21stCentury/24Nov.php).

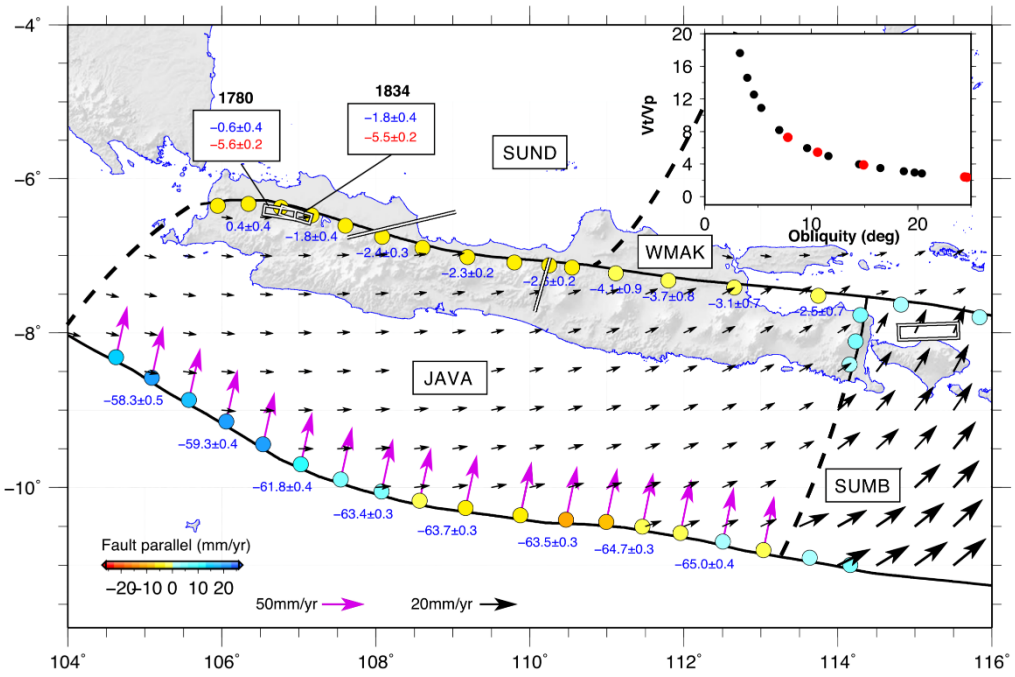
GEODESY AND GEODYNAMICS GROUP

Group leader: Paul Tregoning

In 2016 research in the Geodesy and Geodynamics Group has included studies of a diverse range of geophysical processes including changes to sea level, the Antarctic Ice Sheet, crustal deformation in Indonesia and modelling of Earth's gravity field.

Several advances in glacial isostatic adjustment (GIA) modelling occurred during 2016. A critical assessment of the ICE6G_C model by Peltier et al. (2015) was published by Purcell et al. (2016), and has exposed some of the flaws in the modelling approach adopted by the former group. In particular, the GIA modelling in the Antarctic seas using ICE6G_C over-estimates the present-day uplift rates, meaning that present-day mass loss rates may be larger than previously thought. Lambeck et al. (2016) completed a very detailed assessment of relative sea level indicators to derive a new ice sheet model for North America.

Crustal deformation studies focused on Indonesia in 2016, with results of GPS fieldwork identifying the locations of active faults in East Indonesia (Koulali et al., 2016a). Perhaps the most significant finding was the active slip found on a fault in East Java, quantified to be slipping at ~6 mm/yr. The results highlighted a previously unidentified seismic threat for East Java, drawing attention to the pronounced seismic and tsunami threat to Bali, Lombok, Nusa Tenggara, and other coasts along the Flores Sea. A subsequent study (Koulali et al., 2016b) showed that onshore faults in West Java are accommodating convergence of several mm/yr, again highlighting the importance of considering crustal fault activity on Java in future seismic hazard assessments.



Fault slip rate components from the model of Koulali et al. (GJI, 2016) computed along the Java Trench subduction zone, with rates shown in blue. The fault-parallel component is shown in dots in the inset.

In a new initiative, Dr McClusky was funded by ANU's Myanmar Centre, through the "Government Partners for Development" program between DFAT, ANU and the University of Yangon, to investigate the feasibility of a joint study of the earthquake hazard in Myanmar. He visited the university in Myanmar twice this year and has established the framework in which a GPS observing program can be undertaken in the coming years.

Several staffing changes occurred during 2016. Dr Sebastien Allgeyer joined the GRACE project in October 2015 and has worked on improving the ocean tide modelling in the orbit analysis software. In October 2016, Dr Julia Pfeffer commenced working on an ARC Discovery project, led by Drs Purcell and Tregoning, to extract sea level changes around the Australian coastline from available satellite altimetry, tide gauge and glacial isostatic adjustment models. Ms Bianca Kallenberg submitted her PhD thesis in June 2016, while Mr Janosch Hoffmann resubmitted his PhD thesis in December 2016. Dr Michael Moore graduated this year after 4 years as a PhD student and has returned to his position at Geoscience Australia.

GEOPHYSICAL FLUID DYNAMICS

Group Leader: Andrew Hogg

In Brief

- Adele Morrison was awarded a DECRA Fellowship to begin in 2017.
- ARC Linkage Project funding for the Consortium for Ocean-Sea Ice Modelling in Australian (COSIMA) hosted at ANU (2016-2019).
- Andrew Hogg received the 2016 Priestley Medal from AMOS.
- Dongqin Yin joined the group as a Postdoctoral Fellow.
- Kate Snow graduated from her PhD; Craig McConnochie submitted his PhD thesis; Taimoor Sohail joined the group as a new MPhil student and Yifei Zhou as a PhD student.
- Funding for the ARC Centre of Excellence for Climate Extremes (2017-2023).

Research Highlights

The GFD group conducts research into fluid processes relevant to the earth system. Our current research priorities include oceanic convection, ice-ocean interactions and the large-scale circulation of the ocean.

Ocean models enable us to predict future changes in the ocean-climate system. These models are becoming so complex that they are beyond the remit of individual organisations. Therefore we have developed partnerships with a number of Australian organisations (UNSW, UTas, NCI, Bureau of Meteorology, CSIRO and the Australian Antarctic Division), along with international (GFDL/NOAA) collaborators. These partnerships have led to the successful reconfiguration of a global ocean-sea ice model so as to have a horizontal grid spacing of 1/10°, designed to resolve specific dynamics important to the global ocean circulation (see Figure 1).

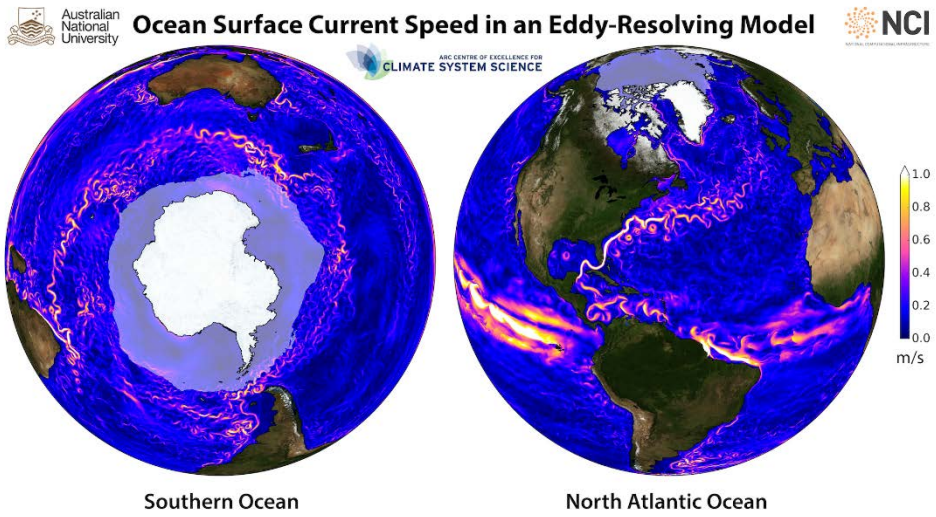


Figure 1. Snapshots of numerical simulation of the global ocean at 1/10° resolution, with 75 vertical levels. This simulation runs on 5232 cores on NCI's Raijin supercomputer. Each model year consumes 40,000 CPU hours.

As part of this project we ensure that these additional dynamics were able to be resolved vertically, however existing methods for developing vertical grids rely heavily on subjective choice. We address this by developing a methodology to objectively construct a vertical grid based on the resolution capabilities of the horizontal grid, such that the two grids complement, and importantly, not undermine, each other (Stewart et al. Submitted). Improving the vertical grid in the 1/10° global ocean model substantially increases the sea surface height variability and eddy kinetic energy, particularly on and around the Antarctic continental shelf and slopes, and leads to a transport increase and densification in the deep ocean.

The rate of melting of the polar ice sheets comprises the largest uncertainty in predicting future sea level rise. During 2016 we have investigated the effect of an external freshwater plume on the dissolution of a vertical ice wall. Such plumes are frequently observed around Greenland's glaciers where they are associated with increased ice loss. Our laboratory experiments confirm the field observations that a subglacial discharge can significantly enhance the ablation rate of the ice face but will not alter the temperature at the ice-ocean boundary.

We have also conducted *the first* convection-resolving simulations of ice dissolution in quiescent homogeneous ambient water (Gayen et al*.,* 2016), in order to examine the physics of melting. The results show that temperature is not the only factor controlling the rate of ice sheet melting; the transport of salt to the ice-water interface also plays a key role. The simulations produced results in excellent agreement with experimental measurements and demonstrated the capacity to accurately simulate these flows despite having to resolve the extremely small scales of the solute boundary layer.

This year we finally brought a multi-year project to completion with a new physical model for the evaporation from Class A pans being published (Lim, Roderick and Farquhar, 2016). Evaporation pans are in widespread use worldwide and used to measure the evaporative demand of the atmosphere. They are of great scientific interest because world-wide measurements show a steady decline in pan evaporation since the 1950s. This new model extends our earlier work by including a more realistic treatment of the radiation regime of an evaporation pan and is expected to find widespread use in attribution studies looking to explain why pan evaporation has declined.

Circulation in the Southern Ocean remains poorly understood and undersampled by observations; the GFD group contributes to knowledge of the Southern Ocean using a combination of numerical simulations and laboratory experiments. The ocean's thermohaline (or overturning) circulation involves upwelling of deep, carbon-rich waters to the surface of the Southern Ocean. Southern Ocean upwelling is thought to be driven by strong westerly winds, implying that the intensification of Southern Ocean winds in recent decades may have enhanced the rate of upwelling. We have used a new framework to study the energetics of Southern Ocean upwelling (Hogg et al. 2016). While increasing winds drag more deep water to the surface, this effect is offset by poleward shifts of the wind stress field, implying that future climate trajectories may not be associated with enhanced upwelling.

In late 2016 the exceptionally skilled and talented technicians of GFD and RSES completed the construction of the Large Rotating Annulus (LRA). This experimental apparatus represents the latest step in the decades-long scientific journey of GFD researchers examining the fundamental physics of the ocean's role in Earth's climate. The LRA extends the dynamical range of laboratory ocean modelling into a regime directly relevant to Southern Ocean processes: rotating flows driven by surface buoyancy and stress forcing and interacting with topography. The flows of the LRA are able to be visualised and quantified at qualities and resolutions far superior to any existing laboratory experiment. This apparatus will be the principle workhorse of the GFD laboratory for years to come, serving valuable roles in both research and teaching.

Internal waves are generated near ocean boundaries and distribute energy throughout the ocean. These energy transfers are thought to be vital to the maintenance of the ocean's overturning circulation. However, the sources and sinks of wave energy, and the dynamics of waves in the ocean interior, are not completely understood. During 2016, we have run very high-resolution wave-resolving numerical models of an idealised sector of the Southern Ocean in an attempt to quantify a newly theorised wave energy source known as "spontaneous generation" (Shakespeare and Taylor, 2016). This process refers to waves being generated, in the absence of forcing from atmosphere, from very sharp fronts and filaments at the ocean surface, which are being actively sheared and strained by the eddying flow. Our simulations indicate a potential role for spontaneous generation in the energy budget of intensely eddying regions of the ocean.

We have significantly carried forward our work on horizontal convection by including the effect of background or planetary rotation, which has a broad interest in the oceanographic research community. The results for geostrophic circulation under planetary rotation show the formation of basin-scale gyres along with deep chimney convection, and have been placed in the context of new theoretical scaling (Vreugdenhil et al., 2016). We have also investigated this problem using novel experiments at our GFD laboratory and showed the departure from the geostrophic regime due to the formation of the deep convective chimneys.

ISOTOPE GEOCHEMISTRY

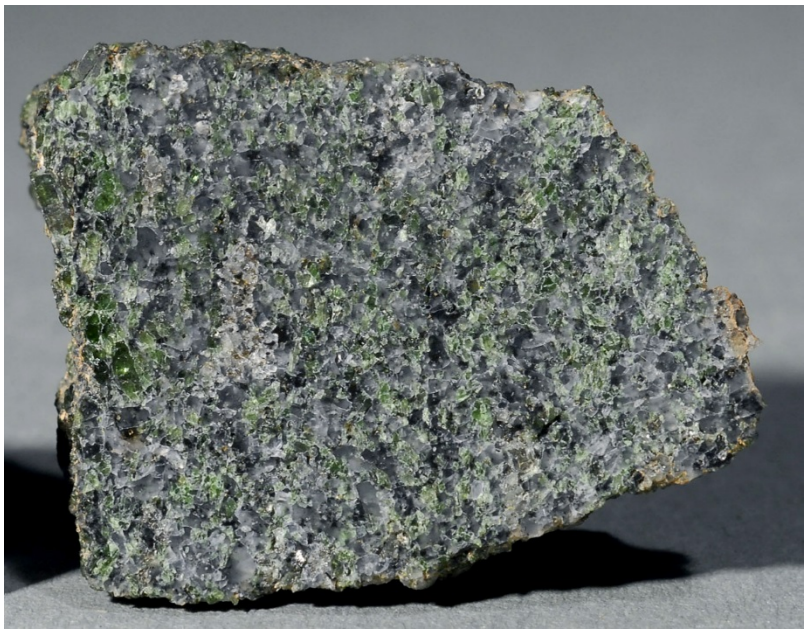
Group Leader: Victoria Bennett

The research activities within the Isotope Geochemistry 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 more than 4.5 billion through to high precision age determinations of young volcanoes, and in scale from planetary systems to individual molecules. Active areas of research within the Isotope Geochemistry area include planetary and early Earth studies including chronology of oldest solar system materials and investigations of earliest life habitats, volatile budgets and volatile cycling from the atmosphere to the deep Earth and exploration of climatic events in deep time. The diverse faculty and research activities under the Isotope Geochemistry banner are linked through reliance on the development and application of leading-edge analytical methods and instrumentation for isotopic measurements, with wide networks of internal, national and international collaborators.

2016 was an exciting and productive year with Isotope Geochemistry faculty and students being the recipients of various honours, featuring in international conferences, and with continued high rates of publication in leading international journals.

Highlights include:

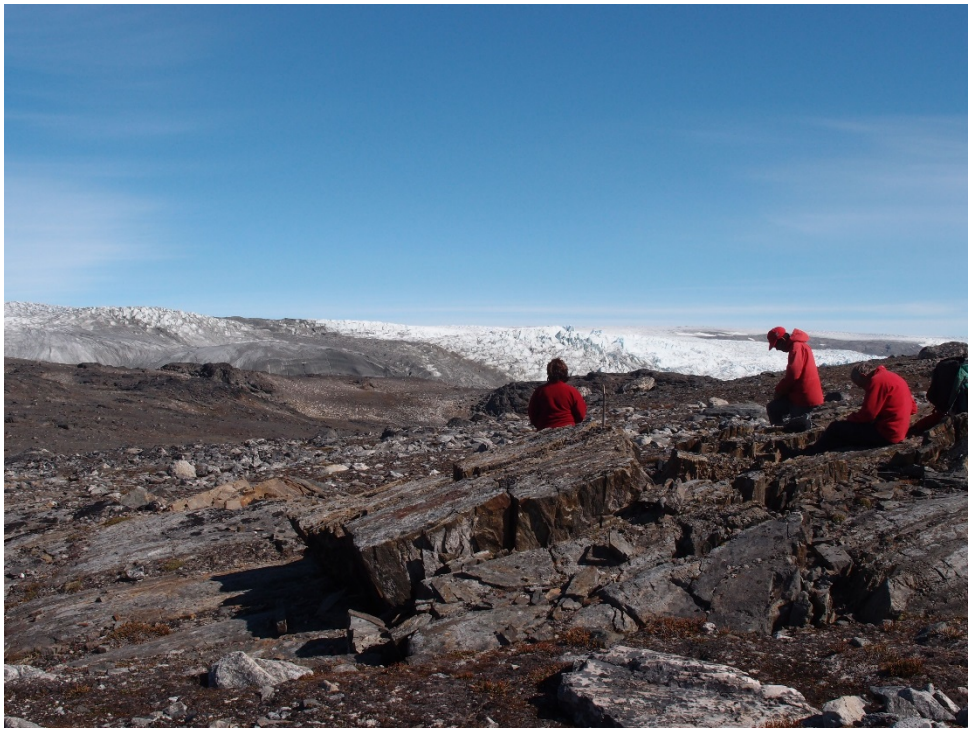
Trevor Ireland was awarded a prestigious American Geophysical Union Fellowship. He is also a collaborator on the NASA Osiris-Rex asteroid return mission and ion the Science Team of the Hayabusa II asteroid return mission.



Photograph of meteorite NWA 7325 - a rock from a previously unsampled asteroid, or possibly (but less likely) from the planet Mercury. Allow this sample contains less than 2 parts per billion uranium, it was possible to get a precise Pb-isotopic age of 4563.4 ± 2.6 Ma at the RSES SPIDE2R lab (published by PhD student Koefoed and co-authors (2016) GCA 183, 31–45). Field of view is 2 cm.

Trevor was an invited speaker at the 2016 Goldschmidt conference; he becomes President of the Meteoritical Society for 2017-2018; and he spent 3 months in Guangzhou Institute of Geochemistry as a Chinese Academy of Science President's International Fellow.

Vickie Bennett was a plenary speaker at the 2016 Goldschmidt Conference, Yokohama Japan presenting a talk on "Deep Time, Deep Earth: Revealing Earth's early history". She also served as the Early Earth theme chair for the Goldschmidt conference, and was the 2016 Chair of the Awards Nomination Committee of the Geochemical Society.



Fieldwork in early Archean terranes of SW Greenland. Vickie Bennett (left) was part of team that discovered the oldest fossil evidence for life in the form of 3.7 Ga stromatolites, providing new insights into the habitats and chemical conditions on the early Earth. Nutman et al., Nature 537, 535–538 (2016).

Marc Norman received an Outstanding Alumnus Award form Tennessee Technological University, where he received his undergraduate degree, and received his award during a dinner in his honour. Marc continues as Executive Editor of the leading geochemistry journal Geochimica et Cosmochimica Acta, overseeing 90 associate editors and 1000 new manuscript submissions per year.

PhD student Hannah James (Supervisor I. Williams) was a semi-finalist at the FameLab Australian science communication competition in March, 2016, Hannah was also awarded a UC National Science Foundation Travel Grant to attend the SPATIAL short course at the University of Utah and was awarded an international student volunteer position position for the World Archaeological Congress in Kyoto Japan August 2016.

PhD student Patrick Carr (Supervisor V. Bennett) gave a talk at the International

Geological Congress, Cape Town, South Africa on his work on the use of tourmaline compositions to track the sources of mineralizing fluids. He also participated in two field trips associated with the IGC.

PhD student Joelle Ducommun (Supervisor M. Kendrick*)* presented a talk on "Serpentine in ultramafic rocks from the Isua Supracrustal Belt, a proxy for Archean Seawater Chemistry?" at the 4th International Serpentinite Conference, Sete, France.

PhD student Suzette Timmerman (Supervisor M. Honda) was invited to attend the DCO (Deep Carbon Observatory) summer school held in Yellowstone National Park. Suzette also visited the University of Alberta to undertake trace element analyses on some of African diamonds in relation to U/He dating of diamonds.

PhD student Kelsie Long (Supervisor I. Williams) presented her research at a meeting of the Willandra Lakes World Heritage Area Aboriginal Advisory committee (February 2016). She is also a volunteer as part of the Engage: University Outreach team serving at the 2016 Director of External Relations. As part of this organization she also spent 2 weeks (one in June and one in November 2016) visiting regional schools and running University outreach workshops.

PhD Student Kelsie Long leading a science outreach workshop at a primary school.

Faculty and students of Isotope Geochemistry area are active in the newly formed SSERVI Australia, which is a node of the NASA Solar System Exploration Research Virtual Institute.

Members of the Isotope Geochemistry Group were active participants in the School Review with V. Bennett and I. Williams giving a presentation on behalf of the Isotope Geochemistry group to the review panel.

2016 Australian Research Council Funding Success:

V. Bennett is a Chief Investigator on the funded ARC Discovery Grant Engineering planetary habitability: Earth's critical first billion years (2017-2019, Allen Nutman, Univ. of Wollongong, lead CI.)

T. Ireland is part of the successful ARC LIEF bid for the Desert Fireball Network (Phil Bland, Curtin University Lead CI).

M. Norman is a Chief Investigator on the funded ARC Linkage grant: Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia (2016-2018, S. Meffre, U. Tasmania, lead CI).

Students in Planetary Geology EMSC3022 class outside RSES observing the planets Mercury, Venus, Mars, Jupiter, Saturn (photo from course instructor T. Ireland).

2016 Student and Staff Milestones:

Marian Sapah has been awarded her PhD (Supervisors T. Ireland and Y. Amelin) and has accepted a faculty position at the University of Ghana.

Piers Koefoed (Y. Amelin) and Thomas Haber (V. Bennett and M. Norman) have submitted their PhD theses with Thomas now having moved to a postdoctoral position at the University of Münster to continue his investigations of lunar impact materials.

We welcomed new PhD students Perrine Tyler (Supervisor T. Ireland) and Laura Stone (Supervisor I. Williams) and Masters student Leonardo Baeza (Supervisor T. Ireland)

Honours students Geoff Bonning (thesis title: Oxygen isotopes in chondrules from ordinary chondrites, Supervisor T. Ireland) and Callum Macfarlane (thesis title: Biogenic sulfur isotope fractionation, Supervisor T. Ireland) successfully completed their programs.

Vickie Bennett was successful in the 2016 promotion round achieving the level of Professor.

Renaud Merle joined Isotope Geochemistry as a postdoctoral fellow working with Yuri Amelin and Marion Grange is spending a year as a visiting scientist from Curtin University working with Marc Norman and Vickie Bennett on precise age determinations of lunar impact related samples to test models for the impact history of the early Earth-Moon system.

Numerous national and international visitors were hosted in the SHRIMP and TIMS laboratories throughout the year creating a lively and dynamic research environment.

Richard Armstrong and Mark Fanning joined the Isotope Geochemistry Group following restructuring within RSES.

David Thomson has fully transferred to the SHRIMP team following a year on secondment from the Engineering Workshop. Bin Fu joins the SHRIMP group as a professional staff member. Shane Paxton (Head of Mineral Separation Laboratory) was honoured for 25 years of service to the ANU.

Xiaodong Zhang received an RSES professional staff development award. We sadly farewell Hongtao Gao after four years of dedicated service as part of the Mineral Separation Lab Team and wish him well.

MARINE BIOGEOCHEMISTRY

Group Leader: Michael Ellwood

The marine biogeochemistry group at RSES has had a dynamic year. The group continues to focus on its research strengths to answer key research problems in marine science, e.g. What is the role the oceans in regulating global climate? How do changes in the bioavailability of trace metals shape the microbial community in the ocean? How do foraminifer and corals calcify? What was the physical and chemical state of the ocean during the last glacial period?

Specific projects being undertaken include:

- Culturing Southern Ocean phytoplankton species under multiple stressors to understand future responses to a changing climate
- Undertaking a detailed examination on the carbon cycle in the Atlantic during the transition into the last glacial
- Developing new tracers to detect air-sea exchange CO_2 in the ocean
- Determining pH and alkalinity variations with the aim of constraining net photosynthesis, respiration, calcification and dissolution rates on the algal ridge at One Tree Island
- Understanding iron cycling in Southern Ocean waters
- Elucidating how carbonate shells formed through detailed geochemistry analysis of reveals carbonate shells.

The group continued to publish high impacting papers with notable additions to the following top ranking journals: Nature Geoscience, Earth Planetary Science Letters, Geochimica Cosmochimica et Acta, Geology.

In 2016 group members continue to contribute to the undergraduate teaching program within RSES. Courses taught by academic group members include: Marine biogeochemistry, Palaeoclimatology and Climate Change, Coral Reef Field Studies, Sedimentology and Stratigraphy and The Blue Planet.

OCEAN AND CLIMATE CHANGE

Group Leader: Eelco Rohling

We research a variety of ocean and climate change topics over different timescales, but mostly over the past 1 million years, using marine sediment cores. We perform an array of analyses in wide-ranging collaborations both within ANU and outside, with a strong international outlook. We routinely include probabilistic statistical analyses and quantitative assessments in our analyses results and interpretations. We collaborate with experts in Earth System, ice-sheet, and Glacio-Isostatic Adjustment modelling, and in geochronology and archaeology. Critical topics concern sea-level change, climate sensitivity, monsoon changes, impacts on biogeochemical cycles (especially the carbon cycle), and the processes behind organic-rich sediment deposition. The group is invested in three of the RSES's new Frontier Themes, namely Ocean & Climate, 21st Century Resources, and Carbon cycle and CO_2 sequestration.

In 2016, the group comprised Prof. Eelco Rohling, Drs Katharine Grant, Gianluca Marino, Fiona Hibbert and Laura Rodriguez-Sanz, as well as PhD students Jess Amies, Rose Manceau, and Tiah Penny, and Masters student Lynton Hurt. We twice hosted a pair of UK visitors for collaborative work: Drs Felicity Williams and Jenny Stanford, each time for a couple of weeks.

Through 2016, we have achieved about 10 publications, including two in Nature Geoscience, and acceptance on a general-public book on the history of the oceans, to appear in 2017 (Princeton University Press). We presented posters and talks at the major EGU (Vienna, Austria), AGU (San Francisco, USA), and AESC (Adelaide) geoscience conferences, as well as various smaller meetings and workshops that ranged in scope from studies of sea-level and palaeoclimate to climate–archaeology interactions, geoengineering, and climate modeling. Prof. Rohling contributed to lecturing at the Urbino Summerschool of Paleoclimatology (Italy). Our new long-term collaboration was followed up through another extended exchange visit of Dr Rodriguez-Sanz to ETH, Zurich (Switzerland).

ORE GENESIS

Group leader: Ian Campbell

Summary

- Helen Cocker submitted her thesis on the platinum group elements in the giant Grasberg gold copper deposit, Papua.
- Bei Chen, from the Guangzhou Institute of Geochemistry, Chinese Academy of Science, joined the Group as a PhD student.
- Funding was received from the ARC Discovery Project to continue the study of platinum group elements in granitic rocks associated with porphyry deposits.

Research Highlights

Professor Campbell and his students, Helen Cocker and Hongda Hao, have been studying the geochemistry of the platinum group elements (PGEs) in evolving granitic systems with the aim of determining why some systems produce Cu or Cu-Au deposits while other apparently similar systems are barren. Studies of four ore bearing (El Abra, Grasberg, Cadia and Northparks) and three barren suites have been completed. The results, which are summarized in Figure 1, suggest that PGE geochemistry can be used to distinguish between ore bearing and barren suites and between gold-copper and copper only systems. A paper on El Abra, Northern Chile was published in the Journal of Petrology last year and papers on Cadia and Northparks have been submitted to a Special Issue of Geochimica et Cosmochimica Acta on PGE geochemistry. The research was the subject of a successful ARC Discovery Project that will start in 2017.

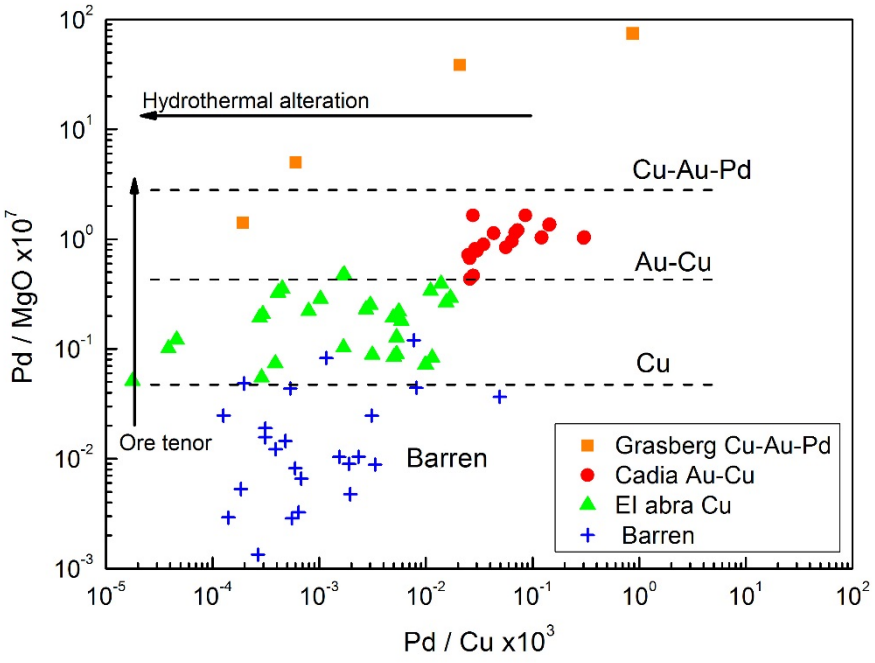


Figure 1. A plot of Pd/MgO against Pd/Cu for three ore bearing and three barren felsic systems (ilmenite and magnetite series granites, Japan, and the Rachite suite, Argentina) with MgO < 3.0 wt% MgO.

PALEO & ENVIRONMENTAL MAGNETISM

Group leader: David Heslop

New Research Projects

Prof. Andrew Roberts began the 3 year ARC Discovery Project “Unmixing First-Order Reversal Curve (FORC) diagrams for quantitative environmental analysis”.

Prof. Andrew Roberts, Dr David Heslop, Prof. Eelco Rohling, and Dr Xiang Zhao began the one-year ANU Major Equipment Committee project “Development of new instruments for paleomagnetic research”.

International Visitors

Assoc. Prof. Greig Paterson, Chinese Academy of Sciences, investigating magnetic hysteresis.

Prof. Qingsong Liu, Chinese Academy of Sciences, working on environmental magnetism of sediments.

Dr Zhaoxia Jiang, Chinese Academy of Sciences, working on the magnetic properties of hematite and goethite.

Dr Ping Liu, Chinese Academy of Sciences, working on microtektites in marine sediments.

Mr Wensi Zhang, Chinese Academy of Sciences, working on magnetotactic bacteria.

Dr Edoardo Dallanave, Ludwig-Maximilians-University of Munich, working on magnetostratigraphy.

New Group Members

Yao Qian, Chinese Scholarship Council HDR Student.

Mingkun Li, Key Laboratory of Marginal Sea Geology, Chinese Academy of Sciences.

Dr Yi Wu, South China Sea Institute of Oceanology, Chinese Academy of Sciences.

Meinan Shi, Department of Marine Science, China University of Geosciences.

Guest Lectures

Prof. A. P. Roberts, School of Earth and Space Sciences, Peking University, China

Prof. A. P. Roberts, Invited speaker, 4th Beijing International Symposium on Paleomagnetism and Earth and Planetary Deep Interiors, Beijing, China

Prof. A. P. Roberts, Keynote speaker, International Education Management Conference, Chongqing, China

Dr D. Heslop, School of Earth and Space Sciences, Peking University, China.

Dr D. Heslop, Qingdao National Laboratory for Marine Science and Technology, China

2016 Research Highlight

In recent years the Paleo & Environmental Magnetism group has been investigating mechanisms by which sediments record the Earth's magnetic field. The presence of magnetic mineral inclusions in igneous rocks and their important contributions to paleomagnetic records are well established, but the presence of such inclusions within detrital particles in sediments and their contribution to the magnetic signals of sediments have been elusive. As part of an ongoing study, we investigated a collection of marine sediments to search for magnetic mineral inclusions using transmission electron microscopic (TEM) and magnetic analyses. TEM observations confirm the abundant occurrence of magnetic nanoparticle inclusions hosted within silicate crystals in marine sediments (Figure 1). We have documented variable inclusion morphologies, including isolated nanoparticles (i.e., octahedra, sub-rounded and irregular shapes), nanoparticle clusters and dendrites. Silicate minerals are relatively stable against diagenetic alteration in sulphate-reducing marine sedimentary environments, which can, therefore, protect embedded mineral inclusions from dissolution. Our results demonstrate that silicate-hosted magnetic mineral inclusions are an important source of fine-grained magnetic minerals in sediments, which provide important constraints on understanding paleomagnetic and environmental magnetic records of marine sedimentary sequences from a wide range of settings. This work was published in Chang, L., Roberts, A.P., Heslop, D., Hayashida, A., Li, J., Zhao, X., Tian, W., Huang, Q. (2016) Widespread occurrence of silicate-hosted magnetic mineral inclusions in marine sediments and their contribution to paleomagnetic recording. Journal of Geophysical Research, 121, doi:10.1002/2016JB013109.

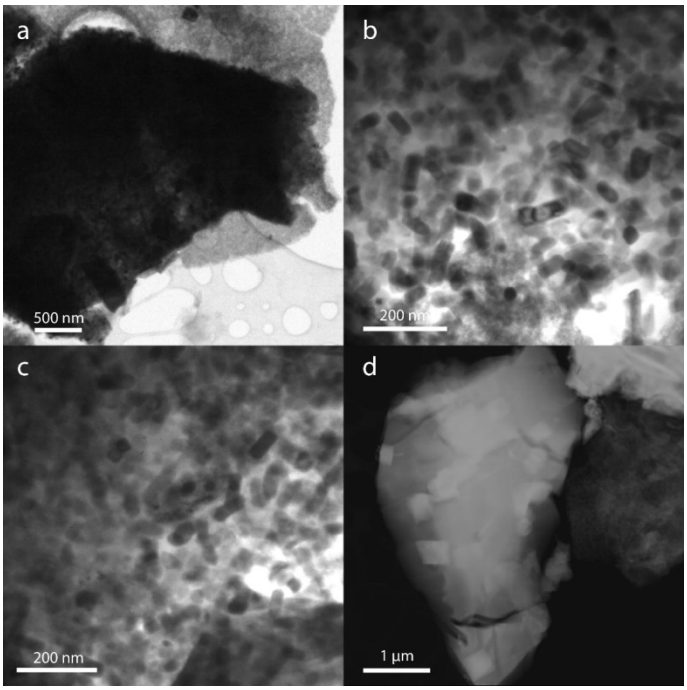


Figure 1. TEM images of dense magnetic nanoparticle inclusions in silicates for a marine sediment sample from the equatorial Pacific.

PALAEOBIOGEOCHEMISTRY

Group Leader: Jochen Brocks

Staff and Alumni

2016 was an exciting year in Palaeobiogeochemistry. Nur Gueneli completed her PhD thesis on late Mesoproterozoic microbial communities and Benjamin Bruisten submitted his thesis on climate cycles and microbial ecology of a Palaeoproterozoic sea. Tharika Liyanage completed her MSc project on biomarkers from a period leading into the great Snowball Earth glaciations.

PhD student Ilya Bobrovskiy continues his work on biomarkers and ancient Ediacaran environments of the White Sea area and made an outstanding discovery that received a positive reply for a pre-submission request to Nature. The full paper will be submitted early 2017.

Eminent geologist Prof. Neil Williams continued as an official visitor to our laboratory and moved into the office next to Jochen's. As an active collaborator on our ARC DP project, "Toppling the Boring Billion: Biomarkers, orbital cycles and primordial life", he has been performing SHRIMP sulphur isotope measurements on HYC samples. In September 2017, Neil and Jochen received permission to enter the McArthur River HYC Mine to collect samples.

In May and June, Dr Jin Su and Dr Huitong Wang from Prof. Shuichang Zhang's laboratory at the China National Petroleum Cooperation visited our lab to study biomarkers from Proterozoic rocks from China. We also hosted three undergraduate students (1 PhB and 2 special projects), so the lab was full and pleasantly busy!

Field trip to Snowball Earth deposits in the Flinders Ranges with Prof. Paul Hoffmann (centre)

Research Highlights

- Evolution of chemical warfare 800 Ma ago drove the emergence of animals (Brocks)
- Dating the rise of algae in the Precambrian and the impact on animal evolution (Brocks, submitted to Nature)
- Discovery of molecular traces of our earliest extinct ancestors: 1.6 billion years old (Brocks)
- New sole-CI ARC Discovery grant “Lost world of complex life: Molecular traces of our primordial ancestors” (Brocks)

PAST CLIMATES & ENVIRONMENTAL IMPACTS

Group leader: Michael Gagan

Overview. 2016 was another exciting and productive year for the Past Climates & Environmental Impacts group. Our research aims to answer fundamental questions about past climate change and environmental impacts, particularly in the Southern Hemisphere and tropical Australasia. Group members are prominent in the use of geochemical tracers in corals, cave formations, marine cores and ice cores to reconstruct temperature, precipitation and vegetation dynamics, and natural hazards such as volcanic eruptions and great earthquakes. While our over-arching goal is to produce new knowledge about Earth's environment, our findings provide the scientific basis required for successful adaption to society's most challenging environmental threats, including anthropogenic climate change.

Members. The group comprises Michael Gagan, Nerilie Abram, Bradley Opdyke, their students and contributions from numerous colleagues. Dr Gagan's long-term research program in Indonesia with Prof. Wahyoe Hantoro and Dr Danny Natawidjaja (Indonesian Institute of Sciences) currently provides world-class opportunities for four PhD scholars. Claire Krause (now at Geoscience Australia) was awarded her PhD for work on a 40,000-year history of the Australasian monsoon recorded by speleothems in Sulawesi, Indonesia. Alena Kimbrough submitted her PhD dissertation on the glacial-interglacial history of the Australasian monsoon (also based on Sulawesi speleothems). Jennifer Wurtzel's PhD (supervised by Dr Abram, based on speleothems from Sumatra) aims to reconstruct post-glacial changes in Indo-Pacific Warm Pool hydroclimates, and Bethany Ellis' PhD on the Holocene history of the Indian Ocean Dipole (supervised by Dr Abram, using corals from west Java) is well underway. Bob Burne was awarded an M.Phil. for his research on organomineralisation in microbialites from the Yalgorup Lakes, Western Australia. During 2016, Dr Abram also supervised two summer research scholars (Ben Nistor and Sebastian Wong) and two special topics research students (Anson Cheung and Jessica Hargeaves) within the group.

Much of our success is due to the Group's outstanding Professional Officers, Joe Cali, Joan Cowley and Heather Scott-Gagan, whose dedication and technical capabilities in the Earth Environment Stable Isotope Laboratory make it all possible.

We congratulate Dr Abram on her 2016 promotion to a continuing Academic Level D (Associate Professor) position at RSES.

New research grants. Dr Abram was awarded an ARC *Future Fellowship* for 2017-2020 to quantify changes in Australia's rainfall belts over the last millennium. Dr Abram is also a Chief Investigator in the ANU node of the ARC Centre of Excellence for Climate Extremes (led by Prof. Pitman, UNSW) awarded for 2017-2023.

Research highlights. The high international standing of our research achievements was well illustrated by several publications in 2016. Dr Abram led a comprehensive PAGES 2k Consortium synthesis of post-AD 1500 palaeoclimate records (published in Nature) that revealed an early 19th-century onset for industrial-era warming across the oceans and continents. PhD scholar Alena Kimbrough and Dr Gagan had lead co-

author roles in a paper in Nature Communications showing links between tropical Pacific hydroclimate modes and century-scale global climate variability over the last 2,000 years. Dr Abram co-authored a paper in Nature Climate Change that assessed recent trends in high-latitude Southern Hemisphere within the broader context of natural climate variability given by palaeoclimate archives.

Dr Opdyke and Jennifer Wurtzel participated in IODP expedition 363 to the Western Pacific Warm Pool. Using material from the cruise, Jennifer will carry out a short research project to assess intervals of Holocene variability in a high resolution marine core collected offshore of Papua New Guinea.

Katie Holder (WA), Bradley Opdyke (RSES) and Jennifer Wurtzel (RSES), "The Australian Contingent" on the deck of the JOIDES Resolution for IODP Expedition 363 to the Indo-Pacific Warm pool.

Awards and honours. Jennifer Wurtzel was a finalist for the ANU 3 Minute Thesis competition. Her presentation titled "Reading the Rain in the Rocks" also won the people's choice award at the ANU Colleges of Science final.

New appointments and service. Dr Abram was an Australian representative for the IPCC scoping meeting for the special report on Climate Change, the Oceans and the Cryosphere, held in Monaco in December 2016. She also continued in 2016 as a Co-Editor-in-Chief for Climate of the Past, and a coordinator for the PAGES 2k project which will enter its 3rd phase in 2017.

Laboratory developments. Dr Abram led a successful ANU Major Equipment Committee grant to install a portable Picarro high-precision water isotope analyser (with new ^{17}O-excess measurement capability) in the RSES Earth Environment Stable Isotope Laboratory.

PLANETARY SCIENCES

Group leader: Trevor Ireland

The Planetary Group has strong links to the Isotope Geochemistry Group, the Planetary Theme and the Planetary Science Institute.

Our research covers aspects of the early solar system through to current state of planetary surfaces reflected in planets and planetesimals.

We have international links through space missions (e.g. NASA Curiosity, Osiris REx and JAXA Hayabusa and Hayabusa 2) and we also source material through meteorites from existing collections.

An exciting new development is the funding of an ARC LIEF grant for continued construction of a Global Fireball Network (CI Prof. Phil Bland, Curtin University) that offers the capability of determining where meteorites are coming from, and having the meteorite in hand in the lab. This is complementary to the Asteroid return missions (Hayabusa, O-REx) that we are also part of. We are linked with NASA SSERVI Australia that provides research links to other planetary researchers worldwide.

People

- Mr Geoff Bonning completed his Honours studies on oxygen isotopes in chondrules from 3 carbonaceous chondrites, and was awarded 1st Class Honours. Well done Geoff!
- Mr Leonardo Baeza commenced MSc studies in to oxygen isotopic compositions of chondrules in Ordinary chondrites.
- Prof. Trevor Ireland will assume the Presidency of The Meteoritical Society on 1 Jan 2016.

Activities

Janaina Avila and Trevor Ireland attended a workshop on nucleosynthesis in AGB stars in Budapest, and the Meteoritical Society Annual Meeting in Berlin.

Janaina Avila also attended the SHRIMP workshop in Granada, Spain.

Trevor Ireland also attended the 7th Hayabusa Joint Science Team meeting at the JAXA campus in Tokyo, Before the Moon workshop in Tokyo, and give an invited talk at Goldschmidt in Yokohama.

Research Activities

We use the SHRIMP ion microprobes for isotopic analysis of very small domains in meteorites and other samples. We are continuing developments on SHRIMP SI for 3 O isotope analysis. Improvements in the electron gun configuration and charge mode analysis should lead to better single analysis precision. This will allow us to distinguish materials from Mars, Vesta and Earth for example, as well as elucidating the mixtures of rock types present in meteoritic breccia.

We are continuing work on SHRIMP SI with collaborators at Macquarie University for the measurement of water in nominally anhydrous materials. This is a difficult task because of the pervasive nature of water on Earth's surface. We are exploring the role of water in meteoritic materials with a view to understanding how water was delivered to Earth.

Outreach Activities

Janaina Avila was strongly involved in the development of the public displays in astronomy and planetary science at the Mt Stromlo Observatory.

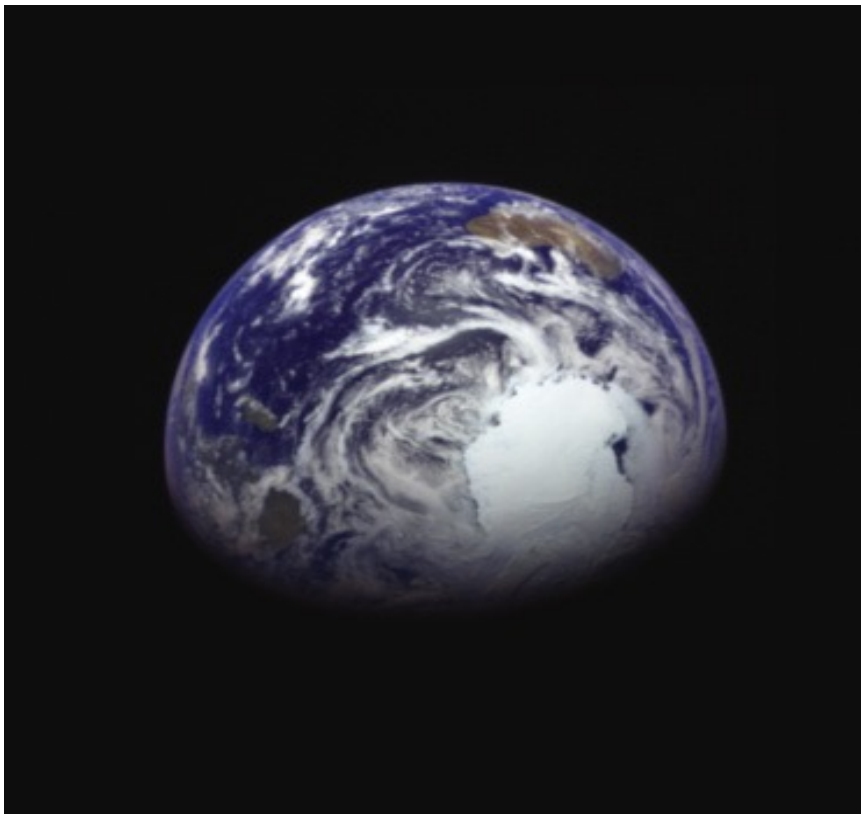


Figure 1. Image of Earth from flyby of Hayabusa 2 on its way to asteroid Ryugu in Dec 2015. Antarctica and Australia are readily visible as the spacecraft uses a polar pass to get into the inclined orbit of Ryugu. Image Courtesy of JAXA.

ROCK PHYSICS

Group leader: Stephen Cox

The Group's research centres on high-pressure, high-temperature laboratory studies of (1) ductile rheology and seismic properties of crustal and mantle materials, and (2) deformation processes associated with fault slip in seismogenic and aseismic slip regimes, including in the presence of reactive pore fluids.

Laboratory measurements of macroscopic physical properties such as seismic wave speeds and attenuation, strength, deformation rates and permeability are interpreted through microstructural studies using optical and electron microscopy. Often it is necessary to prepare, from either natural or synthetic precursors, simpler synthetic materials whose properties are amenable to more detailed interpretation than those of complex natural rocks. Our interest in Earth materials is shared by members of the School's Experimental Petrology Group, whose research focuses primarily upon the chemical aspects of the behaviour of Earth materials.

The experimental studies on fault mechanics are complemented by field-based studies, along with microstructural and isotopic studies and numerical modelling aimed at exploring coupling between deformation and fluid flow in exhumed faults, shear zones and fracture-controlled hydrothermal ore systems.

Our research has application to:

- geodynamic modelling and the interpretation of seismological models
- understanding controls on earthquake nucleation and rupture propagation
- understanding links between deformation, fluid flow and ore deposit formation.

A highlight this year has been continued experimental study of slip processes on bare quartz interfaces, as part of Kathryn Hayward's PhD. The development of a laser interferometer, in collaboration with colleagues in the Research School of Physical Sciences and Engineering, has allowed us, for the first time, to measure slip rates during small but rapid slip events during stick-slip behaviour of laboratory faults. This development was funded by a grant from the ANU Major Equipment Committee. The laser interferometer now allows us to record laboratory slip events on microsecond timescales and with micron-scale resolution of displacement (Figure 1). This facility provides us with an unrivalled capacity to capture earthquakes in the laboratory at confining pressures as high as 300 MPa, temperatures up to 1000°C, and at controlled pore fluid pressures up to 275 MPa. The first results were published recently in *Geology*. Ongoing work will focus on study of the first milliseconds and tens of microns of seismogenic slip to explore earthquake nucleation and the dynamic weakening processes that allow some initially small ruptures to cascade into large, destructive earthquakes. Experiments will be used to examine earthquake nucleation in both crustal and subduction interface regimes.

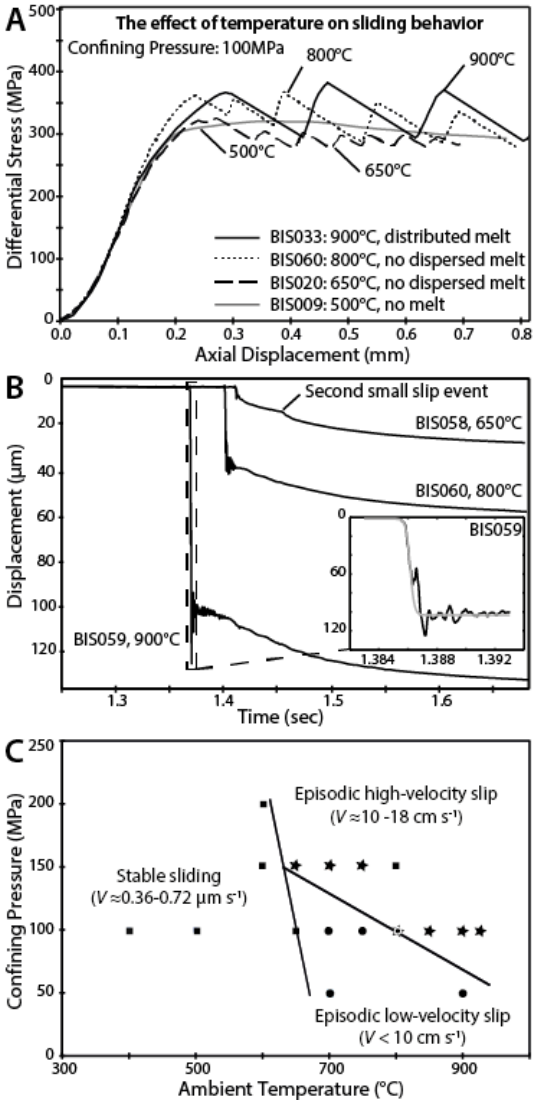


Figure 1. (A) Representative differential stress - displacement curves for experiments undertaken over a range of ambient temperatures. Sliding behaviour transitions from stable sliding at ~ 500C through to low velocity, episodic slip at ambient temperatures of 650C - 800C, and episodic high velocity slip at ambient temperatures > 850C. (B) Data from interferometric sensor shows displacement as a function of time during rapid slip events. Note that the displacement during rapid slip events increases with ambient temperature. Multiple small slip sub-events occur within a singe event in a number of the lower temperature experiments. Inset shows an expanded view of one slip event and has been fitted to a logistic function (red). (C) Experimental slip behaviour plotted in ambient temperature - pressure space. Lines indicate estimated boundaries between different sliding regimes.

Studies by visitor Ulrich Faul, PhD student Chris Cline, visitor Emmanuel David, Berry and Jackson, of the high-temperature rheology of Pt-sleeved, Ti-doped synthetic olivine under water-undersaturated conditions have shown that Ti-hydroxyl defects involving protonated Si vacancies are responsible for previously reported water weakening of mantle olivine (Figure 2).

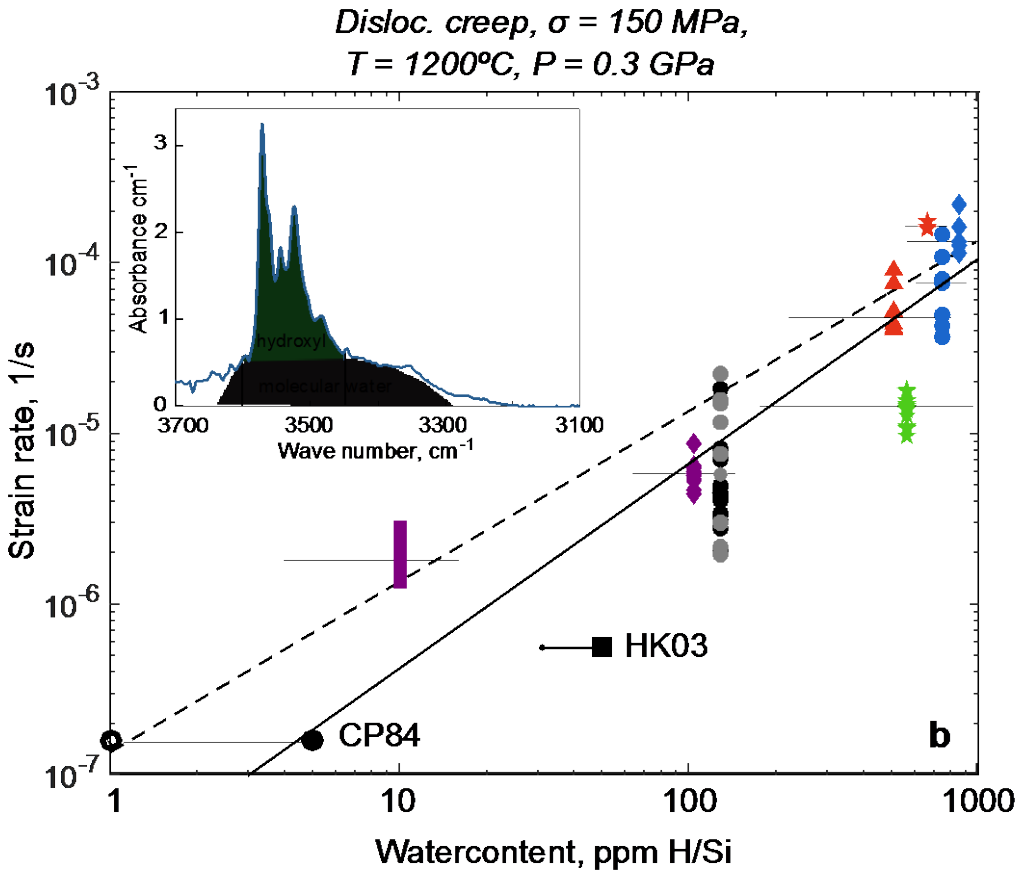


Figure 2. The variation of strain rate for dislocation creep with the concentration of Ti-OH defects in nominally anhydrous olivine. Symbols denote data from multiple specimens tested under various conditions of temperature and stress – normalized to common conditions of 1200°C and 150 MPa uniaxial stress (Faul et al., EPSL, 2016).

Similarly oxidising and hydrous conditions prevailing within Pt sleeves are responsible also for reduced shear wave speeds and increased dissipation observed in parallel low-strain forced-oscillation tests - probably through enhanced grain-boundary sliding. Complementary torsional and flexural oscillation tests (Cline and Jackson) of partially molten synthetic dunite show that its mechanical behaviour can be understood in terms of the relaxation only of the shear modulus, but the method proves to be insensitive to possible relaxation also of the bulk modulus. The ambitious PhD project of Richard Skelton (co-supervised by Jackson and Andrew Walker, University of Leeds) is nearing completion with the development and application of versatile computer software for the modelling of dislocations in minerals including the simulation of dislocation slip with and without adhering point defects involving protons. Completion of another experimental PhD project, by Yang Li, involving a broadband study of the seismic properties of synthetic glass media both dry and fluid-saturated (collaborative with visitor David, Douglas Schmitt, University of Alberta, and Seiji Nakagawa, Lawrence Berkeley Laboratory), has clearly shown that ultrasonic wave speed measurements at MHz frequencies and forced oscillation tests at seismic (sub-Hz) frequencies probe different regimes of stress-induced fluid flow in low-permeability cracked glass materials with implications for interpretation of seismological models for the upper crust.

SEISMOLOGY AND MATHEMATICAL GEOPHYSICS

Group leader: Malcolm Sambridge

During 2016 the Seismology and Mathematical Geophysics group carried out research in structural and source seismology from the crust to the core, with a focus on lithospheric and mantle dynamics, data inference, non-proliferation seismology, natural hazards, geodynamics and community outreach through the Australian Seismometers in Schools program.

Three new academic staff joined the group this year, Drs Caroline Eakin and Andrew Valentine in the second half of the year with Dr Meghan Miller due to arrive in December. We bid farewell to Drs Natalie Balfour, Jan Dettmer, Erdinc Saygin, and Christian Sippl, while long term visitor Dr Benoit Tauzin joined the group.

A focus of mantle dynamics research this year has been on the dynamical origin of the mantle's seismological expression, dynamic topography and the mechanisms driving intra-plate volcanism, while work has also progressed in enhancing real time and far field prediction of Tsunamis and identifying earthquake risk in S.E. Asia. Seismic source characterization of nuclear explosions was studied by utilizing high resolution Earth models and uncertainty quantification of moment tensors. Continuing projects in aspect of regional and deep Earth seismic imaging were also progressed. A new study was also completed using Bayesian sampling algorithms developed in the group, applied to proxy relative sea level estimation from δO^{18} isotope data.

Following involvement in an ARC Centre of Excellence bid in data Science, several members of the group have initiated a school wide discussion on the same topic exploring RSES's potential involvement in this field. Group members are also highly active in the emerging school research theme in Natural Hazards.

The group's seismic instrument pool, both on land and at sea, has been strengthened this year with AuScope investment and again been deployed under the auspices of ANSIR, the national research facility for Earth sounding, in multitude of field projects including forays in Indonesia. Spiral arrays in WA and QLD were completed. A large passive seismic array extending AQ3 was put out in Western QLD with approximately 50 kms spacing under the Auscope Infrastructure program (See Figure). This year we also investigated the use of helicopters to carry out servicing of seismic field deployments. Also a rapid response deployment of instruments in the Petermann ranges was completed following the recent earthquake in the region.

AuScope continues to provide maintenance funds for support of seismic instrumentation and seismometers in Schools programs. The ARC supported research projects within the group in the Discovery, Linkage and Future Fellow programs. Ongoing external funding support for various programs was also received from the US Dept. of Energy, DFAT/AuSAID, and The United Nations Comprehensive Test-Ban Treaty Organization for the Warramunga Array in the NT, which saw some infrastructure upgrades.

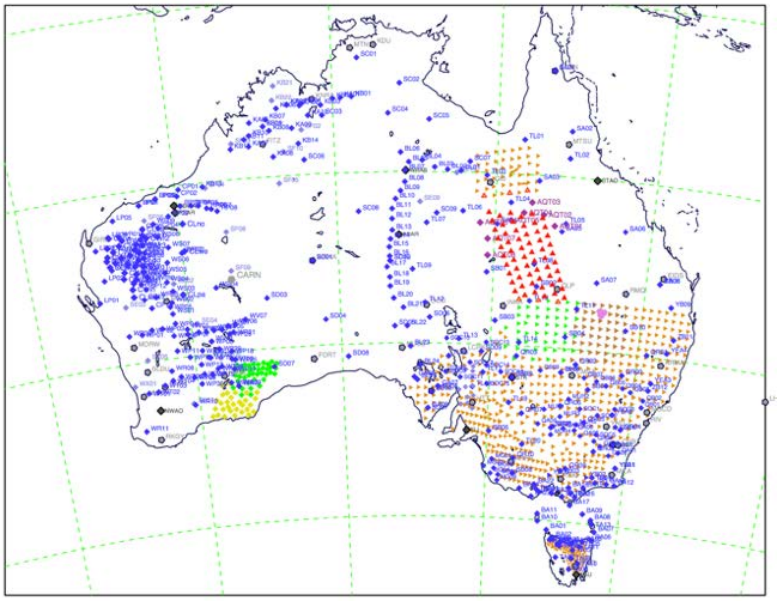


Figure 1. Locations of seismic field deployments of land based seismic instrumentation across all campaigns for 2016 (red).

The Australian seismometers in Schools program was in maintenance mode this year with further development of the AuSIS website, http://www.ausis.edu.au, and engagement through social media, https://www.facebook.com/ausisnetwork/.

The Terrawulf computational facility has seen significant activity in 2016, again supporting research activities across several groups in the school. Group members also made extensive use of the National Computational Infrastructure facility and renewed its large time allocation grants in computational geophysics and mantle dynamics.

STRUCTURE TECTONICS

Group leader: Gordon Lister

2016 was a successful year for the Structure Tectonics Team. Dr Jonathan Pownall started his research on “Tectonic derivers of extreme metamorphism in eastern Indonesia” in association with his ARC–DECRA grant. Oleg Koudashev submitted his thesis “Large scale structure and geochronology of porphyry and epithermal deposits along the northern Australian continental lithosphere”. Sima Mousavi joined the group as a research assistant, and recently completed her PhD in seismology at University of Leipzig. Undergraduate students Fangqin Chen, Ruben Creighton, Jack Muston and Julien Langley started as research interns.

In 2016, research conducted by the Structure Tectonics Team continued to focus on the link between tectonics and mineralisation, mostly in collaboration with Agincourt Resources, AngloGold Ashanti, Vale and Chinova Resources. The research incorporated fieldwork, 4D Tectonic Reconstruction as well as geochronology using SHRIMP U–Pb analyses conducted by Dr Richard Armstrong, and $^{40}Ar/^{39}Ar$ analyses conducted by Dr Marnie Forster, with technical assistance from Davood Vasegh.

External collaboration with industry and academy was boosted in 2016 with several visits to and by the group. Dr Xiao Liang from China University of Geosciences, Beijing spent a few months as a Visiting Fellow with our group. Mr Paul Donchak and Mr Laurie Hutton from the Geological Survey of Queensland, and Ms Jo Wheeler from Geological survey of the Northern Territory also visited the group in association with collaborative projects in the argon lab with Dr Forster. The group also hosted Mr David Burt from Vale Indonesia TBK who visited Prof. Lister as part of a collaborative Linkage project. Prof. Lister visited Agincourt Resources in Sumatra and AngloGold Ashanti in Perth with collaborative research on a Linkage Project.

Following its official opening in 2015, the Argus VI mass spectrometer has been fully-operative in 2016 with more than 100 samples being measured, removing the queue for lab results. The argon lab was visited several times as part of school tours for external visitors including FrogTech and the panel of academics during the school review.

The group presented cutting-edge research at several conferences in 2016 such as EGU (Vienna), AESC (Adelaide), 35th International Geological Congress (Cape Town), and TANG3O (Perth).

Research Highlights

- White mica $^{40}Ar/^{39}Ar$ age spectra and the timing of multiple episodes of high-P metamorphic mineral growth in the Cycladic eclogite–blueschist belt, Syros, Aegean Sea, Greece

Prof. Gordon Lister and Dr Marnie Forster demonstrated that white mica can be highly retentive to argon, therefore, $^{40}Ar/^{39}Ar$ geochronology can directly date microstructures and associated deformation events in metamorphic rocks. Their results from the Cycladic eclogite–blueschist belt, Syros, Greece revalidated the method of asymptotes and limits, showing how it can be used to extract meaningful age limits from the complex $^{40}Ar/^{39}Ar$ white mica age spectra that can result from a well-designed step-heating experiment.

This research was followed by similar work by Sareh Rajabi, Marnie Forster, Talat Ahmad and Gordon Lister who recently submitted a journal manuscript in which they showed for the first time that the muscovite of the shear fabric of the Main Central Thrust in the Himalaya was retentive enough to retain the age of the deformation thus showing the shear zone operated in mid-Miocene.

- Earth's youngest known ultrahigh-temperature granulites discovered on Seram, eastern Indonesia

Jonathan Pownall, in collaboration with Robert Hall, Richard Armstrong and Marnie Forster reported Earth's youngest UHT complex. The 16 Ma UHT granulites from the Kobipoto Mountains of Seram in eastern Indonesia, formed at temperatures of ~950 °C and pressure of ~8 kbar in a modern tectonic system in which slab rollback–driven lithospheric extension caused core complex–style exhumation of hot subcontinental lithospheric mantle. This finding demonstrates that UHT conditions can be produced in the modern plate tectonic regime by slab rollback–induced lithospheric extension, thereby offering one possible solution to the generation of UHT rocks in Neoproterozoic and Phanerozoic orogens for which the original tectonic settings remain unknown. This paper was published by Geology and received widespread media attention.

- Tectonometamorphic evolution of Seram and Ambon, eastern Indonesia: Insights from 40Ar/39Ar geochronology

Jonathan Pownall and Marnie Forster in collaboration with Robert Hall and Ian Watkinson identified two main phases in the tectonic, metamorphic, and magmatic evolution in the island of Seram, eastern Indonesia: (1) an initial episode of extreme extension that exhumed hot lherzolites from the subcontinental lithospheric mantle and drove ultrahigh-temperature metamorphism and melting of adjacent continental crust; and (2) subsequent episodes of extensional detachment faulting and strike-slip faulting that further exhumed granulites and mantle rocks across Seram and Ambon. Using $^{40}Ar/^{39}Ar$ experiments on variety of minerals they identified thermal events at 16 Ma, 5.7 Ma, 4.5 Ma, and 3.4 Ma that support there have been multiple synchronised episodes of high-temperature extension and strike-slip faulting, interpreted to be the result of Western Seram having been ripped off from SE Sulawesi, extended, and dragged east by subduction rollback of the Banda Slab. The outcome of this research is a paper that has recently been accepted in Gondwana Research for 2017 publication.

WATER & REGOLITH SCIENCE

Group Leader: Penny King

The group comprises three academic staff (Penny King, Bradley Pillans and Stewart Fallon), one DECRA fellow (Rachel Wood) and two professional staff (Ulrike Troitzsch and Rebecca Esmay). Our students include Rachel Kirby, Shannon McConachie, Prudence Merriman, Andrew Palm, Christian Renggli and Michael Short. A number of other researchers are associated with our group, including Robert Burne, Patrick de Deckker, Richard Henley, Bear McPhail, Terry Mernagh, Bradley Opdyke and Eva Papp.

Research Highlights

- New constraints on the composition of dust on Mars (King)
- Compound-specific dating of rock art (King, Troitzsch)
- Lake George: a 2.6 Ma sedimentary record of the Quaternary Period (Pillans)
- Tracking chloride in minerals in cement (Troitzsch)
- Impact of biomineralization in coralline algae on coral reefs' Mg-budget (Troitzsch, King)
- Improving the precision on our understanding of when people first occupied Australia (Wood)
- Improved methods for radiocarbon dating of teeth (Wood)
- Intergroup violence amongst early Holocene hunter-gatherers in Kenya (Wood)

Analysing coatings over rock art, western Arnhem Land, NT, Australia.

University Service

- Deputy Chair, ANU College Access & Equity Committee (King)
- Chair, RSES Equity & Diversity Committee (King)
- Chair, RSES Work Health and Safety Committee (Pillans)
- Organiser, Archaeometry seminar series, Research School of Earth Sciences (Wood)

ANU'S ROLE IN THE INTERNATIONAL OCEAN DISCOVERY PROGRAM

IODP (www.iodp.org) is the world's largest and longest-lived geoscience research program, and it is at the frontier of global scientific challenges and opportunities, because ocean drilling is the best method of directly sampling the two-thirds of our world that is covered by oceans. IODP seeks to address global scientific problems by taking continuous core of rocks and sediments at a great variety of sites, from as deep as several kilometres below the sea bed. Its broad aim is to explore how the Earth has worked in the past, how it is working now, and how it may work in future. It uses a variety of platforms, and provides 'ground truthing' of scientific theories that are based largely on remote sensing techniques. IODP membership consists of 25 countries and it has an operational budget of $US180 million p.a.

IODP's key research areas are:

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

Australia and New Zealand are partners (iodp.org.au; http://drill.gns.cri.nz) in the ANZIC consortium within IODP, which involves both geoscientists and microbiologists, supported by an ARC/LIEF grant. Thirteen Australian universities and two government research agencies, and three New Zealand universities and two research agencies, were part of ANZIC in 2016. ANZIC scientists 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. Membership of IODP helps us maintain our leadership in Southern Hemisphere marine geoscientific research.

The Australasian region is vital to addressing various global science problems, and, accordingly, has seen a great deal of ocean drilling since 1968, when the first program was established. In 2016, seven Australian scientists took part in six IODP expeditions. ANU's **Bradley Opdyke** sailed as a sedimentologist, and Jennifer Wurtzel as a physical properties specialist, on the *JOIDES Resolution* Western Pacific Warm Pool Expedition 363 in the Australian region in late 2016. Also on Expedition 363 was Katie Halder, a Western Australian teacher, leading the extensive education and outreach program, streamed live from the ship. The remarkable total of seven *JOIDES Resolution* expeditions has been scheduled in the Australia-New Zealand-Antarctica region in 2017 and 2018, an operational expenditure of $US110 million. This is a huge credit to the quality of applications made by international teams generally led by ANZIC scientists; we succeeded against intense global competition! The *JOIDES Resolution* expeditions in our region from the middle of 2017 are:

- Expedition 371 (Tasman Frontier Subduction, Lord Howe Rise, co-chief scientist Rupert Sutherland, Victoria University Wellington): July 27 to September 26, 2017. [One Australian aboard]
- Expedition 369 (Australia Cretaceous Climate and Tectonics, Naturaliste Plateau): September 26 to November 26, 2017. [Three Australians aboard]

- Expedition 372 (Creeping Gas Hydrate Slides and Hikurangi margin LWD, co-chief scientist Ingo Pecher, Auckland University): November 26, 2017 to January 4, 2018. [Positions not yet allocated]
- Expedition 374 (West Antarctic Ice Sheet Climate, Ross Sea, co-chief scientist Rob McKay, Victoria University Wellington): January 4 to March 8, 2018.
- Expedition 375 (Hikurangi subduction margin, co-chief scientist Laura Wallace, GNS Science, Wellington): March 8 to May 5, 2018.
- Expedition 376 (Brothers Arc Flux, north of New Zealand, co-chief scientist Cornel de Ronde, GNS Science, Wellington): May 5 to July 5, 2018

ANZIC scientists gain in various ways from IODP: through shipboard and post-cruise participation in cutting edge science, by being on international IODP panels, 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. Post-cruise ANZIC analytical funding is available for shipboard scientists, and **Gianluca Marino** of ANU was granted $40,000. A 2016 round of special funding for work on legacy ocean drilling material resulted in nine awards, for a total of $150,000, including one for **Stewart Fallon** of $19,100, and another team with ANU participation.

The Australian IODP Office at ANU is headed by ANZIC Program Scientist, Professor **Neville Exon**, and Professor **Richard Arculus** is the lead Chief Investigator on the ARC/LIEF LE140100047 grant. **Catherine Beasley** is the Program Administrator. The 2016 Australian IODP budget was $A3.2 million of which $US1.8 million went to the US National Science Foundation (NSF) as membership fees. ARC/LIEF had granted us $2 million p.a. for five years from January 2016 (LE160100067), with an additional $875,000 p.a. provided by our Australian members, and another $US300,000 p.a. from our New Zealand colleagues.

IODP Sessions were held on 27 and 28 June at the Australian Earth Sciences Convention in Adelaide. Five northern hemisphere scientists and 11 ANZIC scientists gave an excellent series of talks. The program enabled us to report to the geoscience community on the various IODP expeditions of the recent past and plans for the future. There was also an ANZIC Booth at AESC, run by **Catherine Beasley**. There was a considerable amount of outreach to those not previously aware of IODP, and it generated real interest.

ANU's **Neville Exon** and many others have written an easily readable book reviewing ANZIC's role in the first phase of IODP. The book is entitled "Exploring the Earth under the Sea: Australian and New Zealand achievements in the first phase of IODP Scientific Ocean Drilling, 2008-2013". It has been externally reviewed for ANU Press, is undergoing final editing, and should be published in the first quarter of 2017, both on paper and on line.

RESEARCH SUPPORT

ELECTRONICS GROUP

Andrew Latimore, Tristan Redman, Daniel Cummins, David Cassar, Hideo Sasaki.

Introduction

The Electronics Group provides technical support to the Research School of Earth Sciences and ANU academic research. The Group consists of one engineer and four technical officers. The Group holds the responsibility for maintaining and servicing electronic systems within the Research School of Earth Sciences and provides a development facility able to design and construct state of the art electronic solutions.

2016 Highlights

During 2016 the demand for electronic engineering support across RSES was high and contributed to 65% of the Electronics Group's labour efforts this year. The Group also utilised 22% of labour resources on maintenance tasks and 13% on administrative tasks. The major development projects are summarised in the following sections.

Variable Slit Motor Controller

The Variable Slit Motor Controller (VSMC) project was engineered specifically to control the Rotating Slit Assembly designed for the ICPMS Laser Ablation Cell. The slit assembly itself consists of two opposing slits mounted in a rotating assembly to achieve a highly configurable laser aperture. The VSMC contains two RSES Electronics Group designed digital motor controller units (DMC) to manipulate three small 24V stepper motors to achieve the desirable aperture size. The VSMC is controlled by a Labview program providing the operator with horizontal and vertical slit width resolution of 5µm and 180^0 rotation at a resolution of up to 0.45^0 During 2016 the project was completed, implemented and is operating in the J7 Mass spectrometer laboratory.

200T Gen II Piston Cylinder press automation

The 200T GenII Piston Cylinder press automation project which began in 2014 was completed during 2016. The project involved developing new electronic hardware systems and associated LabView software to completely automate functionality of the 200 Tonne press instrument, allowing complete autonomous operation. The GenII Piston Cylinder press automation project provides automated electric heating and pressure control, piston displacement monitoring, data logging and a graphical user interface. Users are able to configure an experiment and have pressure and temperature profiles run automatically. Data will be displayed on charts during the experiment and later saved to a file. The completed project has been extensively used by staff for high pressure experiments. The instrument is a successful innovation

developed by the RSES Electronics Group in conjunction with the Experimental Petrology technical staff.

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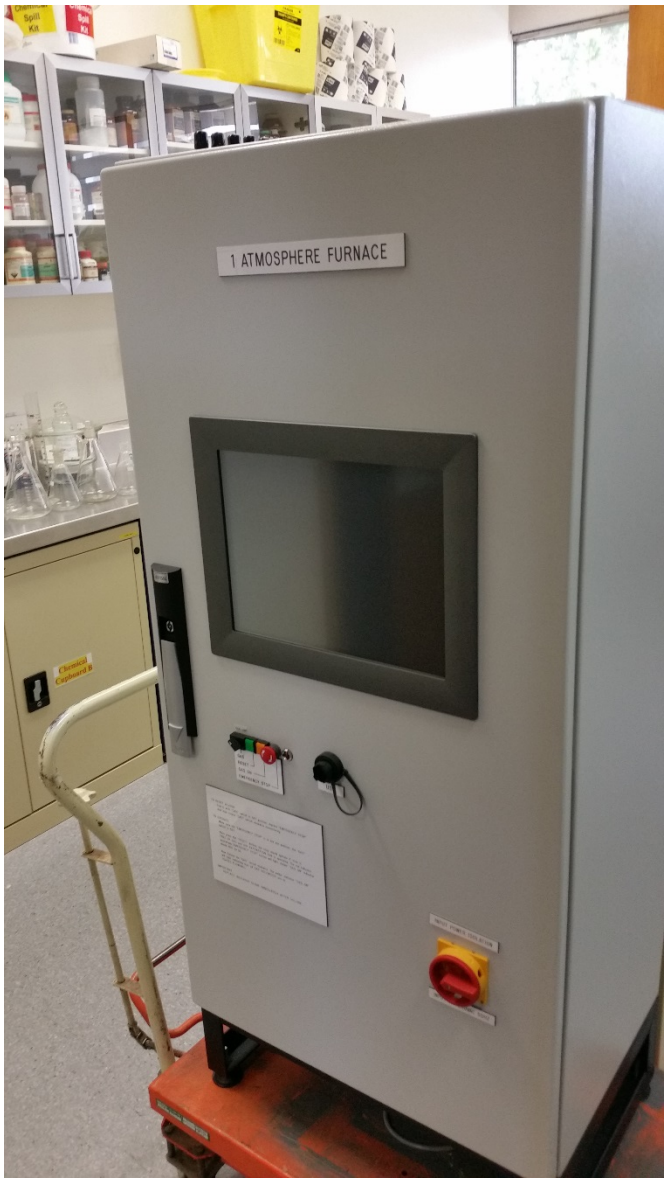
Figure 1. 200T Press GenII in operation

One Atmosphere Furnace Interface

The One Atmosphere Furnace Interface (OAFI) enables users to control and monitor furnace temperatures and gas flows using a central touch screen panel PC. The system replaces an array of obsolete and fragmented hardware currently used to control Mass Flow Controllers (MFCs) with National Instruments data acquisition and control modules to provide a unified, maintainable and expandable interface for both furnace gas and temperature control.

The MFC capabilities are expanded to include control and read-back of up to 50 units, 10 per furnace. Simple charting enables a trend view of furnace parameters over time, such as gas flows and temperature. In addition, the project removes the need to program Eurotherm temperature controllers directly, an often cumbersome task. Users are able to set temperature program parameters and commence a program cycle using the touch screen.



The use of LabVIEW software allows a vibrant and intuitive user interface to be created, allowing the furnaces to be operated easily with minimal operator training. LabVIEW also gives the flexibility to adapt the software to accommodate changing experimental techniques in the future. The project was extended during 2016 to incorporate gas monitoring functionally for laboratory safety and will inform the user of any gas leaks above the safe working threshold. During 2016 a significant amount of development and construction was undertaken and the project is completed ready for installation.

Figure 2. One Atmosphere Furnace Interface ready for installation

MOKU ADC and DAC design and construction

The MOKU project is a multi-function high speed instrument that can generate and analyse signals providing the user with an oscilloscope, spectrum analyser and waveform generator conveniently viewed from an iPad. The RSES Electronics Group was contracted by Liquid Instruments, an ANU startup company to design and construct the printed circuit boards for their MOKU instruments. The instrument design includes high speed amplifiers and acquisition electronics requiring expert circuit board techniques to maintain signal integrity and minimise noise fluctuations. During 2016 the Group was involved with the MOKU second generation project, designing new printed circuit designs, producing prototype boards for the company and also conducting testing of the equipment.

8 Channel cold seal furnace

The 8 Channel Cold Seal Furnace project provides a new experimental facility capable of running 8 furnaces using a computer interface for automated control of sample heating. Data logging will enable viewing and storing of experiment parameters. The project involves programming of proportional, integral, differential (PID) controllers accurately manipulating phase angle firing units to regulate furnace power. The system includes a computer interface and Labview user screen easily giving the client access to all system parameters and historical temperature trends. All electronics and software were developed by the Research School of Earth Sciences Electronics Group. During 2016 the project was completed and the implementation process was started. This involves wiring furnace power lines and communication cables in the laboratory.

Horizontal tube furnace

The Gas Tube Furnace Controller project provides for metered gas flow through a horizontal tube furnace at temperatures up to 1500°C. A sample placed inside the quartz or alumina tube is exposed to the controlled gas, usually CO_2 or SO_2, for a defined time period at a fixed temperature after which it is analysed with separate instrumentation. The composition of the gas after it has reacted with the sample is also analysed. A mechanical assembly was manufactured to house the calibrated gas Mass Flow Controller unit and associated valves to allow various gas sources and purge control. An electronic control unit interfaces the Mass Flow Controller to a purpose-built LabVIEW user interface via a USB link. The system is capable of controlling two experiments simultaneously, and acquires temperature data from up to four thermocouples. Data is recorded to file, along with other user-defined data such as the sample specification.

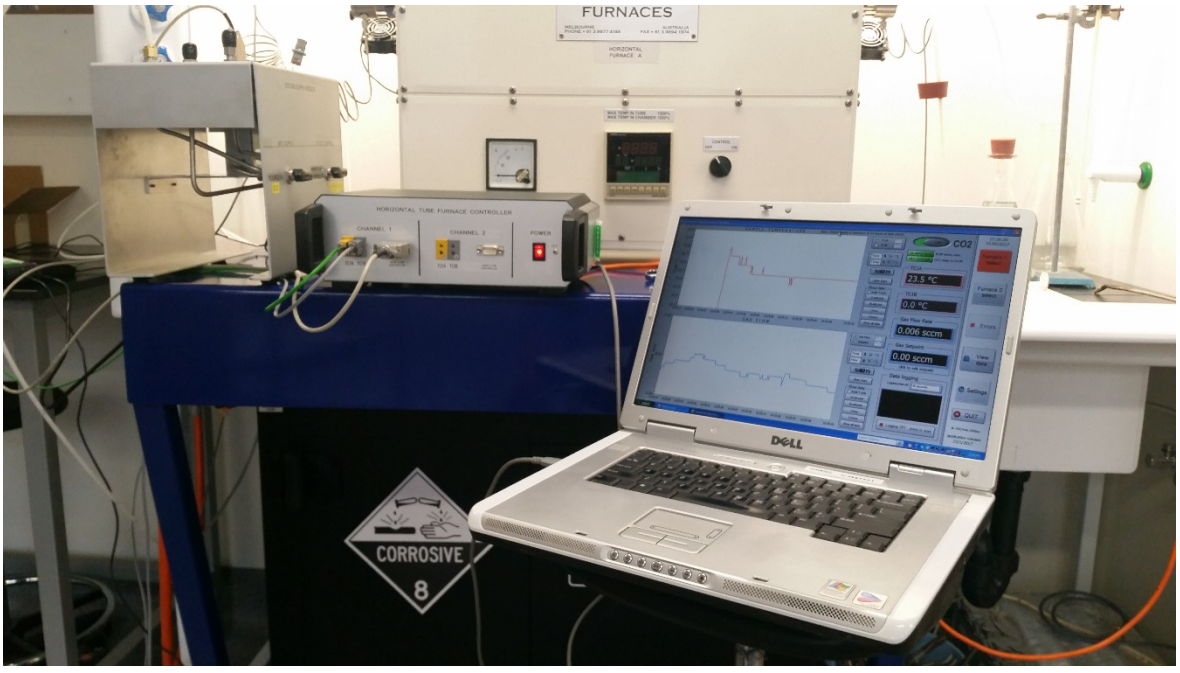


Figure 3. Horizontal Tube furnace and controller

SHRIMP upgrades abroad

During 2016 the RSES Electronics Group was commissioned by Australian Scientific Instruments to build field controllers (FC4) for the Russian and Chinese SHRIMP installations as upgrades improving stability and allowing these mass spectrometers to analyse stable isotopes. The Group was also commissioned to construct 4 IFLEX electrometers and 4 field probes. The construction and testing of these units has taken considerable labour during this period and heavily utilised our automated pick and place, electronic assembly machine. These innovations designed by the RSES Electronics Group have been operating on RSES SHRIMP 2, SI , RG and have provided RSES with superior performance. The data captured at RSES on SHRIMP and subsequent papers written have created a demand for these enhancements abroad and the units are now available to purchase as upgrades through Australian Scientific Instruments.

ENGINEERING WORKSHOP

Engineering Workshop Staffing

Andrew Wilson, Carl Were, Brent Butler, Geoff Woodward, Hayden Miller (50% FTE):

4.5 FTE Staff.

After 31 years of experience in the RSES Engineering Workshop, David Thomson has moved to a full time technical position with the SHRIMP Group.

The Workshop extends its appreciation and thanks to David for many years of service in the workshop.

Activities

There was an increase in the total number of jobs logged this year. More frequent, smaller jobs are being requested.

Internal charge rate for 2015: $45/hour + materials, consumables and running costs.

Turnaround time for engineering workshop requests for 2016 was short.

The core work undertaken in 2016 included:

Vessel refurbishments, consumables and repairs - Dr Andrew Berry. (G. Woodward, C. Were)

SHRIMP maintenance and development, including vibrating reed electrometers, new sample holders, SI ion optic testing and improvements - Prof. Trevor Ireland. (H. Miller, B. Butler, G. Woodward, C. Were, A. Wilson)

Pulley System for deployment of equipment from ship's deck - Dr Michael Ellwood. (H. Miller, B. Butler, G. Woodward, C. Were)

Long plate type heat exchanger for GFD - Dr Ross Kerr. (B. Butler)

Pressure intensifier for Rock Physics – Prof. S Cox (G. Woodward, A. Wilson)

Solar prisms for Photovoltaics Group - CECS ANU (see image overleaf) (B. Butler, C. Were)

High temperature furnace for corrosion testing of materials - CECS ANU, Dr Joe Coventry. (B. Butler, A. Wilson)

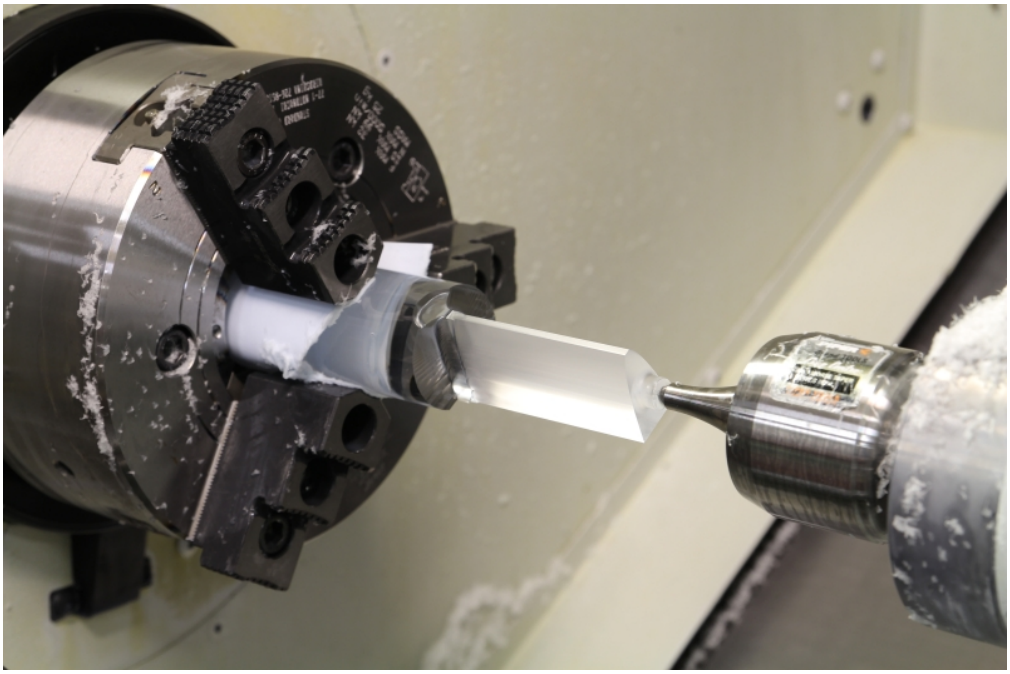


Figure 1. Manufacture of Acrylic Lenses for use on solar panels for CECS ANU

RSES Engineering Workshop Resource Distribution		
Labour Totals	**Hours**	**%**
Uncharged Work	1688	30
Charged Work	4185	71
Total logged hours	5874	
Charged Distribution (Internal RSES/External)		
Research Support RSES	3445	82
External Work	740	18
Total charged hours	4185	
Uncharged Distribution		
Training	241	14
Administration	885	52
Workshop Equipment, Servicing and Repairs	426	25
Other	136	9
Total uncharged hours	1688	

ALUMNI RELATIONS AND PHILANTHROPY

Mary Anne King

2016 marked seventy years since the formal establishment in 1946 of the Australian National University (ANU). At the celebrations in August, Vice-Chancellor Professor Brian Schmidt AC reminded the community that 'ANU has been integral to the building of Australia as a prosperous country with a unique national identity. Our alumni populate the universities of this nation, the corridors of parliament and our governments, the boardrooms and engine rooms of industry and the frontiers of civil society. Our staff and alumni have created a modern Australia.'

Throughout the year our alumni and friends have supported RSES research and education in various ways. Alumni gave their time and expertise to mentor students, present seminars and provide valuable advice to our research groups. The Earth Sciences Future Fund launched in 2015 continues to grow. Donations to this fund, whether large or small, collectively bring change to the lives of our students through scholarships, strengthening our teaching resources, funding field work activities and promoting innovative research.

Some major highlights:

- Alumnus and former Director, Ian Jackson FAA donated $80,000 to support a post-doctoral fellowship;
- John and Kerry Lovering committed $25,000 to establish a scholarship for the Masters of Earth Sciences (Advanced) program with the inaugural recipient to be announced in 2017;
- Alumnus Phil Creaser gave $10,000 to support the geological collections;
- A successful Geology Reunion (1995 -1999) was held at RSES with alumni coming from all over Australia; and
- ANU Alumni Awards Gala Dinner at Old Parliament House was a chance for RSES to say thank you to some of our inspirational and outstanding alumni.

The RSES community is very grateful for the support of our donors, alumni and friends. We are doing what we set out to do: working together to ensure RSES has a secure and prosperous future.

New donors to RSES: Prof. John Lovering AO, FAA and Mrs Kerry Lovering OAM

RESEARCH GRANTS AWARDED DURING 2016

A/Prof. N.J. Abram, Dr D. Ackerley, Dr S.J. Phipps, Dr S.E. Lewis, A/Prof. D. Dommenget 'An ensemble of simulations for Australasian palaeoclimate data-model assessments'; ANU computational merit allocation scheme; 2016; ~$32,000 equivalent.

A/Prof. N.J. Abram, Prof. G. Farquhar, **Prof. E.J. Rohling** 'ANU water isotope capabilities for climate, environmental and biological research.'; ANU Major Equipment Grant; 2016; $210,000.

A/Prof. N.J. Abram 'Quantifying and mitigating changes in Australia's rainfall belts'; ARC Future Fellowships; 2016-2020; $933,000.

Prof. A. Nutman, **A/Prof. V. C. Bennett**, Prof. M. Van Kranendonk 'Engineering planetary habitability: Earth's critical first billion years'; ARC Discovery Project; 2017-2019; $270,000.

A/Prof. A. Berry, Prof. H. O'Neill, E. Mare 'Coordination and valence state of Ge and Ga in silicate glasses quenched from high pressure melts'; Australian Synchrotron Access Program; 2016; $1,720.

A/Prof. J.J. Brocks 'Lost world of complex life: Molecular traces of our primordial ancestors billions of years old'; ARC Discovery; 2017-2019; $406,000.

Prof. I.H. Campbell, A/Prof. A.J. Berry, Prof. J. Richards Prof. J. Blundy 'Predicting gold-copper fertility in mountain belts'; ARC Discovery Project; 2017-2019; $315,000.

Prof. S F Cox, Dr B. Slagmolen, Dr D. Shaddock, **Dr M. Salmon,** Dr A. Okamoto 'Capturing earthquake events in the laboratory'; ANU Major Equipment Committee; 2016; $88,000.

Prof. P.R. Cummins 'Strengthening graduate education and research in earthquakes and active tectonics at Bandung Institute of Technology'; Department of Foreign Affairs and Trade; 2016-2018; $498,460.

Dr D.R. Davies, Prof. I.H. Campbell, Prof. B.L.N. Kennett, Prof. N. Rawlinson 'Earth's intra-plate volcanic engine'; ARC Discovery Project; 2017-2019; $286,000.

A/Prof. M.J. Ellwood, Dr C. Hassler, Dr S. Jaccard, Prof. D. Vance, Dr T. Conway, Prof. W. Maher, Prof. R. Francois, Dr S. Cérantola, Dr C. Boisset, Dr S. Sander, Prof. B. Koch, Prof. S. Trimborn, Prof. V. Slaveykova 'Linking marine primary production to the cycling of dissolved organic compounds and trace elements in Southern Ocean waters'; Swiss Polar Institute; 2016-2018; €260,000.

Dr H.L. Neil, Dr Sinclair, **Dr S.J. Fallon** 'Corals, currents, and phytoplankton: Reconstructing 3000 years of circulation and marine productivity in the world's largest ocean gyre'; Royal Society of New Zealand, Marsden; 2017-2019; $850,000.

A/Prof. Hogg, Prof. M. England, Dr G. Brassington, Dr P. Heil, Dr P. Oke, Dr J.P. Spence, Dr M. Nikurashin 'An Australian consortium for eddy-resolving global ocean-sea ice modelling'; ARC Linkage Project; 2016-2020; $598,000.

Prof. P. Bland, **Prof. T. Ireland,** A/Prof. Tracy Rushmer, A/Prof. J. Horner, A/Prof. G. Benedix, Dr A. Tomkins, Dr J-P Macquart, A/Prof. H. Chennaoui, Dr G. Collins, Prof. P.

Brown, Dr P. Jenniskens, Prof. Dr C. Herd, Prof. T. Swindle, Dr Y. Pendleton 'A global fireball observatory'; ARC LIEF (LE170100106); 2017; $780,000.

Dr M.A. Kendrick 'Halogens and noble gases in oceanic gabbros: implications for seafloor alteration, volatile subduction and flux melting of the crust'; ANZIC post cruise funding; 2016; $39,900.

Dr M.S. Ramsey, Dr R.J. Lee, **A/Prof. P.L. King** 'The spectral and thermal response of active basaltic surfaces: Constraining lava cooling, petrology and flow propagation models'; National Science Foundation (NSF) – Division of Earth Sciences (EAR) – Collaborative Research; 2016-2017; $14,000.

A/Prof. P.L. King, Dr U. Troitzsch 'Crystal structure characterization of carbonates in coralline algae with microdiffraction (07858)'; Advanced Light Source (Lawrence Berkeley National Laboratory) General User Proposal; 2016; 72 hours.

A/Prof. P.L. King, Dr U. Troitzsch 'International travel funding: Crystal structure characterization of carbonates in coralline algae with microdiffraction (ID10908)'; Australian Synchrotron (International Synchrotron Access Program); 2016; $6,400.

A/Prof. P.L. King, Dr U. Troitzsch 'Crystal structure characterization of carbonates in coralline algae with microdiffraction (07858)'; Advanced Light Source (Lawrence Berkeley National Laboratory) General User Proposal; 2017; 48 hours.

Dr G. Mallmann 'Redox evolution of basaltic magmas'; ARC DECRA; 2016-2018; $365,206.

Dr G. Marino 'Glacial-interglacial climate cycles in the equatorial Indian Ocean'; International Ocean Discovery Program (IODP) post-cruise funding; 2016-2018; $40,000.

Dr H. Olierook, **Dr R. Merle,** A/Prof. F. Jourdan, Dr J. Whittaker 'Time constraints on the world's clearest oceanic curved fracture zone: implications for a global plate reorganisation in the Cretaceous'; International Ocean Discovery Program (IODP) consorsium grants; 2016; $10,000.

Dr S. Meffre, Dr J. Whittaker, **Hon. A/Prof. M. Norman**, Dr M. Cracknell, Dr E. Belousova, Prof. W. Collins, Mr M. Arundell, Prof. D, Cooke, Dr R. Maas, Dr D. Huston, Dr R. Musgrave, Dr J. Greenfield 'Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia.'; ARC Linkage Project; 2016-2018; $418,000.

Prof. H. O'Neill, A/Prof. A. Berry, L. Miller 'The high temperature geochemistry of antimony'; Australian Synchrotron Access Program; 2016; $1,720.

Prof. H. O'Neill, Prof. R. Arculus, Dr E. Green 'A new perspective on melting in the Earth and the origin of basalts'; ARC Discovery Project; 2017-2019; $476,000.

Dr A. Purcell, A/Prof. P. Tregoning, Dr D.R. Davies 'Review of the CarbonNet probability approach for reservoir dynamic modelling'; Victorian Department of Economic Development, Jobs, Transport and Resources; 2016-2017; $50,000.

Prof. A.P. Roberts, A/Prof. D. Heslop, Prof. E.J. Rohling, Dr X. Zhao 'Development of new instruments for paleomagnetic research'; ANU Major Equipment Committee; 2016; $60,000.

Prof. M. Roderick, A/Prof. A. Hogg '2.4 Changing oceans and Australia's future climate'; National Environmental Science Program; 2016-2019; $45,000.

Prof. M. Roderick, A/Prof. P. Tregoning '2.10 Coastal hazards in a variable and changing climate'; National Environmental Science Program; 2016-2019; $100,000.

Prof. A. Pitman and 17 other CIs, including **Prof. M. Roderick, A/Prof. A. Hogg, A/Prof. N. Abram** 'The Centre of Excellence for Climate Extremes'; ARC Centres of Excellence; 2017-2023; $30,050,000.

Prof. M. Sambridge, Dr M. Salmon 'Earth imaging and monitoring: Capital and operations'; AuScope Ltd.; 2016-2017; $890,000.

Prof. M. Sambridge, Dr M. Salmon 'Earth imaging and monitoring: Seismometers in Schools'; AuScope Ltd.; 2016-2017; $200,000.

A/Prof. H. Tkalčić '3-D Green's functions for Australia and surrounding regions'; Geoscience Australia; 2016-2017; $50,000.

Prof. R. Roberts, Prof. A. Lawson, Prof. Z. Jacobs, Dr T. Cohen, Prof. M. Bird, Prof. S. Ulm, Prof. C. Turney, Prof. M. Nakata, Prof. D. Curnoe, Prof. S. O'Connor, Prof. S. Haberle, Prof. A. Cooper, Prof. C. Bradshaw, Dr L. Weyrich, Dr B. David, Prof. L. Russell, Prof. B. Brook, Prof. C. Johnson (chief investigators) **Dr R. Wood** (as one of 10 associate investigators) 'Australian biodiversity and heritage'; ARC Centre of Excellence; 2017-2022; $33,750,000.

PEER-REVIEWED PUBLICATIONS

Abram N.J., McGregor H.V., Tierney J.E., Evans M.N., McKay N.P., Kaufman D.S., PAGES 2k Consortium (2016) Early onset of industrial-era warming across the oceans and continents. Nature 536, 411-418, doi:10.1038/nature19082.

Ali S., Ismail S., Nutman A., **Bennett V**., Jones B., Buckman S. (2016) The intra-oceanic mid-Cretaceous (~108 Ma) Kata-Rash arc fragment in the Kurdistan segment of Iraqi Zagros suture zone: Implications for Neotethys evolution and closure. Lithos 260, 154–163, doi:10.1016/j.lithos.2016.05.027.

Allen K., Hönisch B., **Eggins S.M**., Haynes L.L., Rosenthal Y., **Yu J.** (2016) Trace element proxies for surface ocean conditions: A synthesis of culture calibrations with planktic foraminifera. Geochimica et Cosmochimica Acta 193, 197-221.

Aminzadeh M., **Roderick M.**, Or D. (2016) A generalized complementary relationship between actual and potential evaporation defined by a reference surface temperature. Water Resources Research 52, 385-406, doi:10.1002/2015WR017969.

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Ao H., Zhang P., Dekkers M.J., **Roberts A.P.**, An Z.S., Li Y.X., Lu F.Y., Lin S., Li X.W. (2016) New magnetochronology of Late Miocene mammal fauna, NE Tibetan Plateau, China: mammal migration and paleoenvironments. Earth and Planetary Science Letters 434, 220-230.

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