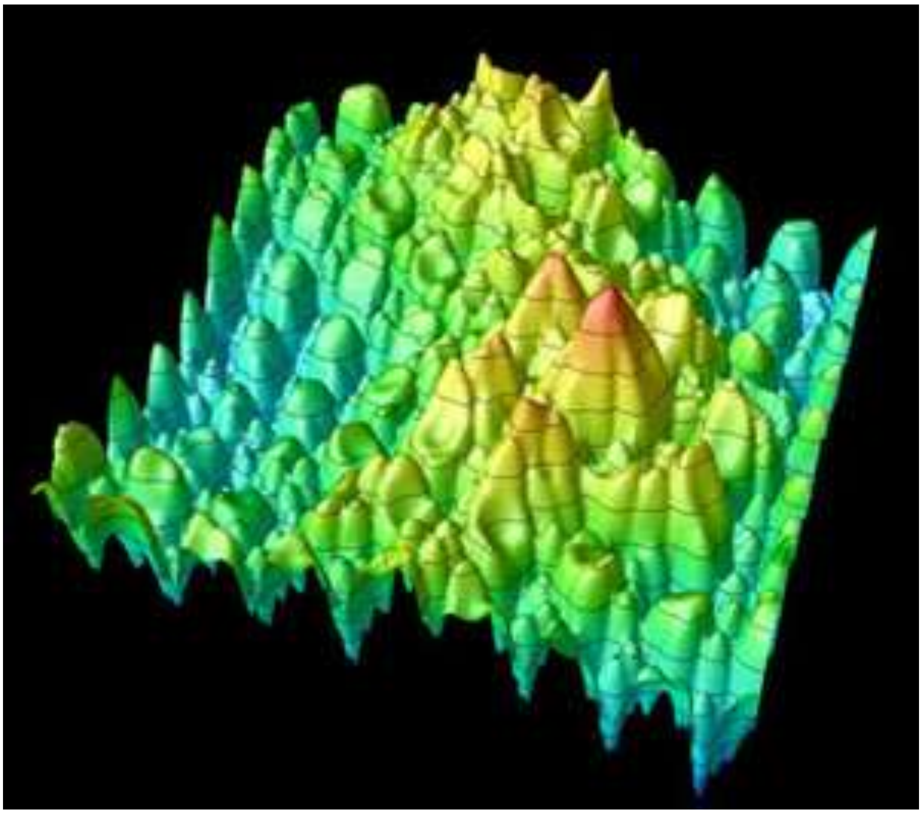
Research School of Earth Sciences

2003 Annual Report



A computer generated perspective image of a mathematical function measuring the fit to data between observed and predicted beam power in an infrasound array.

By locating the maximum of the data fit function one can estimate the parameters of the incoming wavefield. Infrasound detection is an important component in monitoring of the comprehensive test ban treaty (CTBT).

Here the maximum is found efficiently with the aid of the neighbourhood algorithm. An inversion technique, developed at RSES, which is rapidly finding applications across a wide range of geophysical inverse problems.

Reference
Signal Parameter Estimation for Sparse Arrays
Kennett, B. L. N, Brown, D. J., Sambridge, M., and Tarlowski, C., Bull. seism. Soc. Am., 93, No. 4, 1765-1772, August 2003.

ANU
THE AUSTRALIAN NATIONAL UNIVERSITY

RSES 2003 ANNUAL REPORT TO COUNCIL

Overview

The Research School of Earth Sciences (RSES) is one of the top ten, university-based geoscience programs in the world and the nation's premier centre for basic research in the physics, chemistry, material properties and environmental conditions of the Earth. Our research extends across the spectrum of the geosciences – from the conditions attending the emergence of life on Earth to the effect of human activity on the health of the Great Barrier Reef.

Cooperation with other ANU programs were bolstered in 2003 by support from the centre. University Council approved a capital borrowing package that includes co-location of the Department of Earth and Marine Science on the RSES campus, a move that will enhance both geoscience teaching and research at ANU. The Planetary Sciences Institute, a collaboration with RSAA, received funding in 2003 to permit us to begin recruitment of the first two joint faculty appointments.

The School has fully transitioned into the new external funding environment. The $3.50M raised from ARC for 2004 alone represents a 500% return on our entry levy. In the first three years of eligibility, our average success rate of 50% in the Discovery and LIEF programs is more than double the national average. As we approach steady-state funding from ARC sources we have a clear idea, at least for the intermediate future, of how our performance translates into additional income. This permits us to transfer certain direct research costs from the block grant to externally derived income. We undertook an internal round of strategic planning in 2003 in which disencumbered block grant funds were completed for. Six new initiatives representing promising new research directions (described below) were supported.

Most indicators of the present and future health of the School are highly positive. Our success in extramural funding reflects our distinguished international reputation and close correspondence to national and geoscience community research priorities. Despite these encouraging developments, several challenges loom. Paradoxically, one is the success of the U.S. Earthscope program through which the National Science Foundation will pour up to half a billion new dollars into geophysics research over the next decade. While this augurs well for the employment prospects of our students, we anticipate a highly competitive environment in terms of recruiting academic staff in this area. Another concern is the lack of matching funds for large scale federal grant programs at the level routinely available to state universities. While we have been able to increase the number of our RTS students over the past few years, undergraduate geoscience enrollments are down requiring that we redouble our efforts to place the very best of them at Australia's premier research university.

Key Statements

Enhancing our national and international roles

- The Institute for Scientific Information's Highly Cited Researchers (those designated in the top 0.5% of cited researchers
  worldwide and a key indicator in the ranking of ANU as 49th among world universities) Geoscience category lists 8 RSES
  faculty. This represents 11% of the entire nations total across the 23 disciplines covered by ISI.
- 2003 was the first full year of RSES ownership of the Australian National Seismic Imaging Resource (ANSIR), the country's
  principal facility for sub-surface imaging. Additional recurrent funding approved in 2003 to support our Deep Earth Sounding
  initiative meets a national research priority and capitalizes on ANSIR ownership.
  Improving the educational experience of our students
- In 2003, University Council approved capital borrowing including an RSES initiated proposal for $8.7M to co-locate the
  Department of Earth and Marine Science on the RSES campus. When realized, cooperation engendered by this move will
  greatly enhance geoscience teaching at both the graduate and undergraduate levels.
- In 2003 we introduced our Honours/MSc curriculum in Physics of the Earth. The six courses taught were well subscribed.
  Enhancing our research performance
- Increased our utilization of ARC Discovery eligibility to 85% of total.
- Provided significant input into the 2003 National Strategic Plan for the Geosciences, an AAS sponsored activity
  http://www.science.org.au/natcoms/earth-strategic.pdf), that endorsed a research plan essentially inseparable from the
  activities of RSES.
- Completion of a $0.6M expansion and refurbishment of our electronics design and fabrication facilities.
- Undertook a round of internal strategic planning using block grant funds freed up by retirement, a policy of over substitution
  of ARC funds, and supplementary R-funds to: appoint a level C faculty in satellite geodesy, recruit two new positions in
  seismology, recruit in the exciting new area of computational mineral physics, and support a $1M, 5-year proposal for a
  Center for Advanced Data Inference (CADI). In addition, matching funds for two major equipment bids were supported.
  Enhancing our role in research training
- Enhanced efforts at recruitment of RTS students through publication and distribution of a new graduate brochure and
  vast improvements to our web environment.
- Creation of a research intern program (http://rses.anu.edu.au/rses/Interns.html) targeting high-quality Sydney/Melbourne
  students early in their undergraduate career into a track leading to postgraduate enrolment at RSES. We aggressively
  marketed this scheme through mailings, advertisements, and employment of a special projects officer.

- Leading a DEST/EU proposal for a 15 institution, Europe-Australia cotutelle MSc.
  Continuing to develop our staff
- Development of a graduate student induction manual.
- Continuing commitment to upgrade the skills of academic and support staff through attendance at IT, management,
  vehicle safety, and other relevant courses and through formal technical and professional study.
  Seeking appropriate partnerships and alliances, both academic and business
- Appointed Dr Chris McFarlane in ore genesis studies via a jointly-funded arrangement with CSIRO Exploration and Mining.
- Close cooperation with ASI Ltd in developing the new SHRIMP SI ion microprobe and multi-collector ion detection system.
- Engaging a consortium of Australian research units (UWA, JCU, Curtin, UTas, Macquarie, CSIRO E&M, Melbourne, and Monash)
  to prepare cooperative bids for major federal grant opportunities (e.g., a Centre of Excellence bid in Australia's Exploration Future).
- Continued strong linkages with Geoscience Australia, involving a large number of GA visitors and cadets working within the School
  (e.g., ANSIR, SHRIMP, CADI). Diversifying funding base
- We are core participants in the Australian Earth and Ocean Network bid to ARC.
- We are partners in three CRCs — Greenhouse Accounting, Landscape Evolution and Mineral Exploration (LEME), and Antarctic CRC.

Budget Performance

The School's operating grant in 2003 was $8.79 million which was supplemented in the recurrent ledger by a further $1.58 million.
This additional income was made up of internal allocations, including MEC grants, student fees, and transfers and income from other
areas in the University. It also includes external income of $282,000 which was derived primarily from consultancies, hire of research
facilities, the sale of research services and project support. The School also received a transfer of Long Service leave funds of $137,852.
The School's net cash operating position was $1,009,307, with a cash surplus of $75,164 for the year adding to the cash carry forward from
2002. The School regards this surplus as necessary given the salary increases resulting from the new enterprise agreement. As in 2002,
approximately 73% of the School's recurrent expenditure budget was taken up by salaries.

Other income to the School in 2003 from sources external to the University was $6.7 million. This was made up primarily of grants of
$2.99 million, contract research ($1.6m), sales of research services ($1m) and external contributions to projects ($634,000). The rest
came from items such as consultancies, the hire of research facilities, interest on held funds and recovery of expenses from external sources.

Gender Equity Performance

The School's gender profile did not change significantly in 2003. At the end of the year, 25 (26%) of general staff were women. Of the 10
School staff at ANUO9 or above, 3 were women. The small number of women academics

continues to be of concern. Four (19%) of 47
academic staff were women, of which only one holds a standard appointment. Despite internationally increased participation at the
undergraduate and graduate levels over the past ten years, we have yet to see a corresponding increase in women applicants.

Significant Achievements in Research and Teaching

Some highlights from each of the four thematic areas of the School are:

Earth Environment

- The Alpine Iceman Dr Wolfgang Müller's paper in Science, "The origin and migration of the Alpine Iceman",
  presented a stunningly detailed reconstruction of the life of 'Otzi' based on isotopic evidence.
  The story gained world-wide media attention by providing a superb example of geochemistry as a leading forensic science.
- Anthropologic degradation of the Great Barrier Reef Prof Malcolm McCulloch's paper in Nature, "Coral Record of increased s
  ediment flux to the inner Great Barrier Reef since European settlement", conclusively showed that European faming practices had
  significantly increased the sediment load into the Great Barrier reef. Publication of this paper, with its implications to reef degradation,
  generated heated public debate.

Earth Chemistry

- Plutonium and the origin of the atmosphere Prof Harrison discovered evidence, in the form of xenon isotopes in 4.1 to 4.2 billion
  year old zircons, that plutonium was present on Earth for the first 500 million years of its history. This recognition provides a basis
  for us to learn about the physical conditions on Earth during its most formative stage, including the age and origin of the Earth's atmosphere.
- A SHRIMP multi-collector and the origin of the solar system After 20 years in development, the first stable isotope measurements using
  the SHRIMP II multi-collector were undertaken in 2003. Oxygen isotopes in lunar metal grains reveal that solar wind is depleted in 18O
  and 17O relative to the Earth. This supports a radically new view of a primordial 16O anomaly that has puzzled cosmochemists for 30 years.

Earth Materials

- An improved understanding of the Earth's seismic structure Laboratory measurements of the shear modulus and strain
  energy dissipation in an important mantle mineral by Dr Faul and Prof Jackson shows that a globally extensive layer of
  low seismic velocity in the Earth's upper mantle is not due to melting, as long believed, but instead reflects viscoelastic relaxation.
- Spatial distribution of gold mineralisation Dr Micklethwaite and Prof Cox have advanced the theory that spatially

concentrated aftershock activity, following rupture on major faults, focuses the flow of fluids from which gold ores are deposited.
This concept, which can aid in assessing gold prospectivity, has been dubbed the “Golden Aftershocks” hypothesis.

Earth Physics

- Terrawulf Drs Braun and Sambridge commissioned the 128 processor computer cluster, Terrawulf. This system is the centrepiece of the Centre for Advanced Data Inference, an initiative dedicated to extracting unprecedented insights into Earth behaviour from ultra-large datasets. Current investigations include ensemble Earth tomography and tectonic modelling of the Himalaya.
- Structure of the Australian continent Prof Kennett established a large-scale array of broad-band seismometers in central and eastern Australia to better define the transition in the mantle between the ancient core of the continent and the younger belts in the east. Results will lead to a better understanding of how our continent and its mineral resources formed.

Student Numbers

At the end of 2003 the School had 36 postgraduate students enrolled (35 PhD and 1 MPhil). 32 were in the Earth Sciences Graduate Program and four in the Quaternary and Regolith Studies Program. The most popular broad areas of study were Earth Environment (14 students) and Earth Physics (nine students). The popularity of environmentally focused studies is steadily increasing, particularly amongst Australian students. During 2003, 18 students commenced postgraduate study (compared with 9 in 2002) and 11 students submitted their theses.

Major Prizes, Honours and Awards

Staff

- Prof Mervyn Patterson was awarded the Walter Bucher Medal (American Geophysical Union) for “seminal, and innovative contributions to understanding the strength and mechanical behaviour of crustal materials”.
- Profs Anton Hales, John Chappell, William Compston, David Green, Ross Griffiths, Brian Kennett, Kurt Lambeck, Ian McDougall, Mervyn Paterson, and Stewart Turner were awarded the Australian Centenary Medal.
- Prof John Chappell was awarded the David Brown Medal, “for contributions to Geology” (ANU)
- Prof David Green was elected as a Foreign Member of the Russian Academy of Sciences in recognition of his scientific research on the Earth’s mantle and on the genesis of basalts.
- Prof Ian Jackson was elected a Fellow of the American Geophysical Union.

- Dr Hugh O'Neill was awarded the Schlumberger Medal from the Mineralogical Society of London.

Students

- Ms Nerille Abram was awarded the RSES Robert Hill Memorial Prize in recognition of her interdisciplinary research and effective communication in the Earth Sciences.
- Ms Rebecca Fraser and Mr Tim Wyndham recipients of the Mervyn and Katalin Paterson Fellowship in 2003.
- Ms Julia Mullarney was awarded a Summer Fellowship by the Woods Hole Oceanographic Institution, USA, to attend the Geophysical Fluid Dynamics Summer Program, June 23 – August 22.
- Mr Todd Nicholson was awarded the ANU J.G. Crawford Prize for his Ph.D. thesis submitted in 2002.

New Grants

Australian Research Council grants (commencing in 2003)

Discovery grants (2003)

Dr R. Armstrong: Precise global time scale for the oxidation of Earth's atmosphere between 2.6 and 2.0 billion years ago. $60,000 (2003-05)

Dr A. J. Berry and Dr J. Hermann: Water storage in the Earth's mantle – understanding the process of OH incorporation in olivine. $87,000 (2003-04)

Dr J. Braun: Constraining landform response to tectonic and climate changes in an active orogen: a multi-disciplinary approach. $385,000. (2003 – 05)

Prof. J. Chappell, Dr M. Honda, Dr D. Fabel and Dr L.K. Fifield: Production and transport of soil and sediments, determined by cosmogenic radionuclides and noble gases. $295,000 (2003-05)

Prof. J. Chappell and Dr T. Esat: Millenial scale instability of sea level and climate system: new analysis of coral terraces in Papua New Guinea. $295,000 (2003-05)

Dr W. Dunlap and Dr S McLaren: From synchrotron characterisation of single fluid inclusions to Archaen geodynamics: an integrated study of fluid-rock interaction in the primitive crust. $46,200 (2003-05)

Dr M. Gagan: Quantifying the El-Nino-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives. $300,000 (2003-05)

Dr R.W. Griffiths and Dr R.C. Kerr: The fluid dynamics of lava flows: Silicic domes and basaltic channels. $220,000. (2003-05)

Prof. R. Grun and Dr M.K. Gagan:Stable Isotopes in marsupials: reconstruction of environmental change in Australia. $210,000 (2003-05)

Prof. T.M. Harrison, Dr T.R. Ireland and Dr V.C Bennett: A mission to very early Earth: when did conditions suitable
for life emerge on Earth?" $300,000 (2003-05)

Dr M. Honda: Diamonds – a window into the ancient mantle; the origin and Earth's atmosphere and outgassing of the mantle. $50,000 (2003)

Dr T. Ireland: Lithic astronomy: the age and origin of the elements and their incorporation in the solar nebular. $195,000 (2003-05)

Prof. B.L.N. Kennett: Craton edges and sutures in the Australian mantle $340,000 (2003-05)

Prof. K. Lambeck, Dr D. Fabel and Dr P. Tregoning: Looking back to see the future: Change in the Lambert Glacier and the
East Antarctic Ice Sheet. $530,000 (2003-2006)

Prof. G.S. Lister and Prof. M. Harrison:Tectonic reconstruction of the evolution of the Alpine-Himalayan orogenic chain. $710,000 (2003-07)

Dr A.P. Nutman and Dr V.C. Bennett: Early Archaen Ecology – exploring the evidence and habitats for early
(3.6 – 3.85 billion year old) life. $162,000 (2003-05)

Dr A.P. Nutman: Deep crustal section through a late archaen orogon (Greenland): Archaen crustal sutures, abyssal peridotites and gold.
$170,000 (2003-05)

Dr H.S.C. O'Neill, Dr J. Hermann, Dr J. Mavrogenes and Prof. R.J. Arculus: Properties of hydrous fluids and silicate melts at very
high temperatures and pressures. $260,000. (2003-05)

Dr C. Pelejero: Uptake of Atmospheric CO2 in the oceans and implications for global change: new proxy developments. $263,035 (2003-05)

Dr P. Tregoning: Caught in a vice: Modelling crustal deformation in Papua New Guinea. $380,000 (2003-07)

Linkage grants

Dr I. Jackson: High temperature elastic wave speeds of mantle minerals and their seismological implications. $20,000 (2003-04)

ARC Linkage Infrastructure, Equipment and Facilities Grant
Dr J. Braun, Dr M Sambridge ARC LIEF: GeoWulf: An Inference Engine for Complex Earth Systems $376,951(2003)

Other Grants commencing in 2002

Dr A.J. Berry, grant from the Victorian Dept of Innovation, Industry and Regional Development for the Australian Geological Convention.:
$10,795 (2003)

Dr A.J. Berry, ANSTO ASRP grant to undertake work at the Australian National Beamline Facility, Photon Factory, Japan.
$4,370 (2003)

Dr A.J. Berry, Dr J. Mavrogenes and Dr H. O'Neill, ANSTO AMRFP grant to visit GSECARS, Advanced Photon Source, Argonne
National Laboratory, USA. $11,050. (2003)

Dr A.J. Berry, Dr H. O'Neill and Mr S. Sommacal, ANSTO AMNRF grant to visit the European Synchrotron Radiation Facility
, Grenoble, France. $11,150 (2003)

Dr A.J. Berry, ANSTO ASRP grant $6,680 (2003)

Dr E. Tenthorey, Swiss National Science Foundation Research Fellowship for work to be conducted at the ANU $105,000. (2003)

Dr J.G. Wynn, Australian Institute of Nuclear Science and Engineering: AMS C-14 determinations of particle size fractions from
Australian soil organic carbon (SOC) to test Century model of SOC dynamics, $7357 (2003).

Major Equipment Committee

Dr J. Braun, Dr M Sambridge ARC LIEF: GeoWulf: An Inference Engine for Complex Earth Systems $75,000 (2003)

Dr. H O'Neill : High resolution powder X-ray diffractometer with controlled-atmosphere high temperature capabilities $199,000 (2003)

National Institutes

Virtually all RSES Faculty and a number of graduate students and general staff are members of either the National Institute of
Physical Sciences (NIPS) or the National Institute of the Environment (NIE), with several holding joint membership. Prof Chappell
is on the NIE Board of Management, gave a NIE/NITA public lecture, and participated in the "Factor of Ten" environmental expo
as speaker and essayist. Prof Harrison is on the NIPS steering committee. NIE funded a joint RSES/CCRC project on the
environmental legacy of selected naturalists.

Future Directions

Research

In 2003, the National Committee for Earth Sciences, under the auspices of the Australian Academy of Science, launched its National Strategic Plan for the Geosciences (http://www.science.org.au/natcoms/earth-strategic.pdf). The document identified six exciting, emerging research opportunities in the geosciences: Decoding the dirt – environmental challenges on a dynamic Earth, Exploring submerged Australia, Exploring covered Australia, Journey to the centre of the Earth, The origin of life and its role in earth systems, and the Science of other worlds – is anyone out there? With the exception of the second theme, RSES is without question the national leader in developing these research opportunities.

Over the coming years, the School will evolve consistent with the School reorganization put in place in 2002. We look to our Planning Fund (see 2001 Report to Council), success in ARC competitive grants, and initiatives funded via the Vice-Chancellor's re-distribution of the 3% withheld from recurrent budgets to align our research with School, university, community, and national priorities. The Planning Fund will be used to maintain support for those high risk, long term activities of national significance for which the block grant is properly used. During 2003 we undertook an internal competition for support through the Planning Fund and approved proposals for new faculty appointments in planetary sciences (2 positions), deep earth sounding (2 positions), computational mineral physics (1 position), and geodesy (1 position). A new Centre for Advanced Data Inference was funded for 5 years at $200,000/yr and matching funds for both a stable-isotope-capable SHRIMP and 14C accelerator were approved.

Students and Teaching

The School is giving priority to increasing student numbers. My target remains a progressive increase to a student load of around 40 with a 2:1 balance of RTS vs. international students. This represents a real challenge, particularly given decreasing enrolments in physical sciences and the propensity of Australian universities to work against the ultimate best interests of both students and the universities themselves by encouraging their own students to pursue postgraduate study within their undergraduate department. In 2003, the formula for internal allocation of School funds was modified to include a student load factor. Several initiatives (brochure, recruitment officer, improved web page) enhance our visibility in this regard.

Mark Harrison
Director
March 10, 2004

STAFF AND STUDENTS

ACADEMIC STAFF

Director and Professor:

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

Professors:

J.M.A. Chappell, BSc MSc Auckland, PhD ANU, FAAS, FAA
S.F. Cox, BSc Tasmania, PhD Monash
R.W. Griffiths, BSc PhD ANU, FAIP, FAA
R. Grün, DiplGeol, Dr.rer.nat.habil Köln, DSc ANU
I.N.S. Jackson, BSc Qld, PhD ANU
B.L.N. Kennett, MA PhD ScD Cambridge, FRAS, FAA
K. Lambeck, BSurv NSW, DPhil, DSc Oxf, FAA, FRS
G. Lister, BSc Qld, (Hons) James Cook, PhD ANU (from 1 July 2003)
M.T. McCulloch, MAppSc WAIT, PhD CalTech

Senior Fellows:

J. Braun, LicSc Liège, PhD Dalhousie
I.H. Campbell, BSc UWA, PhD DIC London
G.F. Davies, MSc Monash, PhD CalTech
T. Esat, MSc Queens, PhD ANU
M. Honda, MSc PhD Tokyo
T.R. Ireland, BSc Otago, PhD ANU
R.C Kerr, BSc Qld, PhD Cambridge, FAIP
F.E.M. Lilley, BSc Sydney, MSc PhD WOnt
H.St.C. O'Neill, BA Oxf, PhD Manchester
B.J. Pillans, BSc PhD ANU
M.S.Sambridge, BSc Loughborough, PhD ANU

Fellows:

R.Armstrong, BSc MSc PhD Witwatersrand
V.C. Bennett, BSc PhD UCLA
M.I. Bird, BSc Sydney, PhD ANU
D. Brown, BSc Adelaide, PhD ANU (until 2 February 2003)
W.J. Dunlap, BA CarlCol, MS PhD Minnesota
S. Eggins, BSc UNSW, PhD Tasmania
C.M. Fanning, BSc Adelaide
M.K. Gagan, BA UCSantaBarbara, PhD JamesCook
R.R. Loucks, BS Colorado, PhD Harvard (until 14 February 2003)
J.A. Mavrogenes, BS Beloit, MS Missouri-Rolla, PhD VirginiaPolyTech
W. Müller, DiplGeol Vienna, PhD ETH (from 1 November 2003)
M. Norman, BS Colorado, PhD Harvard
A.P. Nutman, BSc PhD Exeter

E. Rhodes, BA DPhil Oxf (from 1 July 2003)
I.S. Williams, BSc PhD ANU

Research Fellows:

A.J. Berry, BSc Sydney, DPhil Oxf
F.G. Fabel, BSc PhD Melbourne
H.U. Faul, Vordiplom Ulm, PhD Oregon
M. Forster, BSc MSc PhD Monash (from 1 July 2003)
G. Hughes, BE ME Auckland, PhD Cambridge
C. McFarlane, BSc Toronto, MSc Calgary, PhD Texas (from 12 August 2003)
C. Meriaux, BPhys Paris XI, PhD Paris VII (until 9 January 2003)
A. Reading, BSc Edinburgh, PhD Leeds
P. Tregoning, BSurv, PhD UNSW
J. Wynn, BSc MSc Utah, PhD Oregon (from 16 February 2003 to 15 June 2003)
G. Yaxley, BSc PhD Tasmania

Postdoctoral Fellows:

C. Alibert, MSc Paris VII, PhD CRPG
C. Bryant, BSc UNE, PhD ANU
G. Dunbar, BSc MSc VicWell, PhD James Cook (from 9 July 2003)
J. Freeman, BSc Curtin, PhD Monash (from 13 October 2003)
A.C. Hack, AssocDip CIT, BSc PhD ANU (from 10 September 2003)
M. Heintz, BSc Nancy, MSc Strasbourg, PhD Montpellier (from 11 November 2003)
J. Hermann, Dip PhD, ETH
A. Kiss, BSc PhD ANU
J.F. Marshall, BSc UNSW, MSc PLD ANU
S.N. McLaren, BSc, PhD Adelaide
S. Micklethwaite, BSc PhD Leeds
C. Pelejero, BSc MSc PhD Barcelona (from 13 January 2003)
A. Pulford, BSc ANU, PhD Wellington (from 1 October 2003)
N. Rawlinson, BSc PhD Monash
E. Tenthorey, BSc McGill MSc Florida PhD Columbia

RESEARCH OFFICERS

D.R. Christie, MA Toronto, PhD ANU
P. Holden, BSc Lancaster, PhD St. Andrews
S.E. Kesson, BSc Sydney, PhD ANU
H.W.S. McQueen, BSc Qld, MSc York, PhD ANU
N.G. Ware, MSc Durham

RESEARCH ASSISTANTS

A. Arcidiaco, BAppSc, GradDip SAInst
B.J. Armstrong, BSc UNISA
M. De Kool, PhD Amsterdam (from 3 November 2003)
R. Decrevel BSurv SA (from 22 September 2003)
P. Fullsack, MAppSc Paris (from 20 November 2003)

I.T. Harman, BSc Armidale (until 17 March 2003)
R.W.L Martin, BSc ANU
A. Purcell, BSc PhD ANU
P. Rickwood, BSc UNSW, Dip Canberra (from 10 November 2003)
R. Stanaway, BAppSc Qld UTech
C. Tarlowski, MSc Moscow, PhD Warsaw (from 23 June 2003)
L. Weston, BSc Macquarie

POST-GRADUATE STUDENTS

PhD Candidates:

N. Abram, BSc (Hons) Sydney
A. Aikman, BSc (Hons) Edinburgh
B. Ayling, BSc Wellington
M. Beltrando, MSc Turin
R. Berdin, BSc MSc Philippines
R. Brodie, BSc QLD
S.N. Burgess, BSc (Hons) Adelaide MSc (Hons) Auckland
J. Celerier, BSc (Hons) Melbourne
R. Da Fonseca, BSc Lisbon
K. Dowell, BSc (Hons) ANU
S. Fishwick, BSc Edinburgh
T. Fujioka, BSc MSc Osaka
R. Fraser, Btech BSc Flinders
A.C. Hack, AssocDip CIT, BSc ANU
C.J. Heath, BSc Monash
F. Herman, Civ Eng, Belgium
T.-K. Hong, BSc MSc, Seoul National
B. Jenkins, BSc UTS
F. Jenner, BSc (Hons) Oxf Brookes
A. Kallio, MSc Helsinki
K. Lilly, BSc (Hons) ANU
X. Liu, MSc, ChineseAcSci, BSc ChinaUnivGeosci
A. Lyman, BSc MSc, Arizona State
H.V. McGregor, BSc James Cook
D. Maidment, BSc UNSW
I. McCulloch, BSc UNSW, GradDip ANU
M. Miller, BA Whitter, MSc Columbia NY, MEng Cornell NY
J. Mullarney, BA Cambridge, MSc Bristol
T. Prastowo, BSc ITS, MSc ITB
K. Procko, BSc Adelaide, BSc (Maths & Comp Sci) Adelaide, BSc (Hons) ANU
D. Qu, Petroleum Inst Jianghan, MSc Academy of Sciences China
P. Rustomji, BSc ANU
E. Saygin, BSc Istanbul Technical
M. Smith, BSc UNSW
S. Sommacal, Laurea in Science Geologiche (BSc) Univ Degli Studi Di Padova
A. Stoltze, BSc Curtin
W. Sun, BSc MSc USTC
V. Toy, BSc MSc (Hons) Auckland

P. Treble, BSc Wollongong, BSc ANU
J. Trotter, BSc MSc Macquarie
D. Wood, BSc Monash
T. Wyndham, BSc ANU
K. Yoshizawa, MSc Hiroshima
Y. Zhou, BSc MSc Chengdu Inst Tech

Masters Candidate:

R. Stanaway, BApp, Qld UTech

A.L. Hales Honours Year Scholarship

N. Tailby
S. Tynan

Physics of Earth Honours Program

F. Gesto
M.Coman

GENERAL STAFF Top of page

Executive Officer:

G. Kretschmer, BSc Flinders, PhD ANU (until 3 June 2003)
K. Jackson (from 28 July 2003)

Assistant Executive Officer:

M. Murphy

Finance Manager:

M. McDonald, BAppSc CCHS, GradDip Monash

Technical Officers:

C. Allen, AB Princeton MSc Oregon, PhD VirginiaTech
J.T.A. Arnold, BSc Sydney, GradDip CCAE
A.R. Beasley, AssocDip CIT
V. Baek-Hansen
P. J. Biggs
Z. Bruce, BSc PhD Canterbury (from 10 October 2003)
J. Cali, BAppSc QIT
D.L. Corrigan
J.A. Cowley, BSc ANU
J. Duan, BE DUT, MSc Murdoch (from 3 November 2003)

J.D. Fitz Gerald, BSc James Cook, PhD Monash
A.W. Forster
J.J. Foster, BSc Sydney, MSc PhD ANU
J.H. Grant (until 27 August 2003)
W.O. Hibberson, BAppSc CCAE (until 19 November 2003)
N. Hill, BA ANU
I. Iatsevitch, BEng Tashkent Polytec Inst, PhD Russian Academy of Sciences
B. Jenkins, BSc UTS
D. Kelleher, AssocDip Cartog CIT
L.P.J. Kinsley, BSc GradDipSc ANU
H. Kokkonen, BAppSc CCAE
C. Krayshek
J. Lanc (until 10 February 2003)
A. Latimore
R.E. Maier
C.J. Morgan
G.E. Mortimer, BSc PhD Adelaide
J. Mya, BSc Mandalay
C. Norris, BSc ANU (from 7 October 2003)
S. Paxton
A.J. Percival
N. Schram, Dip EIE SAIT
D. Scott
H. Scott-Gagan, BSc Sydney
J.M.G. Shelley, MSc Canterbury
S.P. Sirotjuk, AssocDip TAFE
L. Taylor, BA ANU
D.B. Thomson
R.M. Waterford (until 31 March 2003)
G. Watson
C. Were (from 18 August 2003)
A.R.W. Welsh, BAppSc CCAE
R.E. Willison (until 4 April 2003)
A. Wilson
G.F. Woodward
X. Zhang, PhD LaTrobe

Trainee Technical Officer:

B. Ferguson, ADip CIT
C.A. Saint
D. Clark (from 29 September 2003)
D. Cummins (from 17 February 2003)
D. Cassar (from 17 February 2003)

Apprentice:

B. Taylor

Information Technology:

D. Bolt, BSc Sydney
P. Lanc (from 3 March 2003)
S. Phillips (from 8 October 2003)
S. Robertson, DipAppPhys TAFE, MSc BSc ANU

School Librarian - Librarian's Staff:

S. Jackson, BA ANU, GradDip UC
C. Harney, Dip CIT

Administration:

J. Badstuebner, BA James Cook (from 23 June 2003)
S. Blewett, BSc Swansea, PGCE Keele (from 26 August 2003)
C.J. Cullen
P. Delatorre (until 4 July 2003)
P.A. Gillard (from 7 August 2003)
V.M. Gleeson
W.A. Hampton
D.H. Kelly
J. Lo Presti (from 15 October 2003)
M. Lukatela, BA, GradDip, CCAE (until 15 August 2003)
R. MacPherson
R. A. Petch
K. Provins
J. A. Talbot (from 1 September 2003)
M. C. Turner, Dip CIT (until 11 July 2003))
E. Ward

Research School of Earth Sciences Advisory Committee:

Emeritus Prof J.F. Lovering **(Chair)**
Prof T. M. Harrison, Director, RSES
Prof J. Hearn, Deputy Vice Chancellor (Research), ANU
Prof B.L.N. Kennett, RSES
Dr H. StC. O'Neill, RSES
Dr B. Schmidt, RSAA
Prof S. O'Reilly, Director, Department of Earth and Planetary Science, Macquarie University
Dr C. Pigram, Chief of Division, Minerals and Geohazards Division, Geoscience Australia
Prof N. Phillips, Chief, CSIRO Exploration and Mining
Mr G. Hall, Chief Geologist, Placer Dome Asia Pacific
Dr R. Smith, Chief Geologist, Anglogold Exploration Australasia
Dr J. Hronsky, Senior Geoscientist, Exploration Division, WMC Resources Ltd

VISITING FELLOWS ON FACULTY

Top of page

Dr C. Barton (Geoscience Australia)
Dr L. P. Black (Geoscience Australia)
Dr D. J. Brown (Geoscience Australia)

Dr E. Calvo Costa (ICER-CSIC)
Prof W. Compston
Mr A. Cross (Geoscience Australia)
Dr P. R. Cummins (Geoscience Australia)
Dr A. Glickson
Prof G. P. Grey (University of Frankfurt)
Dr J. Claoué-Long (Geoscience Australia)
Dr A. Dutton
Dr G.L. Fraser (Geoscience Australia)
Mr C. Foudoulis (Geoscience Australia)
Prof D. Green
Prof G. Gwanmesia (Delaware State University)
Dr M. Heintz
Dr J. Hermann
Dr M. Idnurm
Dr Y. Jia (University of Saskatchewan, Canada)
Dr K. Kuge (Kyoto University)
Prof P. K. Link (Idaho State University)
Prof G. S. Lister (Monash University)
Dr R.R. Loucks
Dr C. Magee
Prof I. McDougall
Dr C. Montross (Ringwood Superabrasives, ACT)
Dr W. Müller (ETH Zurich)
Dr R. Page (Geoscience Australia)
Prof M. S. Patterson
Prof G. Poupinet (Université J. Fourier)
Dr E. J. Rhodes
Dr B. Rohrlach
Dr D. Rubatto
Prof R. Rutland
Dr T. Sharp (Arizona State University)
Dr N. Spooner
Mr R. Stanaway
Dr C. Tarlowski (CTBTO)
Dr O. Titov (Saint-Petersburg State University)
Prof J. S. Turner
Prof J. Weaver (University of Victoria, Canada)
Dr J. Wynn (University of Oregon, USA)
Dr Y. Yokoyama (University of Tokyo, Japan)

SCHOOL VISITORS ON FACULTY FOR 2003

Top of page

Earth Chemistry

Dr I. Buick, La Trobe University, visited Earth Chemistry for a week in November to work with Dr I.S. Williams on SHRIMP U-Pb dating of zircon from granulites of the Harts Range, central Australia.

Dr S. Clement, Ion Optical Consulting, Canada, visited Dr T.R.Ireland from 28 March - 4 April and from 15 August to 15 September to continue consultative development for the proposed SHRIMP SI instrument.

Dr P. Dawes, Geological Survey of Greenland and Denmark, visited Earth Chemistry in December and, in collaboration with Dr A.P. Nutman, undertook SHRIMP zircon geochronology of Archaean and Proterozoic rock from northwest Greenland and worked jointly with him on a manuscript.

Dr C.R.L. Friend, Oxford Brookes University, UK, visited Earth Chemistry in April- May to work on manuscripts with Drs. V.C. Bennett and A.P. Nutman and undertook collaborative SHRIMP zircon geochronology of Archaean rocks from southwest Greenland.

Dr A. Kennedy, Curtin University, visited RSES and Australian Scientific Instruments in August to monitor the progress of construction of the second SHRIMP II for the West Australian SHRIMP consortium.

Ms K. Kolodner, Hebrew University of Jerusalem, Israel, visited Dr T.R. Ireland from 23 June - 23 September to conduct SHRIMP analyses.

Mr G. Kopi, Senior Exploration Geologist, Geological Survey of Papua New Guinea, visited Earth Chemistry for two weeks in December to work with Dr I. S. Williams on SHRIMP U-Pb dating of zircon from the Owen Stanley metamorphics.

Dr J. Lindsay, JSC Astrobiology Institute, Nasa, USA, visited Earth Chemistry from 7 December - 20 January 2004 working with Dr V.C. Bennett.

Dr T. Matsumoto, Osaka University, Japan, visited Earth Chemistry (Geochronology and Isotope Geochemistry group) in May to work with Dr M. Honda on noble gas analyses of metasomatic apatite in spinel lherzolite from the Newer Volcanics, southeastern Australia.

Prof S.J. Mojzsis, University of Colorado, USA, Prof L. Becker, University of California, Santa Barbara, USA and Dr O.M. Lovera, University of California, Los Angeles, USA visited Prof T.M. Harrison.

Mr N. Riesen, school student, visited Dr T.R. Ireland, Earth Chemistry from 1-5 September as part of the Year 11 Work Experience program.

Dr K. Terada, Hiroshima University, Japan, arrived in November for a 2 month visit to Earth Chemistry to work with Dr I.S. Williams and other members of the SHRIMP group on multi-collector stable isotope analysis of meteoritic minerals.

Prof J. Valley and Dr N. Lord, University of Wisconsin, USA, visited Earth Chemistry for one week in July to assess the performance of the SHRIMP II for multi-collector stable isotope analysis.

Dr D. Wark, University of Melbourne, visited Dr T.R. Ireland from 30 June to 2 July to conduct ion probe research in connection to ARC Project “Lithic Astronomy”.

Ms K. Weaver, University of California Berkeley, USA, visited Earth Chemistry for three weeks in June, to work with Dr V. Bennett and Dr A. Nutman on the trace element and age characterisation of zircon populations for bulk isotopic investigations, focusing on Sr isotopic evolution of the Proterozoic and Phanerozoic mantle.

Mr S. Zasiadczyk, an Honours student from the Department of Geology, ANU, visited Earth Chemistry in July to work with Dr I.S. Williams on SHRIMP U-Pb dating of zircon from the Minotaur/North Revenge mine near Kambalda.

Prof J. Zhang, Prof Z. Bao and Prof X. Lai, from the China University of Geosciences, China, visited RSES on 6 March and presented seminars on the China University of Geosciences and its education and research interests.

Earth Environment

Dr M. Ellwood, National Institute for Water and Atmospheric Research, Hamilton, New Zealand, visited Earth Environment to discuss ongoing collaborative research with Dr S. Eggins on the geochemistry of siliceous sponges.

Dr S. Fallon, Lawrence Livermore National Laboratory, USA, visited Earth Environment to perform trace element analysis of deep-sea sediments during August and September.

Ms E. Grand-Clement, a visiting student from Louis Pasteur University, France, undertook a collaborative visit to RSES, over the period February - June.

Ms M. Inoue from the Graduate School of Science, Tohoku University, Japan, visited Earth Environment (Stable Isotope group) for three months to measure stable-isotope ratios in corals from Indonesia as part of her PhD dissertation: ‘Reconstruction of marine pollution histories based on heavy elements in coral skeletons’.

Mr P. Montagna, University of University of Padua, Italy, visited Earth Environment to analyse corals for trace elements in the ICP-MS Laboratory.

Mr A. Moy, University of Tasmania visited Earth Environment (Stable Isotope group) in May to measure oxygen and carbon-isotope ratios in foraminifera from Southern Ocean deep-sea sediment cores. The work forms part of his PhD research at the Institute of Antarctic and Southern Ocean Studies.

Mr B. Murphy, Northern Territory University, Key Centre for Ecological Research, visited Earth Environment (Stable Isotope group) to work on stable isotopes of kangaroos. He visited in August to learn collagen extraction techniques and to familiarise himself with the equipment available for his project.

Ms R. Pickering, Palaeoanthropology Unit for Research and Exploration, Johannesburg, South Africa, visited Prof R. Grün and Prof M. McCulloch to work on U-series dating of speleothems from the hominid-bearing site of Gladysvale.

Dr A. Pike, Research Laboratory for Archeology and the History of Art, University of Oxford, UK, visited Prof R. Grün and Dr S. Eggins to work on ‘Addressing the reliability of dating methods beyond the range of 14C’; grant funded by the British Academy.

Mr B. Roark, University of California, Berkely, USA visited Earth Environment to work on Sr/Ca and stable isotope response to bleaching and flood plumes in Porites corals from the Great Barrier Reef in collaboration with Prof M. McCulloch.

Ms C. Rowe, Monash University, visited Earth Environment (Stable Isotope group) to measure carbon-isotope ratios in organic matter from Late Quaternary lacustrine sequences in northern Australia. The work forms part of her PhD research in the School of Geography and Environmental Science.

Prof Sir N. Shackleton, University of Cambridge, UK, visited Earth Environment over the period 15-18 December, during which time he presented a seminar on establishing accurate chronologies for Greenland ice-cores.

Ms M. Spooner, Department of Geology, ANU, visited Earth Environment (Stable Isotope group) to measure oxygen and carbon-isotope ratios in foraminifera from deep-sea sediment cores offshore of Western Australia. The work forms part of her PhD research with Prof P. De Deckker.

Dr C. Spötl, University Innsbruck, Austria visited Earth Environment to discuss collaborative work on Austrian speleothems.

Dr D. Stakes, Monterey Bay Aquarium Research Institute, California, USA, visited Earth Environment to use the ICP-MS lab and to present a seminar on research with excerpts of seafloor video images.

Dr J. Stevenson, the Research School of Pacific and Asian Studies, ANU, visited Earth Environment (Stable Isotope group) to measure carbon-isotope ratios in organic matter from Late Quaternary lacustrine sequences in the Philippines and New Caledonia.

Dr P. Toms, University of Gloucestershire, UK, and Dr R. Bailey, University of Oxford, UK, both visited the Luminescence Dating Laboratory while in Australia.

Earth Materials

Dr B. Baumgartner, STOE, Darmstadt, Germany, the manufacturer of the new x-ray diffraction instrument visited Earth Materials (Experimental Petrology group) from 28 September until 3 October to install the system and to instruct staff on its use.

Prof G. Brey, Goethe University of Frankfurt, Germany, visited Earth Materials (Experimental Petrology group) from 1 January to 30 March, continuing collaboration with Prof D.H. Green on genesis of highly undersaturated magmas and on unusual mantle xenoliths from African Kimberlites.

Dr G. Gwanmesia, Delaware State University, USA, visited Earth Materials during February-March.

Dr T. Morishita, Kanazawa University, Japan, visited Earth Materials (Experimental Petrology group) from 23-30 November to work on the laser ablation ICPMS with the help of Dr S. Eggins and Mr M. Shelley.

Dr A. Pack, Institute of Mineralogy and Geochemistry, Cologne, Germany, visited Earth Materials (Experimental Petrology group) to use the laser ablation ICPMS to analyse early solar system phases in primitive chondrites in cooperation with Mr M. Shelley.

Prof I. Parsons, University of Edinburgh, UK, visited Earth Materials (Rock Physics), from 11 November 2002-17 January 2003.

Prof M. Scambelluri, University of Genova, Italy visited Earth Materials (Experimental Petrology group) from 5-26 September to work on subduction zone metamorphism of ultramafic rocks.

Earth Physics

Ms G. Estermann, a student from the Technical University of Vienna, Austria, was appointed a school visitor in Earth Physics (Geodynamics group), for a period of twelve months from 8 October. Ms Estermann is working with Prof K. Lambeck on matters relating to the Cooperative Research Centre for Antarctic Climate & Ecosystems (ACE CRC).

Dr T. Furumura, Dr K. Koketsu and Dr H. Takenaka, Japan, visited Earth Physics (Seismology group) at the end of January with support from the Japan Society for the Promotion of Science. They participated in a workshop at Geoscience Australia on the ground motion induced by earthquakes, and undertook extended discussions on seismic wave propagation issues.

Dr A. Gorbatov, JAMSTEC, Japan, visited Earth Physics in October-November for three weeks to work with Dr M. Sambridge and Prof B.L.N. Kennett on tomographic inversion. He made use of the Terrawulf cluster to undertake ensemble tomography with more than 100 simultaneous global tomographic inversions using different initial conditions.

Dr A. Hogg, Southampton Oceanography Centre, UK, visited Earth Physics (Geophysical Fluid Dynamics group) in January and November to discuss future collaborative research projects.

Dr K. Kuge, University of Kyoto, Japan visited in October to study the propagation of multiple reflection P and S body waves beneath Australia using data from the portable stations. This work forms part of a comparative study of structure in Australia and east Antarctica.

Dr O. Lovera, University of California-Los Angeles, USA, visited the School's Centre for Advanced Data Inference (CADI) and spent a week in September discussing thermochronological inverse problems with Drs. Sambridge and Braun.

Prof S. Manabe, Head of the Earth Rotation Division of the National Astronomical Observatory of Japan, and members of his staff, visited Earth Physics (Geodynamics group) in March to inspect the Mt Stromlo gravity station and discuss the progress of its recovery after the destruction of the surrounding building in the January fires. The superconducting gravimeter was brought online again during their visit after being out of operation for two months.

Ms C. Menesguen, Ecole Normal Supérieure, Paris (Ulm), France, was a visitor in Earth Physics (Geophysical Fluid Dynamics group) for six months (January-June), and carried out a research project on the instability of western boundary currents in the oceans, as an addition to her Master of Physics degree from the ENS, Paris.

Dr G. Poupinet, Université Joseph Fourier in Grenoble, France, spent most of the year at RSES working on the properties of the inner core, principally using data from the upgraded Warramunga Array. His work indicates considerable complexity in structure near the top of the inner core leading to a long coda to the phase PKiKP reflected from the inner core boundary.

Prof H. Schuh, Institute of Geodesy and Geophysics, Vienna University of Technology, Wien, Austria, visited Earth Physics (Geodynamics group) in July this year to discuss cooperative projects in VBI (Long Baseline Interferometry).

Mr G. Sicchitano, a student of Geological Science at the University of Catania, Italy, visitred Earth Physics (Geodynamics) for approximately three months. He arrived at the School on 11 November, to commence work with Prof Kurt Lambeck and Dr Tezer Esat on analysing speleothem data from submerged caves in Catania, Italy.

Dr O. Titov, Geoscience Australia, is a Visiting Fellow in Earth Physics (Geodynamics group). He is conducting research on the processing of VLBI data.

Dr L. Wallace, Institute of Geological and Nuclear Sciences, NZ, visited Dr Paul Tregoning from Earth Physics (Geodynamics group) in August, to collaborate on tectonic studies in Papua New Guinea.

THESES SUBMITTED

Top of page

PhD

Ms L. Glass Petrogenesis and geochronology of the North Australian Kalkarinji low-Ti continental flood basalt province (PhD). Supervisors: Dr H. O'Neill, Dr V. Bennett, Dr I.H. Campbell, Dr S. Sun, Dr I.S. Williams Advisors: Dr I.H. Campbell, Dr I.S. Williams.

Mr A. Hack Experimental investigations into mineral-buffered solubility and speciation in supercritical fluids: The systems SiO2-H2O and Cu-Cu2O-MgO-SiO2-HCl-H2O (PhD). Supervisors: Dr J. Mavrogenes, Dr A. Berry. Advisors: Prof H. O'Neill, Dr J. Hermann, Dr S. Eggins, Prof R.J. Arculus.

Ms E.J. Hendy Coral Reconstructions of Decadal-to-Centennial Climate Variability in the Great Barrier Reef Since 1565 AD (PhD) Supervisors: Prof M.T. McCulloch, Dr M.K. Gagan. Advisors: Prof J. Chappell, Dr C.A. Alibert, Dr J.M. Lough (AIMS).

Mr T. Hong Development and application of a wavelet-based method for modelling of seismic wave propagation (Ph.D) degree approved December 2003. Supervisor: Prof B.L.N Kennett.

Mr X. Liu The effect of K_2O, Cr_2O_3, H_2O and CO_2 on the partial melting behaviour of spinel lherzolite in the system $CaO-MgO-Al_2O_3-SiO_2 \pm K_2O \pm Cr_2O_3 \pm H_2O \pm CO_2$ at 11 kbar (PhD). Supervisors: Dr H. O'Neill, Prof D.H. Green, Dr M.S. Sambridge Advisor: Dr S. Kesson.

Mr W. Lus The metamorphic sole of the Papuan ultramafic belt ophiolite (PhD). Supervisors: Prof D.H. Green, Prof I. McDougall, Prof H. Davies (UPNG). Advisors: Dr H. O'Neill, Dr S. Eggins.

Ms H.V. McGregor Coral Records of Climate Variability in the West-Pacific Warm Pool (PhD) Supervisor: Dr M.K. Gagan. Advisors: Prof J. Chappell, Prof M.T. McCulloch, Dr J.M. Lough (AIMS).

Mr D. Osmond Laboratory models of geophysical flows (PhD). Supervisor: Prof R.W. Griffiths.

Mr P. Rustomji Holocene geomorphology of the MacDonald and Tuross Rivers. (PhD) Supervisor: Prof J. Chappell.

Mr W. Sun The Subduction Factory: A perspective from the rhenium and trace element geochemistry of oceanic basalts and eclogites (PhD) Supervisors: Drs V.C. Bennett, I.S. Williams. Advisors: Dr S. Eggins, Prof RJ Arculus (Geology).

Ms P. Treble Palaeoclimate records constructed from southern Australian modern, Holocene and Pleistocene speleothems (PhD) Principal Supervisor: Prof J. Chappell.

Masters

Mr R. Stanaway Implementation of a Dynamic Datum in Papua New Guinea: A Case study (MPhil) Supervisor: Dr P. Tregoning.

Honours

Ms M. Coman Convective exchange between two connected chambers. (Hons. in Physics of the Earth). Supervisors: Prof Ross Griffiths and Dr Graham Hughes.

Mr F. Gesto Seismic strain, lithospheric deformation and surface topography. (Hons. in Physics of the Earth). Supervisor: Dr Jean Braun.

HONOURS AND AWARDS

Academic Staff

Prof D.H. Green was elected as a Foreign Member of the Russian Academy of Sciences in recognition of his scientific research on the Earth's mantle and on the genesis of basalts.

Prof I. Jackson was elected a Fellow of the American Geophysical Union.

Dr H. O'Neill was awarded the Schlumberger Medal from the Mineralogical Society of London.

Profs A. Hales, J. Chappell, W. Compston, D. Green, R. Griffiths, B. Kennett, K. Lambeck, I. McDougall, M. Paterson, and S. Turner were awarded the Australian Centenary Medal.

Prof J. Chappell was awarded the David Brown Medal, "for contributions to Geology" (ANU).

Dr M. Gagan was awarded an Alan Cox Visiting Professorship by the Department of Geological and Environmental Sciences, Stanford University, USA.

Prof D.H. Green delivered the Umbrove Lecture at University of Utrecht and was appointed as Crosby Visiting Prof at Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.

Prof I. Jackson was awarded a Visiting Professorship, Ehime University, Matsuyama, Japan, May-August.

Dr M. Sambridge was nominated for the Vice-Chancellor's award for excellence in graduate student supervision.

Dr V.C. Bennett was elected a fellow of the Geological Society of America.Students
Ms N. Abram was awarded the RSES Robert Hill Memorial Prize in recognition of her interdisciplinary research and effective communication in the earth sciences.

Ms R. Fraser and T. Wyndham were joint recipients of the Mervyn and Katalin Paterson Fellowship Award.

Mr J. Freeman was awarded Best Oral Presentation: 17th Victorian Universities Earth Science Conference.

Ms J. Mullarney was awarded a Summer Fellowship by the Woods Hole Oceanographic Institution (WHOI), USA, for her to attend the Geophysical Fluid Dynamics Summer Program at WHOI, 23 June - 22 August.

Mr T. Nicholson was awarded the J.G. Crawford Prize for his Ph.D thesis submitted in 2002.

Mr D. Wood was awarded Best Oral Presentation: Structural geology Section 17th Victorian Universities Earth Science Conference.

POSTGRADUATE AWARDS AND SCHOLARSHIPS

An International Postgraduate Research Scholarship was awarded to Ms F. Jenner who commenced her PhD studies under the supervision of Dr V.C. Bennett.

PhD Students Mr J. Célérier and Mr A. Aikman under the supervision of Prof T.M. Harrison.

PhD student Mr A. Kallio under the supervision of Dr T.R. Ireland.

PhD student Mr R. Fonseca under the supervision of Dr I.H. Campbell.

PhD student Mr T. Fujioka under the co-supervision of Prof C. Chappell and Dr M. Honda.

PhD student Ms K. Procko under the supervision on Prof B.L.N. Kennett.

PhD student Mr T. Prastowo under the supervision of Prof R.W. Griffiths.

PhD student Ms S. Burgess under the supervision of Prof M. T. McCulloch.

PhD student Ms K. Dowell under the supervision of Dr J.A. Mavrogenes.

PhD students Ms M. Miller, Mr M. Beltrando and Mr D.Wood under the supervision of Prof G. S. Lister.

PhD student Mr E. Saygin under the supervision of Prof R. W. Griffiths.

PhD student Mr R. Brodie under the supervision of Dr M. S. Sambridge.

PhD student Ms R. Berdine under the supervision of Dr M. K. Gagan.

PhD student Ms K. Lilley under the supervision of Dr D. Fabel and Prof K. Lambeck

Summer Research Scholarships

Summer Research Scholarships were awarded to the following:

Mr J. Hiess, of Canterbury University, New Zealand, under the supervision of Dr T.R. Ireland.

Mr N. Detchon, of the University of Western Australia, under the supervision of Dr M. S. Sambridge and Prof J. M. A. Chappell.

Mr R. Ruddick of the University of Tasmania, under the supervision of Dr P. Tregoning.

Ms S. O’Driscoll of the University of Waikato, New Zealand, under the supervision of Prof M. T. McCulloch.Student Internship

Ms J. Clarke of Monash University, commenced Student Internship under the supervision of Dr T.R. Ireland.

Mr D. Viete of Monash University, commenced Student Internship under the supervision of Prof G. Lister.

Mr N. Tailby of the ANU under the supervision of Dr A. Berry and Dr H. O'neill.

Student Internships

Ms J. Clarke of Monash University, commenced Student Internship under the supervision of Dr T.R. Ireland.

Mr D. Viete of Monash University, commenced Student Internship under the supervision of Prof G. Lister.

Research Activities

Earth Chemistry

Files available in PDF

Earth Environment - Annual Report 2003

Contents

Introduction

Earth Environment integrates a group of leading researchers and postgraduate students who have research interests in environmental change and the long-term interaction between mankind and its environment. Research is directed toward understanding globally significant processes within the themes:

- climate and sea-level change
- human evolution and migration
- megafauna extinction
- landscape evolution
- soil production and erosion
- sediment and nutrient fluxes to waterways and the oceans.

Earth Environment focuses on determining the timing and rate of change of major environmental and earth surface processes, and using trace element and isotopic systems to constrain the nature of past and present environments. Emphasis is given to developing detailed records that span a few tens to several hundred thousand years of the Earth's recent history. The results are used as a basis for understanding past and present environmental change with the ultimate aim to predicting future environments. Earth Environment specialises in the reconstruction of high-resolution environmental records from growth bands preserved in fossil and modern corals, speleothems (cave deposits), and layered sedimentary deposits.

Earth Environment research activities are underpinned by world-class laboratory facilities that enable analysis of virtually any trace element or isotope system, including

- radiogenic isotopes (U-series, U-Pb, Rb-Sr, Sm-Nd, Lu-Hf)
- light stable isotopes (Li, B, C, N, O)
- heavy stable isotopes (Mg, Ca, Fe, Cu, Zn, Mo, etc.)
- cosmogenic isotopes (Be-10, C-14, Al-26, Cl-36).

The instrumentation base includes thermal ionisation mass spectrometry (TIMS), Excimer laser ablation combined with multi-collector sector-ICPMS and quadrupole-ICPMS, dual inlet and continuous flow gas-source stable isotope mass spectrometry (DI-CF-IRMS), optically stimulated luminescence (OSL), electron spin resonance (ESR), radiocarbon and gamma ray counting equipment, palaeomagnetic laboratory, as well as clean room and sample preparation facilities. Accelerator mass spectrometry (AMS) and charge collection TIMS are accessed through the neighbouring Research School of Physical Sciences and Engineering.

Our research is led by the academic staff members Prof. J. Chappell, Dr S. Eggins, Dr T. Esat, Dr D. Fabel, Dr M. Gagan, Prof. R. Grün (Area Coordinator), Prof. M. McCulloch, Dr B. Pillans and Dr E. Rhodes. The research endeavour is greatly enhanced by our research associates and postdoctoral fellows Dr C. Alibert, Dr J. Desmarchelier, Dr G. Dunbar, Dr J. Marshall, and Dr C. Pelejero, as well as our academic visitors Dr E. Calvo, Dr J. Jia, Dr P. Montagna, Dr W. Müller, Dr A. Pike, Ms R. Pickering, Dr. B. Roark, and Dr J. Wynn. Much of our research is carried out by our dedicated PhD students: Ms N. Abram, Ms B. Ayling, Ms R. Berdin, Ms K. Dowell, Ms R. Fraser, Mr T. Fujioka, Ms E. Hendy, Ms K. Lilly, Mr I. McCulloch, Ms H. McGregor, Mr D. Qu, Mr M. Smith, Ms J. Trotter, Mr T. Wyndham and Mr Y. Zhou.

Earth Environment has been highly successful in procuring government ARC grants. In 2003, Prof. J. Chappell was the leading investigator of two large ARC grants, with Dr T. Esat on Millenial-scale instability of sea level and the climate system: new analysis of coral terraces in Papua New Guinea and with Dr M. Honda, Dr D. Fabel and Dr K. Fifield on Production and transport of soil and sediments, determined by cosmogenic radionuclides and noble gases. Dr M. Gagan was chief investigator of Quantifying the El Niño-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives with W. Hantoro (Indonesian Institute of Sciences), J. Lough (AIMS), G. Meyers (CSIRO) and G. Dunbar. Prof. R. Grün was the leading investigator on Stable isotopes in marsupials: reconstruction of environmental change in Australia with Dr M. Gagan, Dr D. Bowman (NTU) and Dr R. Wells (Flinders). Prof. M. McCulloch led two ARC projects, with Dr Hearty (JCU) and Prof Halliday (ETH) on Sea levels, sea surface temperatures and El Nino variability during warm interglacials and jointly with Dr Lough (Australian Institute of Marine Sciences) on The coral record and environmental impacts in the Great Barrier Reef: quantification of anthropogenic fluxes. Dr C. Pelejero is an ARC APD fellow on Uptake of atmospheric CO2 in the oceans and implications for global change: New proxy developments.

In 2003, Dr E. Calvo was awarded an ARC APD fellowship with the grant The key role of the Southern Ocean in atmospheric CO2 sequestration, and Dr S.M. Eggins was co-Chief Investigator on newly awarded ARC Discovery-Project Uncoupling past salinity and temperature signals in the Indo-Pacific Warm Pool: implications for climate change in the Australian region with Prof. P. DeDeckker (Geology).

Several staff members, Prof. Chappell, Drs Fabel, Pillans and Rhodes, and students, Mr Bernal and Mr Smith, are members of the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME).

During 2003 there have been a number of personnel changes. We are pleased to welcome Dr E. Rhodes (formerly University of Oxford) to lead the luminescence laboratory. Dr. G. Dunbar (formerly of Victoria University of Wellington) joined the area as Research Associate on the ARC Discovery grant: Quantifying the El Niño-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives. Ms Jo Lo Presti also arrived to provide support as the new Area Administrator. During 2003 several staff members left to take on new responsibilities, Mrs P Delatorre at the ACT government and Mr A. Alimanovic at the University of Melbourne. We thank them for their dedicated work and wish them all the best for their future.

Earth Environment attracted four new PhD students in 2003: Ms S. Burgess will work on the geochemistry of Plesiastrea versipora, Ms K. Dowell on the formation of opals, Ms K. Lilley on constraints on glacial history of East Antarctica from cosmogenic dating and isostatic modeling, Ms R. Berdin Late Quaternary Climate and Typhoon Variability in the Northern

Indo-Pacific Warm Pool Reconstructed from Raised Coral Reefs of the Philippines and Mr T. Fujioka on applying cosmogenic noble gases to geological processes at the Earth's surface.

The following students finished their PhDs: Mr Juan Pablo Bernal-Uruchurtu on "In situ measurement of U-series disequilibria in iron oxy/hydroxides and its application to weathering geochronology". Dr Bernal returned to his native Mexico to work in the Geological Survey. Ms Erica Hendy submitted "Coral Reconstructions of Decadal-to-Centennial Climate Variability in the Great Barrier Reef Since 1565 AD". Dr Hendy started a postdoctoral position at the Lamont Doherty Geological Observatory in New York. Ms Helen McGregor's thesis was entitled "Coral Records of Climate Variability in the West-Pacific Warm Pool". Dr McGregor took on a postdoctoral position at the Universität Bremen. Mr Paul Rustomji submitted "Holocene geomorphology of the MacDonald and Tuross Rivers" and Ms Pauline Treble "Palaeoclimate records constructed from southern Australian modern, Holocene and Pleistocene speleothems". Drs Rustomji and Treble moved to the US to work at UCLA.

The highlights of 2003 were Wolfgang Müller's paper in Science on "The origin and migration of the Alpine Iceman", presenting a reconstruction of the life of Ötzi which caused world-wide media attention and Malcolm McCulloch's Nature paper "Coral Record of increased sediment flux to the inner Great Barrier Reef since European settlement" which threw the scientific cat amongst Queensland's sugar cane farmer pigeons causing a very public, very heated debate. The quality of our research is documented by numerous publications in the leading earth sciences journals including Nature, Science, Earth and Planetary Science Letters, Geochimica et Cosmochimica Acta, Geology, Geophysical Research Letters, and Quaternary Science Reviews.

Our other PhD students and recent graduates also published in leading international journals, with outstanding papers by Nerilie Abram in Science on "Coral reef death during the 1997 Indian Ocean Dipole linked to Indonesian wildfires"; Helen McGregor in Geochimica et Cosmochimica Acta on "Diagenesis and geochemistry of Porites corals from Papua New Guinea: implications for paleoclimate reconstruction"; Pauline Treble in Earth and Planetary Science Letters on "Comparison of high resolution sub-annual records of trace elements in a modern (19111992) speleothem with instrumental climate data from southwest Australia".

The breadth of the research activities of Earth Environment are documented in the projects detailed in the annual report. Involving many colleagues and Earth Environment staff members and colleagues in Australia and overseas, Nerilie Abram worked on "Holocene variability of the Indian Dipole" ; Bridget Ayling on "Modern and palaeoclimatic conditions at Oeno Atoll and Henderson Island, SE Pacific: geochemical signatures of environmental conditions and diagenetic history"; Samantha Burgess on "Plesiastrea versipora: hermatypic coral at its southern latitudinal limit"; Eva Calvo and Carlos Pelejero on "Marine Isotopic Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inferences" and "280-year long Sr/Ca and δ18O records from Flinders Reef, western Coral Sea", John Chappell on "Contrasting regimes of soil production"; Stephen Eggins on "Daily banding and modulation of Mg/Ca in foraminiferal calcite by symbiont photosynthesis and respiration";

Tezer Esat on “Accurate dating of rapid rises of sea level in the last glacial cycle”; Derek Fabel on “Basal thermal regimes of former ice sheets constraints using cosmogenic nuclides”,“Estimating neotectonic movement in southern Victoria using cosmogenic burial dating” and “Tracing the post-Younger Dryas retreat of the northern Fennoscandian Ice Sheet using cosmogenic radionuclide exposure ages”; Toshi Fujioka on “Extremely low erosion rates at the gibber plain in South Australia;Rebecca Fraser on “Stable isotope analysis of bone collagen and tooth enamel of Australian marsupial faunas: a baseline study investigating the implications for palaeodiet and palaeo-environmental reconstruction”; Michael Gagan on “Coral records of surface-ocean evaporation: the “other half” of the hydrological cycle”; N.S Grumut on “Coral radiocarbon records of Indian Ocean water mass mixing and wind-induced upwelling along the coast of Sumatra, Indonesia”;Yiefei Jia on “Thorium/Uranium systematics of Precambrian deep-sea pelagic black shales: implications for redox state of the early atmosphere” and “15N-enriched Archean crust or 15N-depleted crust recycled into -6 ‰ upper Mantle?”; John Marshall on “Coral Ba/Ca Record of Runoff from the Fitzroy River”; Malcolm McCulloch on “Impact of European Settlement on Sediment and Freshwater Runoff into the Inner Great Barrier Reef” and “Geochemical Records of Bleaching Events from the Great Barrier Reef”; Helen McGregor on “Coral *18O records of late Holocene amplification of the El Niño-Southern Oscillation”; Paolo Montagna on “Climate variability of the last millennium revealed by high-resolution stable isotope record in an Italian speleothem (NW Sardinia)”; Andrew Moy on “Late Pleistocene palaeoceanographic and geochemical evolution of the South Tasman Rise”

Wolfgang Müller on “In-situ trace elemental and Sr isotopic analysis of teeth by LA-ICPMS”, Alistair Pike on “In-situ uranium series dating of the Omo Kibish I human”; Brad Pillans on “Revised ages for Miocene hominid-bearing sediments at Haritalyangar, Indian Siwaliks”;Dingchuang Quo on “A seven-year regulation of the El Niño-Southern Oscillation 3,700 years ago”; Roark on “Geochemical Records of Bleaching Events from the Great Barrier Reef”; Martin Smith on “Geochronology of Long-Term Landscape Evolution, NW NSW”; Julie Trotter on “Conodont Geochemistry proxies for understanding palaeoenvironments, bioevents and geoevents of the Palaeozoic”; Timothy Wyndham on “Biogeochemical cycling of trace metals in coastal seawater”; and Jonathan Wynn on “Soil organic carbon and carbon isotope inventories of the Australian Continent”.

None of the scientific endeavours could be carried out without the active involvement of our excellent support staff: Mr A. Alimanovic (radiocarbon, cosmogenic isotopes), Mr J. Cali (stable isotope instrumentation), Mrs J. Cowley (stable isotope measurement), Mr D. Edwards (palaeomagnetism), Mr N. Hill (luminescence), Mr D. Kelleher (radiocarbon, fieldwork management), Mr L. Kinsley (mass spectrometry instrumentation), Ms J. Lo Presti (area administrator), Dr G Mortimer (chemistry and mass spectrometry), Mr S. Robertson (IT, ESR), Mrs H. Scott-Gagan (stable isotope measurement), and Mrs L. Taylor (ICP-MS, U-series chemistry).

Holocene variability of the Indian Ocean Dipole

N.J. Abram and M.K. Gagan

The Indian Ocean Dipole (IOD) is an ocean-atmosphere climate oscillation that has profound effects on rainfall throughout the Indian Ocean region. It is believed that IOD events can be triggered by anomalously strong Asian summer monsoon conditions and/or strong El Niño events. Detailed knowledge of these interactions is generally limited to recent decades and it is not clear how the IOD will be affected by projected future changes in monsoon or El Niño strength due to greenhouse warming. In order to develop an improved understanding of the long-term interactions of the IOD with the monsoon and El Niño systems we used modern and fossil corals from the Mentawai Islands (southwest Sumatra, Indonesia) to reconstruct eastern IOD upwelling events over the past 6000 years.

Four strong IOD upwelling events were reconstructed over the 140-year period from 1858-1998. These events are characterised by strong cool anomalies in coral Sr/Ca, along with dry anomalies in coral residual d18O. Similar cool/dry periods were reconstructed in corals dated at 1940, 4410, 4440 and 6340 cal yBP. These palaeo IOD events appear to have been particularly frequent in the ~4400 cal yBP corals, with strong events identified in at least three of the twenty years of coral record, and weaker upwelling apparent in many of the other years. To further examine the similarities/differences between IODs in the past and present, composite events were created using the modern and fossil coral IOD records (Fig. 1). IOD cooling has a similar timing in the annual cycle in the modern and palaeo composites, however the palaeo upwellings appear to have been more intense and lasted approximately two months longer than the modern IOD upwellings. Both composites also record dry conditions during IOD events, however the strength and duration of drying are again greater in the palaeo composite.

The Mentawai coral records clearly show that the IOD has been a persistent feature of Indian Ocean climate since at least the mid-Holocene. The consistent timing of the IOD within the annual cycle suggests that the seasonally reversing wind fields of the Asian monsoon have been a critical factor in driving IOD upwelling throughout this period. The influence of the Asian monsoon may also account for the enhanced strength and duration of palaeo IODs as it is well documented that the Asian summer monsoon was stronger than present during the early-middle Holocene. The monsoon was at its greatest strength around 9000 yBP and decreased progressively throughout the Holocene, however the Mentawai corals suggest that there was a maximum in IOD activity around 4400 yBP. This maximum may be due to a combination of IOD triggers, with the increasing frequency of strong El Niño events after ~6000 yBP together with the stronger monsoon producing optimum IOD conditions at around 4400 yBP.

We conclude that the Holocene variability in the IOD system recorded by the Mentawai corals appears to have been related to synergistic variations in the strength of the monsoon and El Nino systems. Given the predictions of greenhouse-gas driven increases in Asian summer monsoon strength, it is likely that IOD events will become more common and more intense over the coming century.

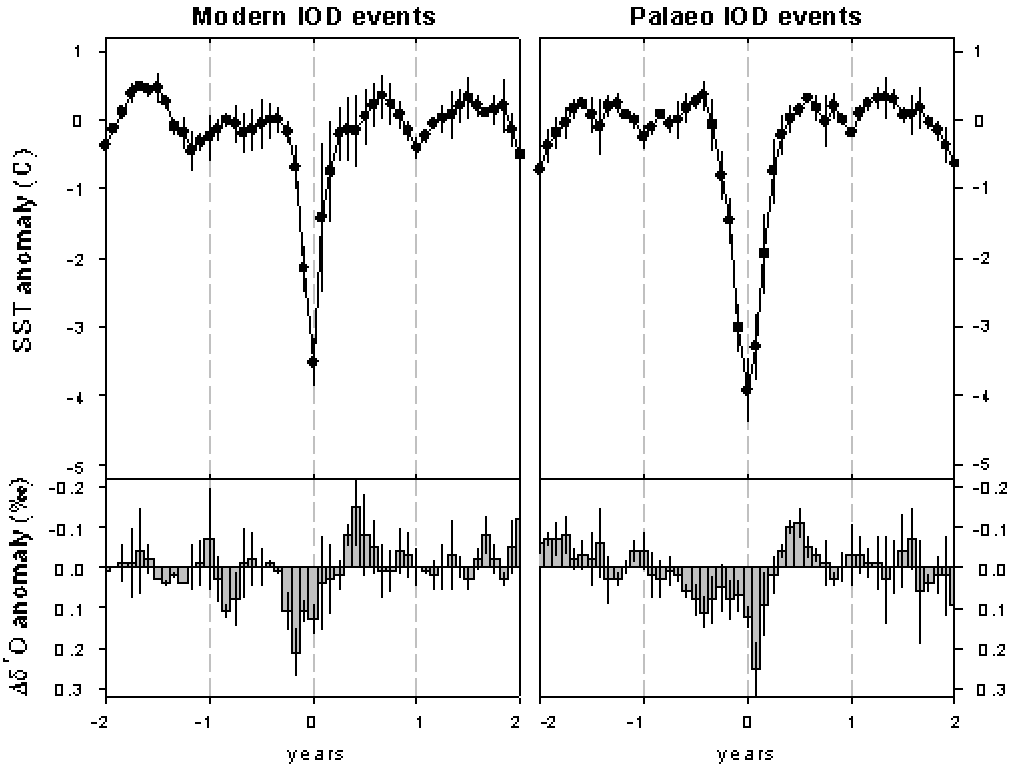


Figure 1. Composite coral records of the IOD. Composite modern and palaeo IOD events were reconstructed by averaging the coral Sr/Ca SST (circles) and residual δ18O (grey bars) anomaly records of four modern and five palaeo IOD upwelling events. Error bars show the standard error for the composite records. X-axis scale refers to the number of years before or after peak IOD cooling.

Modern and palaeoclimatic conditions at Oeno Atoll and Henderson Island, SE Pacific: Geochemical signatures of environmental conditions and diagenetic history

B. Ayling, M.T. McCulloch and M.K. Gagan

This study is aimed at reconstructing climatic conditions during Marine Isotope Stage 9 (MIS 9), an interglacial period spanning 320-300ka. In particular, high resolution data illustrating seasonal processes from MIS 9 are sought, as such records are of particular interest to paleoclimatologists but none yet exist for any interglacial prior to MIS 5e. This reflects both (a) the lack of suitable fossil coral to work on due to limited existence of paleoreefs older than MIS 5e, and (b) post mortem effects of diagenesis on coral, resulting in degradation of primary skeletal geochemistry. In this study fossil Porites and Tridacna are being used to reconstruct records of recent and paleo sea surface temperature (SST) and hydrologic balance.

A 5 week field expedition to Oeno Atoll and Henderson Island, SE Pacific was completed during February and March 2003 to collect modern and fossil samples, and a range of species of fossil coral (Porites, Montastrea and Favid) believed to be of MIS 9 age (based on previous U-series analyses) were recovered. A modern Porites core was also sampled from Oeno Atoll, 180km NW of Henderson Island. These fossil carbonates have been the subject of careful screening for diagenetic effects prior to stable isotope and trace element analysis. Initial examination of the fossil Porites for diagenesis revealed excellent preservation of primary porosity, with calcite cementation absent (see Figure 1d). The modern Porities coral is displayed in figures 1a c for comparison. Limited dissolution has affected the fossil coral as evident by creation of void space in the calcification centres (Figure 1e, 1g), etched pore walls (Figure 1f) and the creation of microporosity in the bulk skeleton (see Figure 1h).

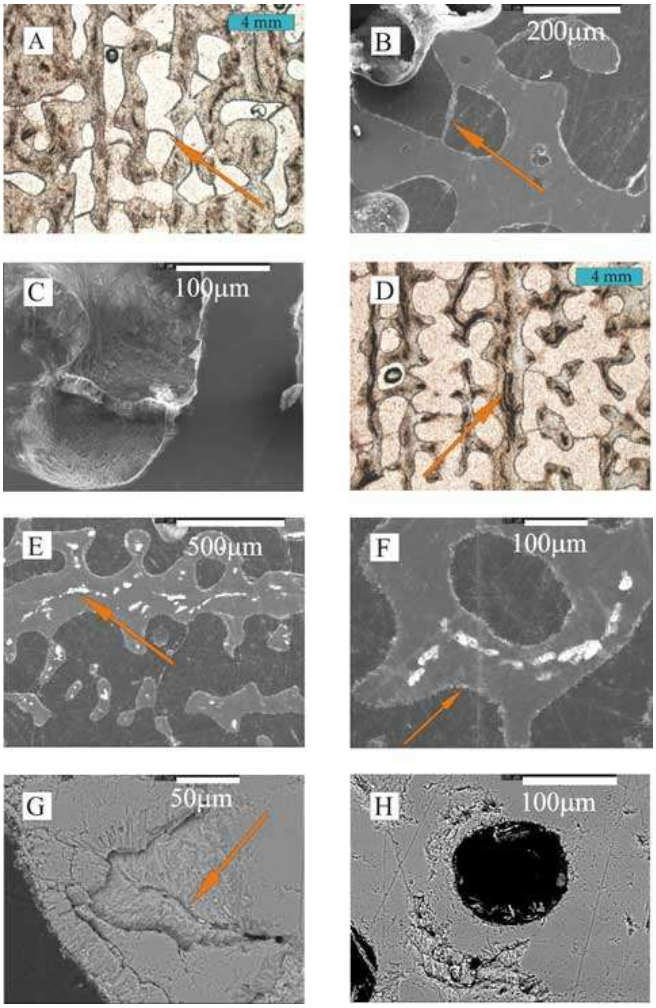


Figure 1. (a) Modern Porites petrographic thin section (plane polarized light). Arrow indicates dissepiments. (b, c) Modern Porites SEM images, arrows indicate dissepiments. (d) Fossil Porites petrographic thin section (plane polarized light). Arrow indicates discoloured centres of calcification where dissolution has occurred. (e,f) Fossil Porites SEM images, arrows indicate altered centres of calcification. (g) Fossil Porites backscattered electron image, illustrating radial aragonite crystals around centre of calcification (indicated by arrow). (h) Fossil Porites BE image illustrating microporosity of bulk coral skeleton.

Preliminary stable isotope results suggest a 0.2‰ difference in δ18O between the modern and fossil Porites, equating to less than 1°C difference in temperature between MIS 9 and present climate (see Figure 2). Skeletal Sr/Ca is more sensitive to diagenesis than δ18O, and initial TIMS results indicate a mean offset of 0.5 mmol/mol between the modern and fossil Porites, which is equivalent to a decrease of ~10°C (see Figure 2) and is inconsistent with the δ18O data. The fossil Porites Sr/Ca record could be the product of diagenetic effects, differences in temperature between modern and MIS 9 climate, or possible changes in oceanic Sr/Ca over interglacial/glacial timescales. Trace element geochemistry on multiple Porites samples affected by varying degrees of diagenesis is being investigated to resolve this problem.

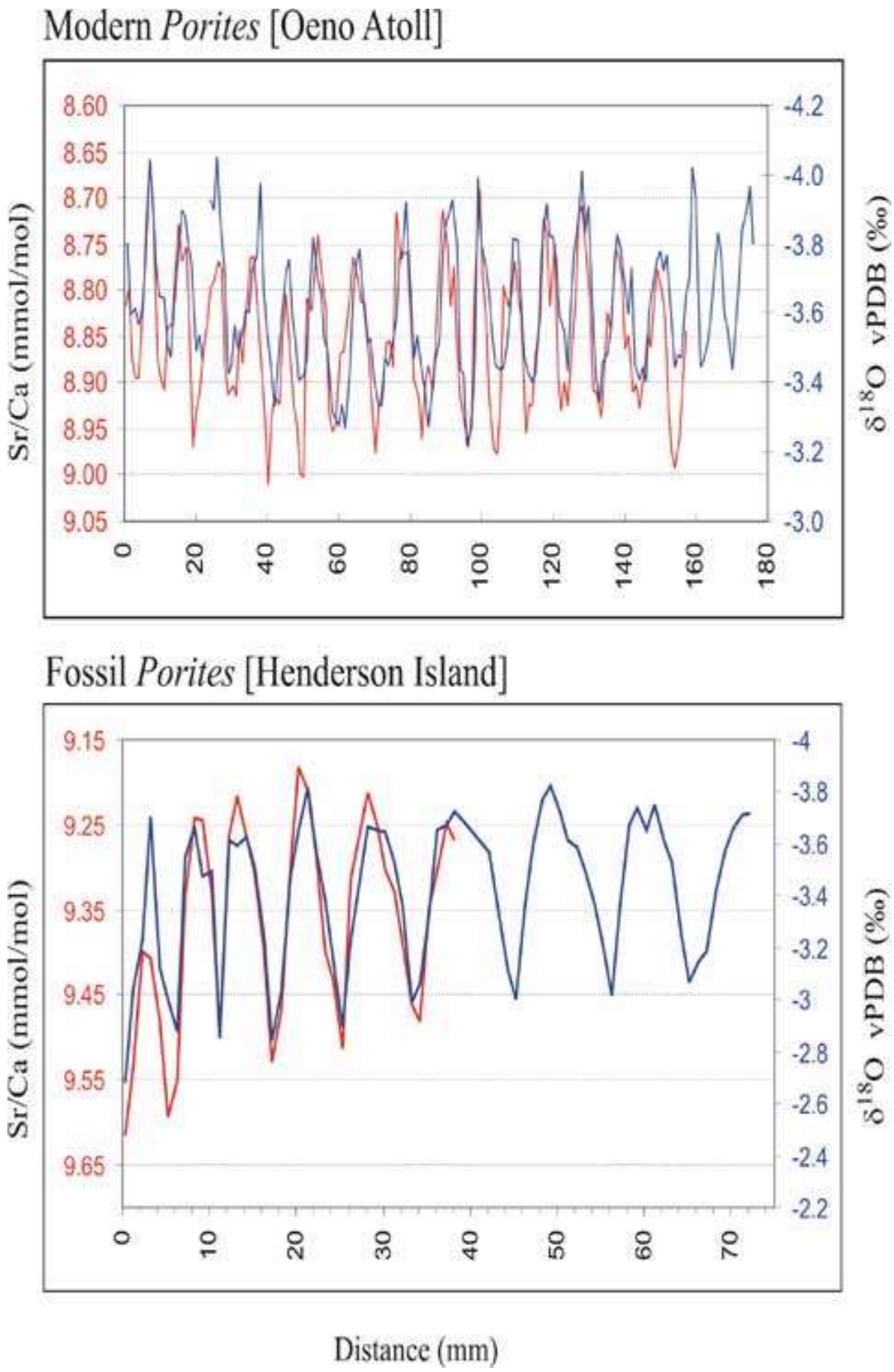


Figure 2. Sr/Ca and δ18O records for modern and fossil Porites.

Plesiastrea versipora: Hermatypic coral at its southern latitudinal limit

S.N. Burgess

Corals growing in high latitude waters are sensitive to changes in climate, especially seasonal fluctuations in sea surface temperature. In the cool-water, high-energy environments of South Australia scleractinian corals record variability of temperature, salinity and ocean circulation in the Southern Ocean. Scleractinia are typically stenotypic organisms with distributions limited by relatively minor fluctuations in environmental variables. Plesiastrea versipora (Lamarck, 1816) is a unique species of scleractinia, because it occurs around the entire Australian coastline, which suggests it tolerates a wider range of climatic variation. In high latitudes, P. versipora occurs in most encrusting reef systems, with colonies of massive habit up to 3 m in diameter and growth rates of 2-4 mm per year. Therefore, individual colonies may prove to be a good sentinel organism for changes in environmental conditions in southern Australia and by extension the Southern Ocean on centennial timescales. Fieldwork was conducted in collaboration with the Great Australian Bight and Shelf Seas Program within the South Australian Research and Development Institute (SARDI). Core samples of up to 500 mm were obtained from two regions, including Spencer Gulf and Gulf St Vincent, South Australia (Figure 1). Laser ablation-inductively coupled plasma mass spectrometry (LA-ICP MS) will be used to measure climatic tracers including temperature and upwelling proxies from high-latitude corals. Skeletal extension rates of P. versipora will be compared for intra- and inter-annual differences in environmental conditions between the cool, nutrient-enriched shelf waters and the warm, low-nutrient gulf waters.

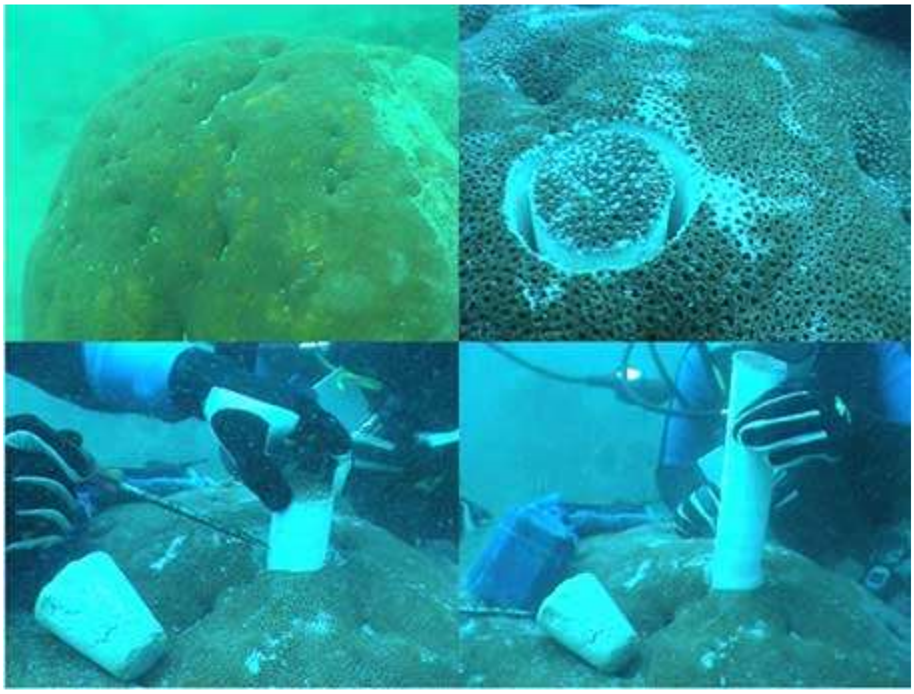


Figure 1: A Plesiastrea versipora colony at Seacliff reef, South Australia and extracting a sample core.

280-year long Sr/Ca and d18O records from Flinders Reef, western Coral Sea

E. Calvo, J.F. Marshall, C. Pelejero, M.T. McCulloch, J.M. Lough1 and M.K. Gagan

The combination of parallel Sr/Ca and d18O records in corals allows reconstruction of past changes in sea surface temperature (SST) and seawater d18O composition (McCulloch et al., 1994). The latter provides climatic information related to changes in the hydrologic cycle and can be interpreted as a salinity proxy. Since the d18O signal is affected by both SST and seawater isotopic composition, a salinity record can be obtained by removing the temperature signal using a parallel Sr/Ca record, a proxy for SST, obtained from the same coral. Low resolution (5-year intervals) Sr/Ca and d18O analyses, going back to 1710 AD, have been performed on a Porites coral core collected from Flinders Reef, an offshore reef on the Queensland Plateau (17ºS, 149ºE), 250 km from the north-east coast of Australia. For the last 280 years, the preliminary Sr/Ca-SST record shows an increasing long-term trend towards the warm temperatures recorded during 1990, when the coral was collected. An increasing trend towards more negative d18O values (warmer and/or less saline conditions) is also observed in the isotopic record, which also reflects the 20th century warming. Despite this general common trend, interdecadal variability differences between both records suggest that temperature alone cannot explain the d18O changes observed in this site of the Coral Sea. A freshening of surface waters after 1870 has recently been reported from coral cores collected from the inshore region in the Great Barrier Reef and interpreted as indicating a weakening in trade winds and ocean circulation (Hendy, 2002). In the Flinders coral, however, an apparent freshening occurs in the early 1800s, followed by a subsequent transition to more saline conditions during the first half of the 20th century.

Hendy, E. J. et al. Science 295, 1511-1514 (2002)

McCulloch, M.T. et al. Geochimica at Cosmochimica Acta, 58, 2747-2754 (1994)

1 Australian Institute of Marine Science, Townsville, Australia

Contrasting regimes of soil production

J. Chappell, E. Rhodes, L.K. Fifield1, N. Spooner2, A. Heimsath3, and B.J. Pillans

The evaluation of long-term landscape processes using cosmogenic nuclides has focused on contrasting regimes of soil production in agricultural landscapes in southeast NSW and southwest Western Australia. Previous determinations of soil production on soil-mantled granite hillslopes in the Bega Valley, NSW, found that the production rate ranges from about 10 to 50 mm per thousand years, and decreases as soil depth increases. These measurements were based on the concentrations of 10Be produced by cosmic rays in quartz contained in near-surface rocks. We recently confirmed these results at other sites in the Bega Valley. However, on applying the same methods in soil-mantled granite terrain near Moora, WA, unexpectedly we found production rates of only 2-3 mm per thousand years: apparently, 10 times slower than in eastern NSW.

The origin of this paradox lies in the impacts of past episodes of aridity, which occurred repeatedly in WA throughout the Quaternary. The soils at the sites near Moora were formed largely from sand that was repeatedly remobilised: cosmogenic 10Be indicates that alternation between soil- and sand-mantles has occurred throughout at least the last million years. To understand the history and to determine rates of soil regeneration at the end of each arid, sandy phase, we are now combining measurements of cosmogenic nuclides with optical dating of sand particles within the soil profiles.

1 RSPhysSE
2 Formerly RSES
3 Dartmouth College, Hanover NH, USA.

Daily banding and modulation of Mg/Ca in foraminiferal calcite by symbiont photosynthesis and respiration

S. Eggins, A. Sadekov1, and P. De Deckker2

The Mg/Ca composition of tiny, calcium carbonate tests (shells) that are secreted by planktonic foraminifera, is widely assumed to be controlled by seawater temperature. This assumption underpins the increasing use of the bulk Mg/Ca composition of fossil foraminifera tests to estimate past seawater temperatures and to reconstruct palaocean and climate records spanning hundreds of thousands of years. Using two high-resolution microanalysis techniques (electron microprobe mapping and laser ablation-ICPMS depth profiling), we show that tests of the planktonic foraminifera Orbulina universa comprise mulitple low- and high-Mg growth bands see Figure 1. The number of paired bands is typically between 3 and 6, which is consistent with the number of days reported between final chamber formation and gametogenesis in laboratory culture experiments, and thus with a diurnal origin. The amplitude of Mg/Ca variation within individual tests and across many daily growth bands cannot be accounted for by the limited range of seawater temperature in the shallow, euphotic-zone habitat (0-100m depth) of O. universa. We propose that Mg/Ca composition of calcite precipitated by O. universa is modulated by changes in pH, due to the day-night, photosynthesis-respiration cycle of algal symbionts. These results indicate that the Mg/Ca composition of calcite precipitated by O. universa is sensitive to influences that modify the biological activity of foraminifera and their algal symbionts. The results challenge a fundamental assumption of Mg/Ca palaeo-seawater thermometry that the Mg/Ca composition of foraminiferal calcite is solely determined by seawater temperature.

1 Department of Palaeontology, Moscow State University, Moscow, Russia
2 Department of Geology, Australian National University

Figure 1. Mg/Ca intensity map of O. universa chamber wall cross-section measured by electron microprobe (Cameca SX100) and (2) Mg/Ca composition depth profile measured through the same chamber wall by laser ablation-ICPMS.

Accurate dating of rapid rises of sea level in the last glacial cycle

T. Esat, J. Chappell, J. Desmarchelier, L.K. Fifield1 & M.T. McCulloch

Northern hemisphere climates switched repeatedly and abruptly between cold and warm states during the ice ages. This now widely-known but unexplained finding poses uncertainties about future climate. A key to this problem is the exact chronology of past sea level and climatic changes, which we aim to establish by improved dating of millenial-scale sea level changes during the last 100,000 years that are recorded in coral terraces at Huon Peninsula, PNG.

We have focused on precise dating of rapid sea level excursions that occurred between 30,000 and 65,000 years ago. U-series disequilibrium ages of some 50 previously-dated samples from key stratigraphic points were remeasured using ICP-multicollector mass spectrometry. New methods were established for identifying subtle micrometre-scale phenomena that falsify ages, using electron microscopy, laser-ablation ICP mass spectrometry, and electron microprobe trace element mapping. The new evaluation methods were combined with age remeasurements by U-series and Accelerator Mass Spectrometry (AMS) radiocarbon, and precise sets of ages were established from existing samples for two key sea level rises (32.6 and 37.8 ka). Advances overseas with the chronology of abrupt climatic shifts in Greenland ice cores and north Atlantic marine sea records indicates that the rise at 37.8 ka corresponds to the major Heinrich-4 ice break-out.

1 RSPhysSE

Basal thermal regimes of former ice sheets constrained using cosmogenic nuclides

D. Fabel, J.Harbor1, A. Stroeven2, C. Clarhäl2, J. Kleman2, D. Elmore3 and D. Fink4

The motion of ice sheets occurs as a result of internal deformation and basal sliding, which includes direct sliding of ice over its substrate, internal deformation in the substrate, and enhanced deformation in basal ice. Basal sliding is ineffective where basal ice is below the pressure melting point (cold based, or frozen bed conditions) and most effective where basal ice is at the pressure melting point (warm based, or thawed bed conditions), so that water is present. Reconstructions of the last glacial maximum Fennoscandian and Laurentide ice sheets are extremely sensitive to assumed basal thermal patterns, resulting in estimates of ice thickness that vary on the order of 1 km.

Recognition of subglacial boundaries between sliding and frozen-bed areas for former ice sheets is typically based on distinct morphological contrasts between areas with glacial landform assemblages and relict areas showing little alteration of pre-existing features. However some of these boundaries, especially on continental shield areas, are clearly visible from air photos but have minimal topographic expression (Fig. 1). Understanding the chronology and erosional development of such boundaries is important to provide insight into the pattern and persistence of basal conditions under ice sheets.

Geomorphic evidence and cosmogenic radionuclide concentrations of bedrock outcrops on either side of sliding boundaries on low-relief upland plateaus in northern Sweden (Fig. 1) are consistent with negligible erosion in relict landscape (frozen bed) areas due to the last glaciation, but also indicate very limited erosion in the sliding areas. This pattern and magnitude of landscape modification indicates that sliding was short lived in these areas, likely as a transient phase during deglaciation. These sites demonstrate that short periods of sliding are in some cases sufficient to produce landscapes that are recognized as 'glacial' from air photos.

Glacial landforms attributed to sliding in areas formerly covered by ice sheets must be viewed as the cumulative total area that has experienced sliding at any time during a glaciation. At this stage it is not possible to determine during which phase of ice sheet glaciation the sliding occurs, but it is unlikely to happen simultaneously in all sliding areas. Therefore, the actual extent of sliding areas during different ice sheet phases is presumably considerably less than the cumulative total area, which has important implications for establishing appropriate basal boundary conditions for ice sheet reconstructions at different times during a glaciation.

1 Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana, U.S.A.
1 Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden

3 Department of Physics, Purdue University, West Lafayette, Indiana, U.S.A.
4 AMS-ANTARES, Environment Division, ANSTO, RMB 1, Menai, NSW 2234, Australia.

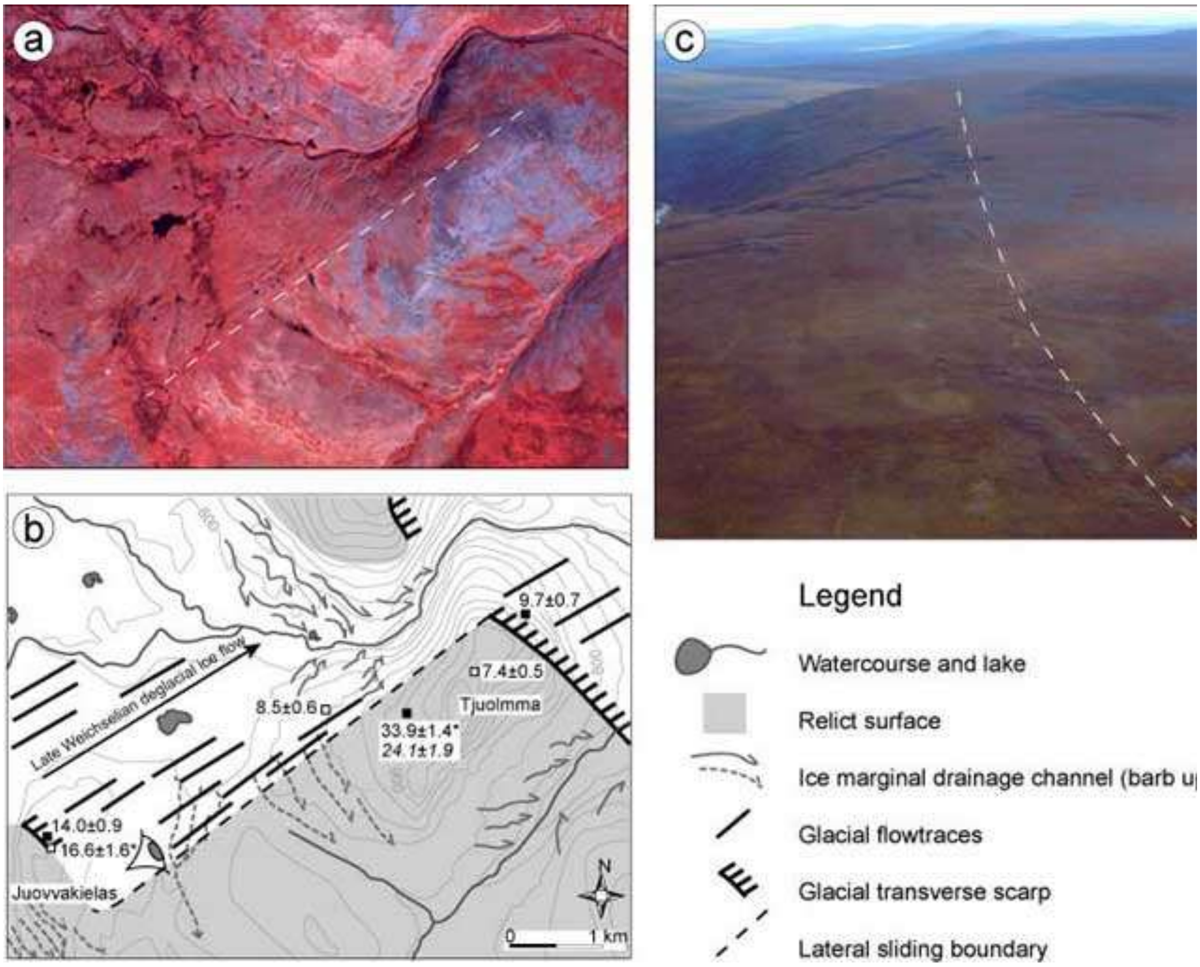


Fig. 1. Infra-red air photo (a), geomorphological map (b) and oblique airphoto (c) of Mt. Tjuolmma and Juovvakielas on Ultevis. The oblique air photo (c) is taken from the point shown by the eye symbol in (b). Pre-Late Weichselian lateral meltwater channels are crosscut by till lineations and the lateral sliding boundary. The channels can be traced on the glacially eroded side of the boundary as water-filled depressions aligned with the down-stream continuation of the lateral channels. The lateral sliding boundary itself appears as a sharp feature on air photos and terminates in transverse lee-side scarps. Sample locations are marked by open squares (erratic samples) and closed squares (bedrock samples). 10Be and 26Al (italics) apparent exposure ages with uncertainties are given in thousands of years. An asterisk indicates a weighted mean age.

Estimating neotectonic movement in southern Victoria using cosmogenic burial dating

D. Fabel

The aim of this project is to determine the age of several tectonically displaced sedimentary deposits in the Cape Liptrap area of southern Victoria using cosmogenic burial dating.

The geomorphology of this region testifies to the profound influence of faulting in shaping the landscape. While quantitative constraints on the displacement history of these faults are not yet available, dramatic evidence for recent movement is indicated by kink-bands in

~125,000 year old cemented dune limestone near Cape Liptrap. There are no numerical ages for tectonically offset older sedimentary deposits that could provide further constraints on the age and rate of neotectonic movement. We are using a relatively new chronological technique, cosmogenic burial dating, utilising the radioactive decay of cosmic-ray produced Be-10 and Al-26 in buried quartz, to estimate these ages. Based on the differential decay of the in-situ produced cosmogenic nuclides Be-10 (radioactive half-life = 1.51 ± 0.03 Ma) and Al-26 (0.705 ± 0.02 Ma) in quartz, the technique is widely applicable to dating up to approximately 5 million year old quartz-rich sediments. The ratio Al-26/Be-10 in quartz is dominated by the nuclide production rate ratio for all but the very slowest erosion rates where radioactive decay starts to become significant. Because Al-26 and Be-10 are produced at a constant ratio, independent of absolute production rates, the Al-26/Be-10 ratio in quartz is robust against temporal production rate variations. In a steadily eroding landscape, quartz grains within the soil and sediment contain Al-26 and Be-10 concentrations in this predictable ratio. If these quartz grains are subsequently buried, for example deep within a sedimentary deposit, then cosmogenic nuclide production within those grains is attenuated by the overburden and inherited Al-26 and Be-10 concentrations diminish by radioactive decay. Because Al-26 decays more rapidly than Be-10, the Al-26/Be-10 ratio decreases exponentially with time. By measuring the Be-10 and Al-26 concentrations using accelerator mass spectrometry, the current Al-26/Be-10 ratio in the sample can be determined, and the burial time calculated.

Preliminary results indicate that coarse sand and gravel overlying horizontally cut marine platforms at elevations ranging from 4 18 m above present mean sea level were deposited between 630 ka and 1.15 Ma. Although the results are intriguing, they are complicated by post burial cosmogenic nuclide production. We are currently evaluating methods of obtaining reliable ages for samples with complex burial histories.

Tracing the post-Younger Dryas retreat of the northern Fennoscandian Ice Sheet using cosmogenic radionuclide exposure ages

D. Fabel, A. Stroeven1, T. Dahlgren2, J. Harbor3, C. Hättestrand1, J. Kleman1 and D. Fink4

The aim of this collaborative project is to determine the rate of retreat of the Fennoscandian ice sheet from the Younger Dryas limits in northern Norway to the terminal limits in the northern Swedish mountains (Fig. 1). The north to south retreat history is poorly constrained due to a lack of datable material. We are working to provide new constraints on the timing and pattern of deglaciation using cosmogenic nuclide apparent exposure ages.

The work involves mapping and dating depositional and erosional geomorphological features related to the former ice sheet margin. Because the ice sheet initially had warm-based conditions close to its margin, the dominant morphology is one of eskers and aligned lineation systems, such as crag-and-tails. Abundant meltwater eroded bedrock locally to considerable depth and deposited fans or deltas perched above current local base levels (Fig. 1). However, subglacial conditions during final deglaciation were generally cold-based, inhibiting the formation of eskers and lineation systems, although there are widespread (lateral) meltwater channel erosional imprints and occasional plucking scars.

Each geomorphological setting was examined for its value in providing deglaciation ages, testing the initial assumption that, (i) abundant erosion on crags of crag-and-tails, across transverse erosional scarps, and in meltwater channels has exposed bedrock surfaces without a prior exposure history and (ii) depositional features contain embedded boulders without a prior exposure history (on the surfaces of eskers and deltas, and erratics). Preliminary results indicate that meltwater channels, transverse erosional scarps, and erratics yield deglaciation ages that are consistent with the limited ages provided by other methods, but that crag-and-tails yield apparent exposure ages that are too old, presumably because of a prior exposure history that was not fully removed by glacial erosion.

1 Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden
2 Department of Geology, University of Tromsø, Tromsø, Norway
3 Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana, U.S.A.
4 AMS-ANTARES, Environment Division, ANSTO, RMB 1, Menai, NSW 2234, Australia.

Fig. 1. (A) Crag and tail. Ice flow was from right to left. (B) Perched glaciofluvial delta dissected by meltwater channels. (C) Esker

Stable isotope analysis of bone collagen and tooth enamel of Australian marsupial faunas: a baseline study investigating the implications for palaeodiet and palaeo-environmental reconstructions

R.A. Fraser, R. Grün, and M.K. Gagan

Fossil mammal faunas are a major source of palaeoecological information: the diversity and abundance of species from well-dated deposits can provide proxy data for past vegetation and palaeoclimates. The stable isotopes of carbon, nitrogen and oxygen within fossil bone and teeth are an additional source of diet and climate information. Whilst the use of stable isotopes in palaeodiet research is employed extensively overseas in the archaeological and ecological fields, it remains vastly under used in Australian palaeoecology.

There remains uncertainty about how stable isotopes reflect animals' diet and climate in the Australian context, therefore this project has begun by measuring the d13C and d18O tooth enamel from modern marsupial herbivores; kangaroos, wombats and koalas. By analysing these tissues from modern species with known dietary preferences, from distinct geographic, floristic and climatic regions, we can investigate the existing relationships between diet, environment and the isotopes measured.

d13C in tooth enamel analysed in 2003.

Kangaroo specimens: initial isotopic analysis of enamel CO3, (using the Kiel Carbonate device/ MAT 251) from the incisor and four molars within an individuals' tooth row revealed significant differences in d13C between teeth. The average difference for 28 specimens gathered from south eastern Australia and Queensland was 4.06 ‰, the largest difference was 7.21‰ within a Macropus rufus jaw from Wilcannia in arid far-western New South Wales. The most noticeable pattern observed in the enamel CO3 isotope data shows that the early formed incisor and first molar are predominantly more negative in d13C than the other molar teeth, which formed later in adulthood. This is shown in figure 1. It is unclear whether this variation in d13C values reflects plant diet variability, perhaps due to greater seasonality in the environment, or physiological effects that may be age dependent. Ongoing investigation involves sampling kangaroos that have inhabited regions of varying percentages of C4 and C3 grasses to ascertain if grass diet availability can explain these differences.

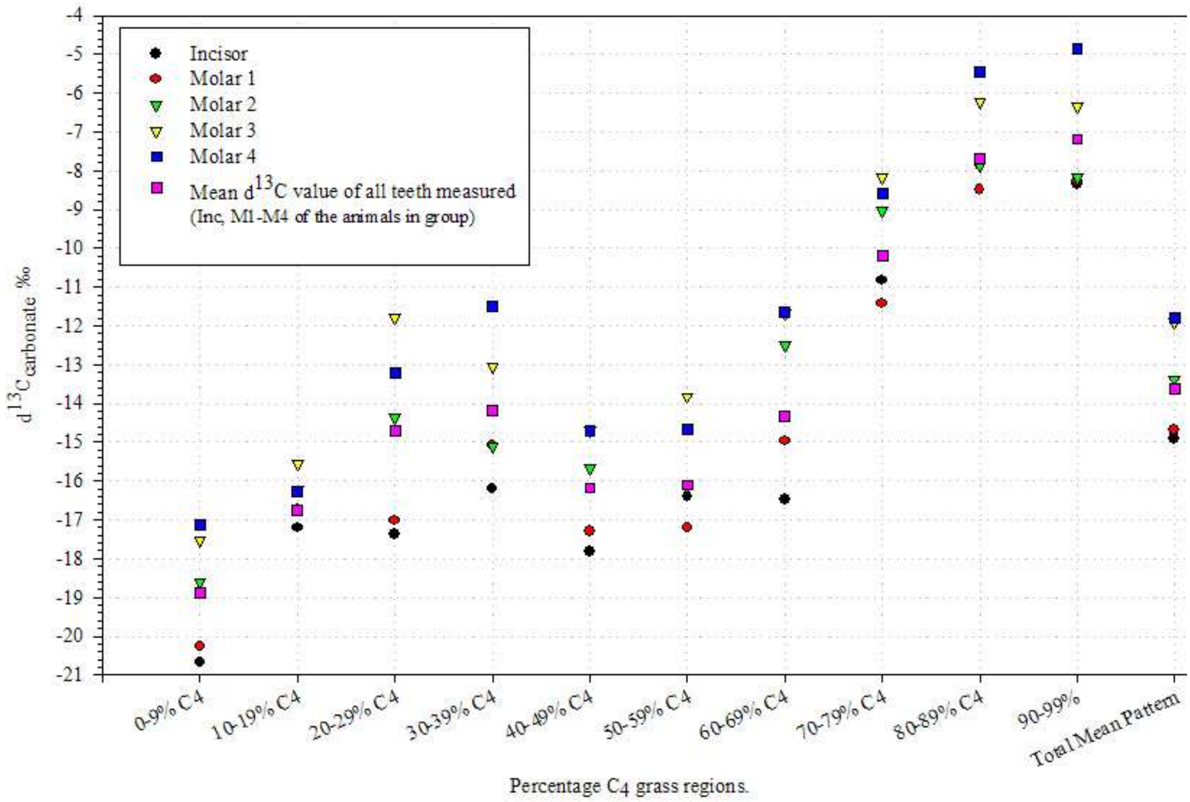


Fig 1: Pattern of isotopic values within different teeth of Kangaroos from regions of varying percentages of C4 grasses.

Ultimately, these modern baseline data will aid the interpretation of isotopic values found in fossil faunas. Gaining an insight into the diets of Australia's extinct megafauna, and the changing diets of extant fauna (such as kangaroos) over time in response to changing climate and vegetation regimes, will increase our understanding of ecological change.

Extremely low erosion rates at the gibber plain in South Australia

T. Fujioka, J. Chappell, M. Honda, I. Yatsevich, K. Fifield and D. Fabel

The Australian continent has been considered to be the most stable continent. There is, however, only a few quantitative data to assess this hypothesis, although low erosion rates are expected in the most of arid area in Australia. Cosmogenic surface exposure dating has been utilized for quantitative estimation of erosion rates near the ground surface. In an attempt to provide evidence of Australian continental stability, we have measured cosmogenic 21Ne and 10Be in three silcretes from Orapinna and CooberPedi in semi-arid South Australia.

In order to accurately determine the amount of cosmogenic 21Ne in the samples, a new method was developed to evaluate nucleogenic neon, which is a critical interference in estimating cosmogenic neon. Nucleogenic neon is produced by a reaction of oxygen in the crust and subsequently incorporated into minerals ("trapped" nucleogenic), and/or it is produced "in-situ" where a particles are provided from the decay of U and Th within minerals ("in-situ" nucleogenic). We estimated the amount of "in-situ" nuleogenic 21Ne using production rates derived from U and Th contents in the samples, and silcrete formation ages at the site (55±5 Ma). We calculated the amounts of "trapped" nucleogenic 21Ne from the amounts of fissiogenic 136Xe in the samples using the crustal production ratio (nucleogenic 21Ne/fissiogenic 136Xe). Using this method, it was determined that 10-20% of excess 21Ne was nucleogenic in origin.

Minimum exposure ages and maximum erosion rates were calculated from the amounts of cosmogenic 21Ne, after correction for nucleogenic 21Ne. All samples studied showed long exposure ages (>4 Ma) and low erosion rates (<0.1 m/Ma). The erosion rates in this study appear to be extremely low compared to commonly quoted erosion rates estimated in Australia (5 to 50 m/Ma) and they are among the lowest ever measured globally.

Coral records of surface-ocean evaporation: the “other half” of the hydrological cycle

M.K. Gagan, L.K. Ayliffe* and M.T. McCulloch

Evaporation is more prevalent than precipitation over the oceans and is the fundamental driver of the global hydrological cycle. Yet little is known about marine evaporation in the past, nor its role in global climate change. Changes in tropical surface-ocean evaporation rates in the past could induce atmospheric feedbacks that amplify the global climate response to minor forcings. For example water vapour, the premier atmospheric greenhouse gas, is thought to be an important factor driving glacial-interglacial climate change, but its potential role remains unclear because the past record of marine evaporation in the tropics is largely unknown.

We show here that season-specific measurements of skeletal Sr/Ca and d18O in corals offer the opportunity to reconstruct rates of tropical marine evaporation in the past. A significant attraction of the coral Sr/Ca and d18O technique is its ability to estimate sea-surface temperature (SST) and seawater d18O simultaneously. Precise determinations of coral Sr/Ca allow us to subtract the temperature component from the coral d18O signal and monitor seasonal changes in seawater d18O. Coupled measurements on the same coral sample avoid the problem of using separate time series to study coupled oceanic and atmospheric phenomena. Surface-dwelling Porites corals from the Dampier Archipelago, northwest Australia are ideal for quantifying the relationship between surface-ocean evaporation, seawater d18O, and sea-surface salinity (SSS). Mean annual solar radiation and evaporation rates on the hot, subtropical coast of northwest Australia are among the highest on Earth. In such a setting, salinity and seawater d18O vary together because evaporation, which increases salinity, also concentrates the heavy isotope of d18O.

Previous work has demonstrated that precise, high-resolution measurements of coral Sr/Ca at Dampier track seasonal variations in SST. Figure 1A shows that subtle differences between the Dampier coral Sr/Ca-SST and d18O-SST curves (defined as residual Dd18O), mimic the timing and magnitude of strong seasonal changes in SSS. 18O enrichments in the coral record become progressively greater in austral spring and reach maxima in November-December. This pattern coincides with the sharp austral spring rise in solar radiation, air temperature, and SST, all of which would serve to increase surface-ocean evaporation and the concentration of Dd18O and salt in seawater.

The veracity of the linear correlation between coral Dd18O and SSS can be confirmed by comparison with the relation for equilibrium evaporation of water at 26 oC, the mean SST at Dampier (Fig. 1B). The slopes of the d18O/SSS regression lines are in close agreement, 0.23 ‰ psu-1 for the coral data versus the theoretical slope of 0.25 ‰ psu-1. Also, equilibrium evaporation at 26 oC should yield water vapour depleted in d18O by 8.7 ‰, relative to seawater. This is in good agreement with the depletion of 8.1 ‰ for evaporated water given by the intercept of the regression line for coral Dd18O and SSS.

Based on these results, we conclude that high-resolution coral Dd18O records have the potential to yield insights into marine evaporation rates in the past. The technique is being applied to improve our understanding of the specific mechanisms by which subtle changes in past insolation seasonality were converted to significant changes in the global climate.

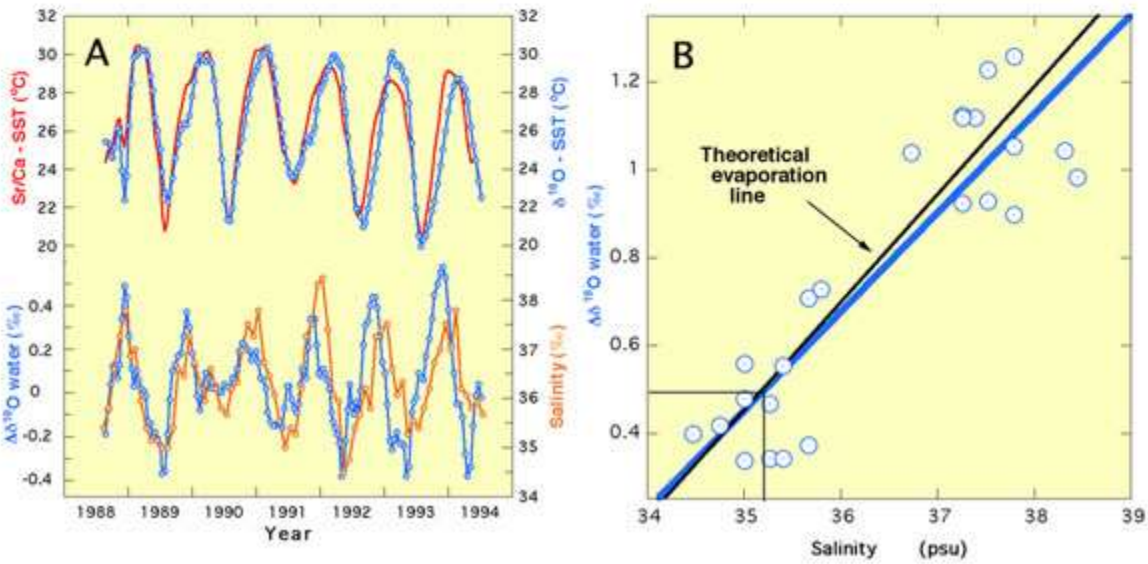


Figure 1: Relationship between surface-ocean evaporation, coral residual d18O (Dd18O), and salinity. (A) Comparison of Sr/Ca-SSTs (red curve) and d18O -SSTs (blue curve) for Porites lutea from the Dampier Archipelago, Western Australia (20º36'S, 116º45'E). The Sr/Ca-SST and d18O -SST relations are: TSr = 167.8 16013 * (Sr/Ca) and T18O = 0.82 - 5.59 * d18O. Lower curves show seasonal changes in coral Dd18O (blue) and monthly salinity

(orange). Residual δ18O is obtained using: Dd18O = ∂d18O/∂T * [T18O - TSr], where ∂d18O/∂T is the temperature-dependent oxygen isotope fractionation (-0.18 ‰ per ºC) determined for Porites. (B) Comparison of linear regression lines for coral Dd18O and salinity (blue line) with the theoretical line for equilibrium evaporation of water at 26ºC (black line). The regression equations are: Dd18O coral = 0.225 * DSSS 7.4 and Δd18O theoretical = 0.246 * DSSS 8.1.

* Present address: Department of Geology and Geophysics, The University of Utah, USA.

Coral radiocarbon records of Indian Ocean water mass mixing and wind-induced upwelling along the coast of Sumatra, Indonesia

N.S. Grumet1, N.J. Abram, J.W. Beck2, R.B. Dunbar1, M.K. Gagan, T.P. Guilderson3,4, W.S. Hantoro5 and B.W. Suwargadi5

Radiocarbon (14C) in the skeletal aragonite of annually banded corals track radiocarbon concentrations in dissolved inorganic carbon (DIC) in surface seawater. As a result of nuclear weapons testing in the 1950s, oceanic uptake of excess 14C in the atmosphere has increased the contrast between surface and deep ocean 14C concentrations. We have used accelerator mass spectrometric (AMS) measurements of 14C/12C ratios (D14C) in Porites corals from the Mentawai Islands, Sumatra (0ºS, 98ºE) and Watamu, Kenya (3ºS, 39ºE) to document the temporal and spatial evolution of the 14C zonal gradient in the tropical Indian Ocean. Our intrabasin comparison of coral D14C records from the coasts of Sumatra and Kenya reveals a distinct difference in water mass mixing processes across the equatorial Indian Ocean basin.

The rise in D14C in the Sumatra coral, in response to the maximum in nuclear weapons testing, is delayed by 2-3 years relative to the rise in coral D14C from the coast of Kenya (Figure 1). Kenya coral D14C values rise quickly because surface waters are in prolonged contact with the atmosphere. In contrast, wind-induced upwelling and rapid mixing along the coast of Sumatra entrains 14C-depleted water from the subsurface, which dilutes the effect of the uptake of bomb-produced 14C by the surface-ocean. Differences during the steady state pre-bomb period also suggest that rapid mixing at the Mentawai site leads to a greater influence of deeper water depleted in 14C. Convergence of the Mentawai and Watamu D14C records later in the bomb produced 14C rise is attributed to a water mass renewal rate of thermocline waters off the coast of Sumatra of between 2 and 3 years. Results from a box model confirm that a water mass renewal rate of approximately 2.5 years can account for the observed lead-lag relationship between the Watamu and Mentawai coral D14C records.

Bimonthly AMS D14C measurements on the Mentawai coral reveal mainly interannual variability with minor seasonal variability. Singular spectrum analysis of the Sumatra coral D14C record reveals a significant 3-year periodicity. These results lend support to the concept that interannual variability in Indian Ocean upwelling and sea-surface temperatures is related to ENSO-like teleconnections over the Indo-Pacific basin.

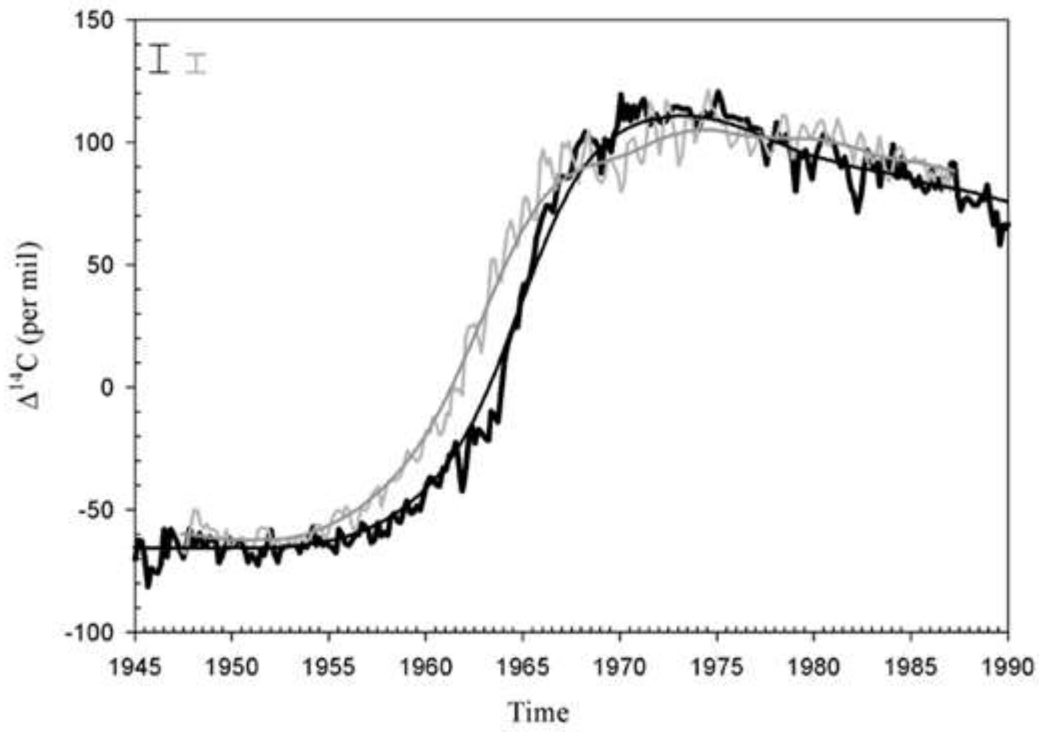


Figure 1: Bimonthly Mentawai (thick black line) D14C time-series superimposed on the long-term Mentawai trend (thin black line) from 1945 to 1990. The long-term trend was calculated using singular spectrum analysis. Coral radiocarbon levels respond to atmospheric testing of nuclear weapons in the mid 1950s. The increase in D14C recorded at Watamu (thin and thick grey lines) leads the increase at the Mentawai Islands by 2-3 years during the initial rise of bomb 14C between 1954 and 1963.

1 Department of Geological and Environmental Sciences, Stanford University, Stanford, California 94305

2 NSF AMS Facility, Department of Physics, University of Arizona, Tucson, Arizona, 85721

3 Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, Livermore, California 94551

4 Institute of Marine Sciences, University of California at Santa Cruz, Santa Cruz, CA 65064

5 Research and Development Center for Geotechnology, Indonesian Institute of Sciences (LIPI), Bandung 40135, Indonesia.

Thorium/Uranium systematics of Precambrian deep-sea pelagic black shales: implications for redox state of the early atmosphere

Y. Jia, M.T. McCulloch and C. Allen

To address the question of the redox state of the Precambrian atmosphere-hydrosphere system via sediments requires measurement of redox sensitive trace elements, and inter-element ratios, in deep water black shales with a chemical sedimentary “hydrogenic” component. This approach is endorsed by recent progress in research of redox-sensitive trace metals records in late Proterozoic and Phanerozoic sedimentary rocks, which has provided important clues to how the redox state of depositional environments has changed over time. Many conventional studies, in contrast, have been on first cycle volcanogenic turbidites with a minimal hydrogenic input (Taylor and McLennan, 1995). Accordingly, we have analysed the redox-sensitive, trace element compositions of the 2.1 Ga black shales in Birimian Blet, West Africa, and the 2.7 Ga Archean counterparts in Timmins, Canada, Tati Belt, Botswana, and Kanowna District, Western Australia. These pyrite-bearing black shales, which were originally argillaceous sediments containing organic matter and low in thermal maturity, were primarily deposited in the deep-sea pelagic environments. Th/U ratios are lower in the Proterozoic shales (0.38-0.82, average 0.67), and Archean shales (0.47-3.65, average 2.43) relative to “conventional” Archean upper crust (3.8), PAAS (4.7), or average upper continental crust (3.8). Calculated U concentrations from hydrogenic component are between 0.90 and 2.45 in the Proterozoic shales, and range from 0.06 to 0.96 for the Archean black shales. Given the conservative behavior of Th in the sedimentary cycle, variably low Th/U ratios in these Precambrian black shales signify that U6+, soluble in oxidized surface waters, was reduced to insoluble U4+ in reducing bottom waters, as in the contemporary Black Sea. The results are consistent with a locally to globally oxidized atmosphere-shallow hydrosphere pre-2.0 Ga.

Taylor S.R. and McLennan S.M. (1995) Reviews of Geophysics, Vol 33, pp 241-265.

15N-enriched Archean crust or 15N-depleted crust recycled into -6 ‰ upper Mantle?

R. Kerrich1 and Y. Jia

To investigate the origin and evolution of nitrogen in the atmosphere, crust, and mantle systems during Earth’s early history. Nitrogen concentrations and isotopic compositions have been measured on 2.7 to 1.0 Ga Precambrian metasedimentary rocks from Botswana, Canada and Ghana; pre-metamorphic 2.7 Ga VMS deposits in Canada; and on post-metamorphic hydrothermal micas from 2.7 to 1.8 Ga quartz vein systems in Zimbabwe, Canada, and Ghana, . Archean sedimentary kerogens, K-silicates in VMS deposits, and K-micas in hydrothermal systems that sample average crust, yield d15N values of 15-24 ‰, compared to 2 to 6 ‰ in Phanerozoic counterparts. Palaeoproterozoic equivalents have intermediate d15N of 7 to 12 ‰, implying a secular decrease in crustal d15N. In parallel, N contents increase from tens to hundreds of ppm in the Archean, up to hundreds to thousands of ppm since the Palaeoproterozoic. The 15N-enriched nitrogen in both Archean sedimentary rocks and hydrothermal vein systems cannot be caused either by long-term diffusional loss of 14N, or by N-isotopic shifts due to metamorphism; such fractionations are £2‰ as established from empirical studies of Phanerozoic terranes with progressive metamorphism, and experiments. Moreover, pre- and post-metamorphic Archean samples have 15N enriched values in common. Retention of near-primary 15N-enriched values is endorsed by the lack of covariation of C/N with d13C or d15N, or with metamorphic grade. It is possible that the 15N-enriched values stem from a different N-cycle in the Archean, with large biologically mediated fractionations, yet the magnitude of the fractionations observed exceeds any presently known. The 15N-enriched nitrogen does not robustly constrain Archean redox-state. We attribute the 15N-enrichment to a secondary atmosphere derived from CI-chondrite-like material and comets with d15N of +30 to +42‰. Shifts of atmospheric d15N to its present values of 0‰ can be accounted for by a combination of early growth of the continents and sequestering of atmospheric N2 into crustal rocks, recycling into the mantle, and mantle degassing. Consequently, these shifts are tracked by the secular change of d15N in continental crust. If Earth's surface environment became oxygenated at ~ 2 Ga, then there were no associated large N-isotope excursions. Based on a few 15N depleted Archean cherts Marty and Dauphas (2003) proposed that recycling of 15N depleted Archean crust could shift the upper mantle from a primordial value of +6 to +8 ‰ to the observed value of -5 ‰. Our new data rule out this model.

Marty B., Dauphas N., (2003) Earth Planetary Science Letters, Vol 216, pp 433-439.

1 University of Saskatchewan, Canada

Coral Ba/Ca Record of Runoff from the Fitzroy River

J. Marshall, M.T. McCulloch and G. Brunskill[1]

A 250 year record of Ba/Ca in a Porites sp. coral was obtained from Humpy Island, located on the inner shelf some 30 km north of the mouth of the Fitzroy River. The Ba/Ca record is similar to that obtained for the Burdekin catchment, in that there are numerous peaks from 1850 to the present, but prior to 1850 there are much fewer Ba/Ca peaks with the exception of periods related to drought-breaking floods. While the relationship between increased Ba/Ca and European settlement appears to hold for the Fitzroy as well as the Burdekin, there are some significant differences. Firstly, the periods of runoff for the Burdekin and Fitzroy are not always coeval, as evidenced by the modern instrumental record. However, this can be seen as independent evidence for the relationship between Ba/Ca and river discharge. Secondly, there does not appear to be a relationship between the height of the Ba/Ca peak and the discharge volume; for example, the highest Ba/Ca peak is in 1947, but the Fitzroy discharge at this time is only moderate. Thirdly, the Ba/Ca peaks for the Humpy Island coral are not as large and the background levels are more noisy compared to the Havannah coral. This could be a reflection of the interaction between the Fitzroy estuary and the increased tidal range in this region.

1Australian Institute of Marine Science, PMB3, Townsville MC, Qld 4810, Australia

Impact of European settlement on sediment and freshwater runoff into the inner Great Barrier Reef

M.T. McCulloch

European settlement and accompanying landuse changes had a profound effect on the Australian landscape. In the river catchments bordering the GBR, pastoral grazing, cultivation, mining, urban development and land clearing associated with these activities have led to significant increases in sediment and associated nutrients reaching the coral reefs of the inner GBR. Direct quantification of the magnitude of long-term changes is mainly limited to studies of the several inshore reefs impacted by the Burdekin River. These studies show that from the 1870s onwards there has been a five- to tenfold increase in the sediment load delivered by this system. The Burdekin has one of the largest catchments (second only to the Fitzroy River) and is the single most important source of sediment into the GBR. We have examined in detail the relationship between the intensity of cattle grazing, short-term climate variability (i.e. droughts and floods) and resultant suspended sediment loads delivered by the Burdekin River. We can demonstrate that there is a strong link between increased cattle numbers such as occurred during the mid-late 1970s and increased sediment fluxes. This situation is exacerbated during drought-breaking floods. In addition, we show that freshwater runoff into the inner GBR has increased significantly, a consequence of reduced vegetation cover, compacted soils and hence reduced water infiltration rates. Finally, it is argued that contrary to previous suggestions, turbidity in the inner GBR has also increased as a result of enhanced sediment supply. Although turbidity is predominantly controlled by wind driven resuspension events, previous workers have mistakenly assumed that sediment supply is not a limitation. Following European settlement as much additional sediment has been delivered to the inner GBR as during the previous ~1000 years. Due to the relatively long time constants for sediment isolation, together with an imbalance in the sand/silt fraction, it is estimated that ~1/2 of the resuspended load presently contributing to turbidity is of recent (post 1870) origin. This work suggests that the combination of greatly enhanced sediment and nutrient fluxes entering the GBR, together with more pervasive freshwater flood plumes, maybe having even greater ecological consequences than hitherto thought.

Coral d18O records of late Holocene amplification of the El Niño-Southern Oscillation

H. V. McGregor and M. K. Gagan

El Niño-Southern Oscillation (ENSO) is recognised as a major modulator of global climate, producing severe climate impacts, including extreme drought and flooding, in regions far from the tropical Pacific. Characterising the behaviour of ENSO during the Holocene has become an important tool for exploring the natural variability of the ENSO system, and can give clues as to how this system may vary in the future.

We have investigated changes in ENSO warm event (El Niño event) amplitude and frequency during the mid to late Holocene, using annually-resolved d18O anomaly records in fossil and modern corals sampled from Koil and Muschu Islands, Papua New Guinea (PNG). The d18O anomalies in coral records from this region reflect ENSO-induced processes, with positive d18O anomalies occurring during El Niño events.

Three fossil coral records from 7.6-7.1 ka and four from 6.1-5.4 ka show smaller d18O anomalies compared to the present, suggesting reduced El Niño frequency and amplitude at this time. These coral results are consistent with another western Pacific coral record, eastern Pacific palaeo-lake data, and recent modelling studies, all of which show El Niño suppression through the mid-Holocene.

Our fossil coral record from 2 ka shows a 10% reduction in El Niño amplitude, whereas a coral from Madang, PNG, aged 2.5 ka (Tudhope et al., 2001) and another from Christmas Island (central equatorial Pacific), aged 1.7 ka (Woodroffe et al., 2003) show increased El Niño amplitude relative to present. Although these results appear contradictory, the coral data for 2.5 to 1.7 ka may actually represent a shift in the nature of El Niño at this time. This shift is revealed in the detail of the annually-resolved d18O anomaly records (Fig. 1). The three d18O anomaly records show large amplitude, multi-year El Niño events: the 2.5 ka coral records an extreme 4-year El Niño, similar in duration to the 1991-1994 event and larger in amplitude than the 1997/98 event; the Muschu Island 2 ka coral shows a prolonged 7-year El Niño, longer than any recorded Holocene or modern event; and the 1.7 ka microatoll of Woodroffe et al. (2003) records an extreme El Niño, also larger than the 1997/98 'event of the century'. The change in the nature of El Niño at ~2ka suggests stronger ocean-atmosphere coupling in the tropical Pacific and shows that the ENSO system has the potential for more extreme variability than that observed in the modern instrumental record.

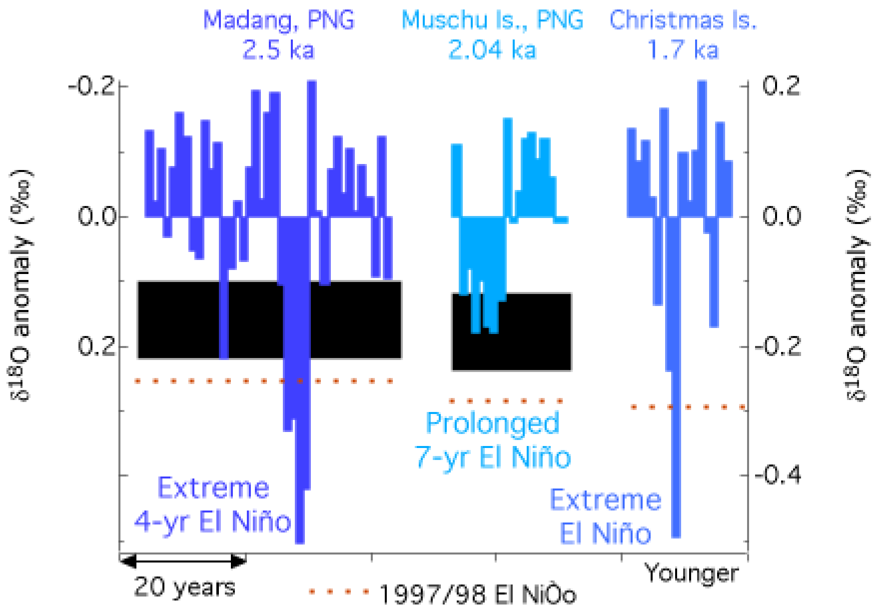


Figure 1: Comparison of extreme El Niño events for the period 2.5-1.7 ka recorded by tropical Pacific coral d18O records. The black boxes indicate moderate El Niños (±1s from the average modern coral El Niños) for this study and that of Tudhope et al. [2001]. Red dashed lines indicate the magnitude of d18O anomalies recorded by Pacific corals during the very strong 1997-98 El Niño. During El Niños negative d18O anomalies (warmer/wetter) are recorded by central equatorial Pacific Porites [Woodroffe et al., 2003], while positive d18O anomalies (cooler/drier) are recorded by western equatorial Pacific corals.

Tudhope, A. W., et al. (2001) Science, 291, 1511-1517, 2001.
Woodroffe, C.D., et al., (2003) Geophysical Research Letters, Vol 30, 1358, doi:1310.1029/2002GL015868.

Climate variability of the last millennium revealed by high-resolution stable isotope record in an Italian speleothem (NW Sardinia)

P. Montagna1, M. Gagan, M. McCulloch, H. Scott-Gagan, F. Antonioli2, S. Silenzi3, C. Mazzoli1

Reconstructing multi-centennial climate variability is crucial in the Mediterranean region where continental climatic and environmental records are limited. The chemical and stable isotopic compositions of speleothems are capable of providing reliable continental palaeoclimatic records because speleothem calcite is generally unaffected by post-depositional processes. In addition, speleothems are well-datable by U-series disequilibrium methods (Schwarcz, 1980).

We have obtained a high-resolution d18O record for a speleothem, collected from the Grotta Verde, located on Capo Caccia promontory on the northwest coast of Sardinia (Fig. 1). The promontory mainly consists of limestone, dolomitic limestones and dolostones, Mesozoic in age. The U/Th age of the speleothem spans 1328±190 years from the base to the actively growing upper surface, indicating an average growth rate of about 130 micrometres per year.

The millenial-scale high-resolution d18O record consists of 234 microsamples collected along the 17cm long growth axis of the Grotta Verde speleothem (Fig. 2). The first 9 cm were sampled with a 100 micron spatial resolution whereas microsamples every 2-3 mm were collected for the other 8 cm. The d18O values show significant changes in temperature and precipitation during the last millennium, comparable with the low-frequency signals observed in a long European tree-ring chronology (Esper et al., 2002) (Fig. 3). Based on this correlation, between 900 and 1250 AD, the speleothem d18O record indicates relatively wet and warm conditions corresponding to the so-called Medieval Warm Period (MWP). By contrast, alternating dry/cold and wet/warm conditions from 1200 to 1850 AD mark the well-known Little Ice Age (LIA).

Following the LIA, a gradual warming trend culminates with a temperature maximum around 1930-1940 AD. Surprisingly, the 20th century warming is interrupted by a cooling trend from 1940 to 1995 AD. This mid-20th century temperature maximum is in good agreement with changes in the North Atlantic Oscillation (Jones et al., 1997), one of the major modes of climate variability in the Northern Hemisphere. This work demonstrates that, by using strategic sites, it is possible to extract high-resolution climate records for the last ~ 1000 years.

Figure 1. Location map showing the studied site. Arrow indicates the Grotta Verde, on the northwest coast of Sardinia.

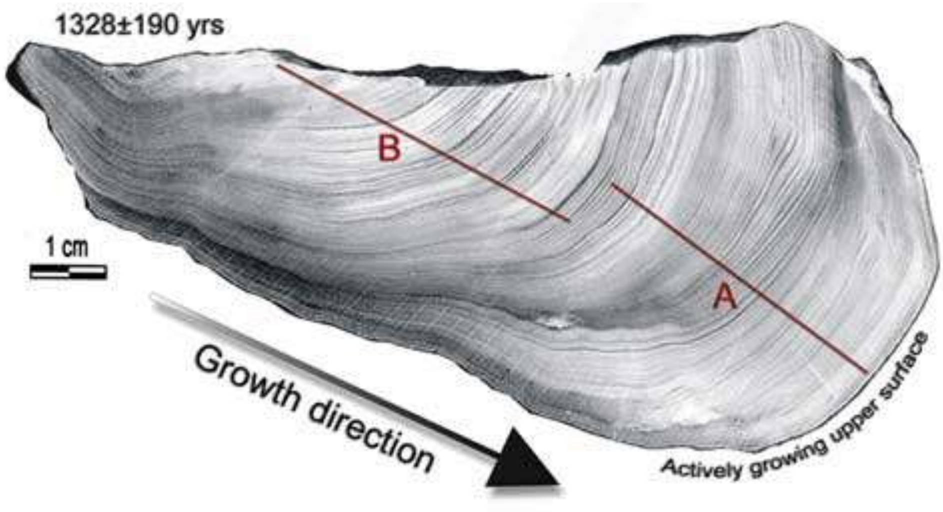


Figure 2. Longitudinal cross-section of the studied speleothem. Tracks A and B were sampled for stable isotopes with a spatial resolution of 100 µm and 2-3 mm respectively.

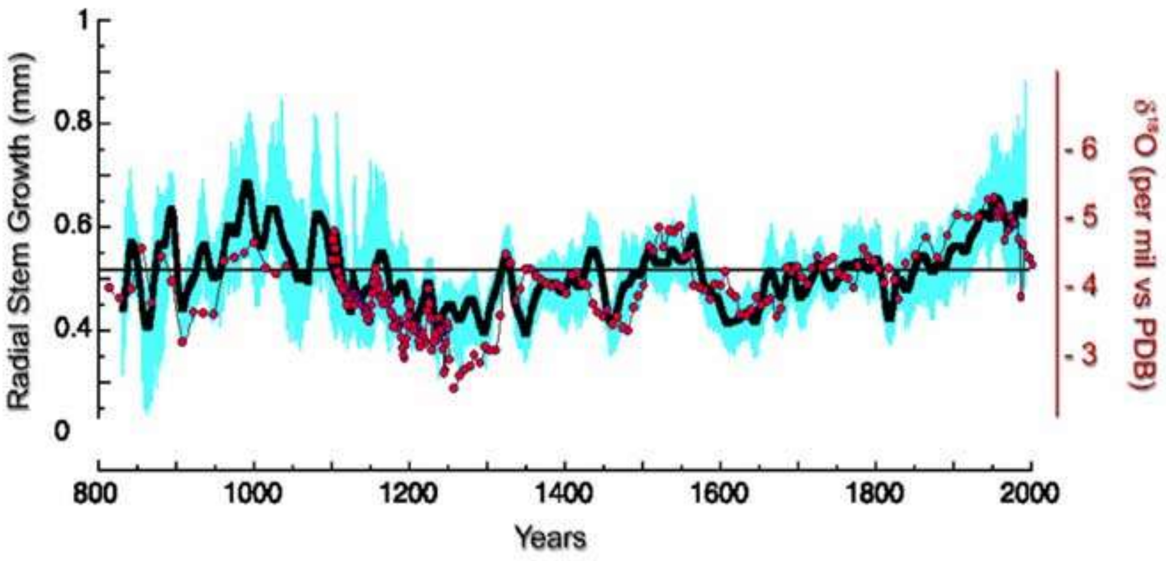


Figure 3. Longitudinal profile of d18O values (red dots) compared with the 20-year smoothed Northern Hesmiphere extratropics reconstruction of radial stem productivity in high elevation and high latitude forest environments since ~ 800 (black) and two-tailed 95% bootstrap confidence intervals (blue) (from Esper et al., 2002). d18O profile was adjusted considering the different growth rate along the growth axis of the speleothem.

1 Dept. of Mineralogy and Petrology, University of Padua, Italy.
2 ENEA, Casaccia, S. Maria di Galera, Roma, Italy.
3 Central Institute for Research Applied to the Sea, Via dei Casalotti, Roma, Italy.

Esper J. et al. (2002) Science, 295, 2250-2253.
Jones P.D., et al (1997). International Journal of Climatology 17, 1433-1450.
Schwarcz H.P. (1980). Archaeometry, 22, 3-24.

Late Pleistocene palaeoceanographic and geochemical evolution of the South Tasman Rise

A. D. Moy, W.R. Howard & M.K. Gagan

This study uses a series of sediment cores recovered from the South Tasman Rise (STR), to reconstruct the palaeoceanographic and geochemical evolution in the Pacific sector of the Southern Ocean. Sediment cores MD972106 (45.2ºS, 146.3ºE, 3300m) and RS147GC34 (45.1ºS, 147.7ºE, 4001m) preserve records covering the last 160,000 years, with chronology controlled by AMS radiocarbon dates and benthic d18O (tied to SPECMAP). Collaborative research between the IASOS/ACE CRC - University of Tasmania and RSES - The Australian National University have enabled palaeoceanographic variables to be measured allowing us to estimate changes in past deep-water ocean circulation, carbonate chemistry and pCO2.

In water masses close to and below the calcite saturation horizon, planktonic foraminifera shell weights have been used as an index of dissolution at the seafloor and thus, used to estimate past deepwater [CO3=] in the Atlantic and Pacific Oceans (Broecker and Clark, 2001) . In waters situated well above the calcite saturation horizon, Barker and Elderfield (2002) , have shown planktonic foraminiferal shell weight variations over glacial-interglacial periods are related to surface water [CO3=] through time in response to changing atmosphere pCO2.

At the STR, the core sites are located close to the calcite saturation horizon and past changes in carbonate chemistry should be reflected in the sediment records at these sites. Planktonic foraminiferal shell weight results show increasing values during glacial periods (Termination I and Termination II), suggesting an increase in deepwater [CO3=] during these times (Figure 1). The most interesting aspect about the planktonic foraminiferal shell weights at the STR is the excellent correlation of planktonic (G. bulloides) d18O and planktonic shell weights over the past 160,000 years (Figure 1). These results suggest a couple of possible scenarios:

Planktonic foraminiferal shell weights measured in cores sites close to the calcite saturation horizon have been used as an index of dissolution. The tight correlation between shell weight and d18O, suggest the d18O values reflect selective dissolution of d18O enriched outer surfaces of the planktonic foraminifera measured.

(2) If marine calcification is sensitive to the concentration of atmospheric CO2, its effects should be seen in surface water pCO2 and [CO3=]. Planktonic foraminifera shell weights at the STR, show glacial-interglacial variations that may record calcification rates of planktonic foraminifera in surface water. If this is the case, then the d18O reflects changes in ice volume and SST that are tightly linked to changes in atmospheric CO2 (and planktonic foraminifera shell weight).

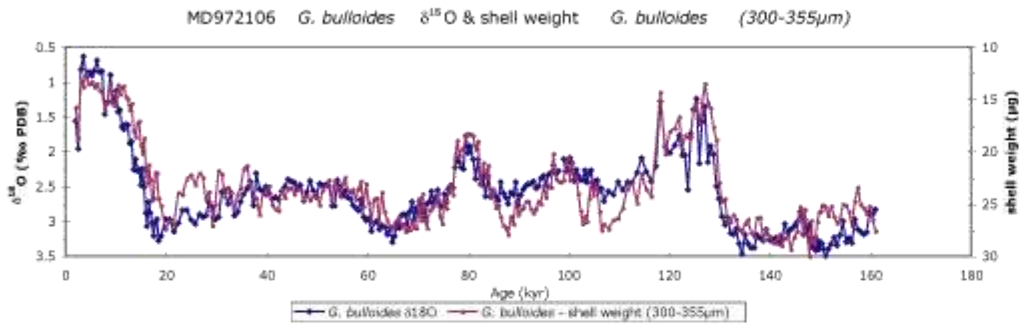


Figure 1. Oxygen isotope and shell weight data covering the last 160,000 years from core MD972106
at the South Tasman Rise

Barker, S. and Elderfield, H., 2002. Foraminiferal calcification response to Glacial-Interglacial changes in atmospheric CO2. Science, 297: 833-836.
Broecker, W.S. and Clark, E., 2001. Glacial to Holocene redistribution of carbonate ion in the deep sea. Science, 294: 2152-2155.

In-situ trace elemental and Sr isotopic analysis of teeth by LA-ICPMS

W. Müller

Fossil biominerals, as the commonly solely preserved constituents of past organisms, are a source of valuable information in anthropology, archaeology, and palaeontology. However, their chemical composition is often altered by interaction with their surrounding - depositional environment making it difficult to retrieve accurate in-vivo compositional signatures by bulk sample analysis.

Using a new approach, high-spatial resolution compositional profiling of teeth by laser-ablation inductively-coupled-plasma mass spectrometry (LA-ICPMS and LA-MC-ICPMS), it is possible to: 1) detect domains in dental enamel that have escaped alteration through analysis of alteration-prone elements (e.g. U, Y, Ce, La) and comparison to levels found in modern enamel; 2) extract time-series information stored in sequentially-grown tooth enamel (Figure 1); and 3) perform essentially non-destructive analysis of rare and thus precious (e.g. hominid) fossil specimens with minimal damage.

This approach is being used to reconstruct human subsistence patterns (migration and palaeodiet) at seasonal resolution by combining Sr isotope (migration) and Sr/Ca, Ba/Ca, Zn/Ca trace elemental analyses (palaeodiet) measured by laser-ablation-ICPMS (Fig. 1). Another application is the accurate reconstruction of palaeo-exposure of humans to toxic metals (such as Pb) during e.g. ancient mining operations (Figure 2).

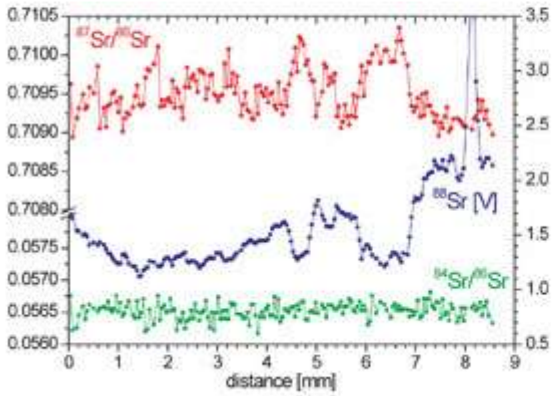


Figure 1. In-situ Sr isotopic analysis by LA-MC-ICPMS of human enamel (incisor, Uzbekistan; ~3rd century A.D.), performed in order to distinguish between sedentary and nomadic lifestyles. The variations may suggest annual migration (red, 87Sr/86Sr), and correlated changes in palaeodiet (blue; lower Sr/Ca implies more animal proteins relative to plant food), which appear to be antiphase. (Sr intensity only is preliminarily used as proxy for Sr/Ca ratio; in the future, Sr/Ca, Ba/Ca, Zn/Ca ratios and Sr isotopes will be simultaneously analyzed by ICPMS and MC-ICPMS.) Enamel growth occurs over ~5 years (0.5-6 years).

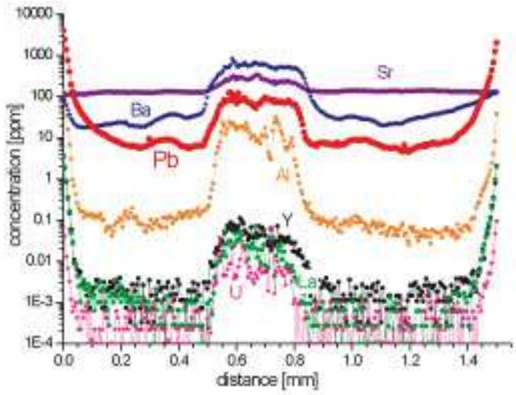


Figure 2. Trace elemental profile by LA-ICPMS of a human tooth that has lain in Pb-contaminated soils for ~800 years from an early medieval Pb-Ag mining town (Germany). Inner left and right enamel is characterised by extremely low U, La, Y levels and constant, albeit comparatively high Pb concentrations (~8 ppm; interpreted to be in-vivo), whereas dentine (centre) and outer enamel shows various degrees of Pb alteration/contamination.

Marine Isotopic Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inferences.

C. Pelejero, E. Calvo, G.A. Logan1 and P. De Deckker2

A detailed record of alkenone-derived sea-surface temperatures (SSTs) offshore western New Zealand has been generated. It is based on data from marine deep sea core SO136-GC3 (42º18'S, 169º53'E, 958m water depth) and covers the penultimate deglaciation and Last Interglacial. SSTs were 3.5 to 4.5ºC warmer than present, peaking 4.5 thousand years ahead of ice volume minima. The short duration of Marine Isotopic Stage 5e off New Zealand exhibits a striking parallelism with the record of air temperatures at Vostok, Antarctica. Changes in latitudinal SST gradients for the Southwest Pacific, from New Zealand to the equator, are also assessed, showing values consistently lower than today. In this region, this situation usually occurs during periods with positive values of the Southern Oscillation Index and thus, La Niña conditions. By inference, we suggest that our assessed low thermal gradients might be indicative of a prevalence of either persistent or more frequent La Niña like conditions, particularly during early Stage 5e.

1 Petroleum and Marine Division, Geoscience Australia, Canberra, Australia
2 Department of Geology, The Australian National University, Canberra, Australia

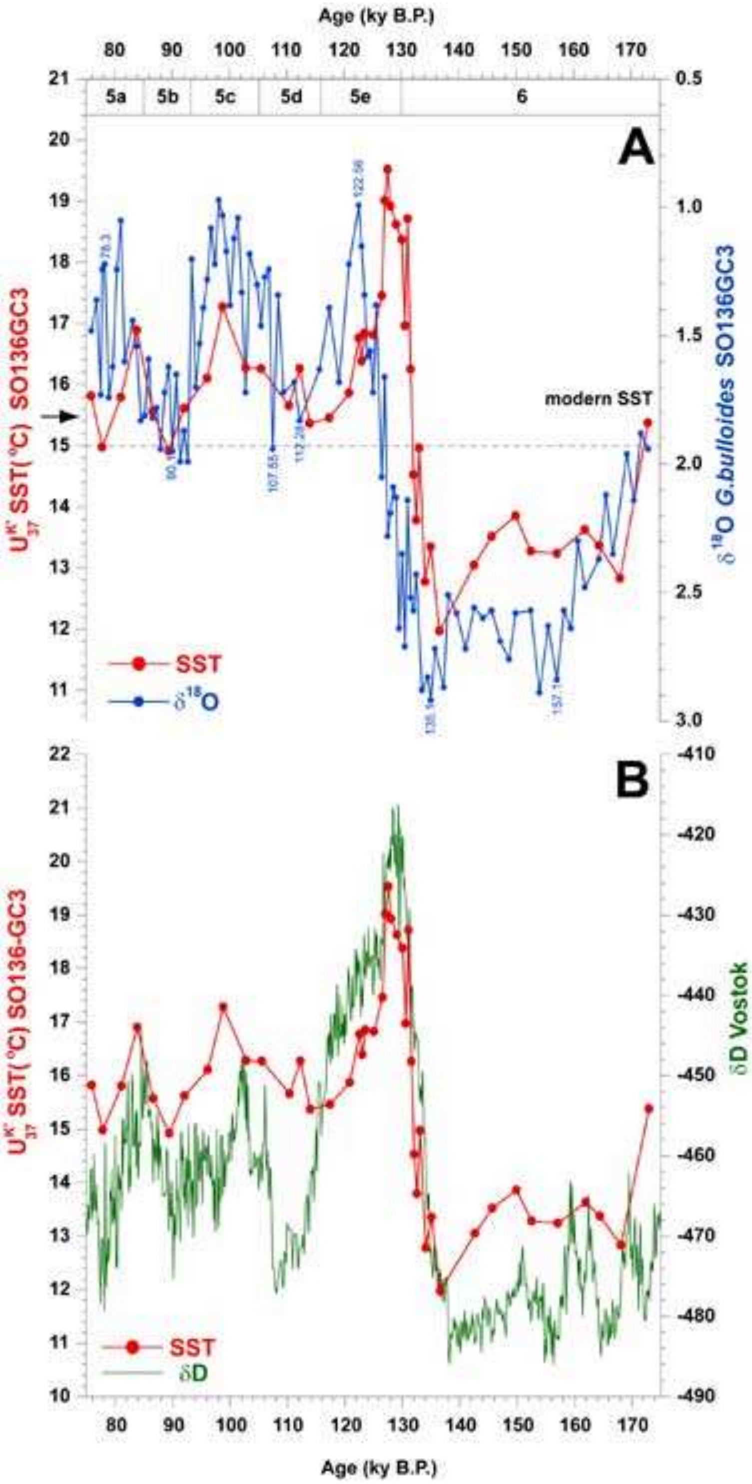


Figure 1: (A) Globigerina bulloides d18O and U K'37 -SSTs for core SO136-GC3 (vertical numbers correspond to age model pointers). Arrow and dashed line mark the U K'37 -SST for the uppermost Holocene sample and the modern annual mean SST, respectively. (B) U K'37 -SSTs for core SO136-GC3 compared to dD from Vostok, a proxy for air temperature in Antarctica.

Back to Contents

In-situ uranium series dating of the Omo Kibish I human

A.W.G. Pike1, S. Eggins, R. Grün, C. Stringer2, M.H. Day2, A. Bartsiokas3, R.E.M. Hedges1

We have made the first application of laser ablation plasma mass spectrometry (LA-ICP-MS) to the U-series dating of a fossil hominid.

Until now, the most successful 230Th/U chronologies have been obtained where archaeological material is inter-stratified with calcium carbonate (speleothem) deposits which remain closed to the migration of U after deposition. Co-occurrence of such deposits with hominid fossils is rare, thus attempts have been made to directly date the fossils, despite difficulties in understanding post depositional U migration into bones and teeth. Sample size requirements for conventional mass spectrometry can prove too destructive for dating valuable specimens, especially given that modelling uranium uptake requires measurement of the spatial distribution of U-series isotopes across entire bone sections.

LA-ICP-MS provides high spatial resolution, and rapid measurement of U-series isotopes with minimal sample destruction. Previous studies were successful on zircon samples which typically have >100 ppm U, whereas bones typically have 1-50 ppm U. We have developed a method that provides accurate U-series isotope ratios on fossil bones containing >3ppm U, using an ArF 193nm excimer laser and a Finnigan Neptune ICP mass spectrometer. The laser is focussed to a spot 200mm x 20mm on the sample in a He atmosphere to maximise sampling efficiency and pulsed at 20Hz, giving a crater depth of approximately 10mm. Results are calibrated using bones for which U-series isotopes have been measured using conventional mass spectrometry. The 95% confidence for calibration is typically ± 1.5% for 234U/238U and ± 2.0% for 230Th/238U, which for a typical bone gives an overall 2s precision on measurements of 2-4%. While this is less precise than conventional mass-spectrometry the advantages of high spatial resolution outweigh the disadvantages of diminished precision.

We applied LA-ICP-MS to a fragment of the Omo Kibish I skull and used the diffusion-adsorption (D-A) model to calculate a date of 93 +8-5 ka (Figure 1). Omo Kibish I has been classified as morphologically modern human and has never been directly dated, but is thought to be 130±5 ka from U-series dates on associated shells. Shells, however, are notoriously open systems and U-series has been shown in some cases to over estimate the age due to leaching of U or underestimate due to uptake of U. The diffusion-adsorption model predicts characteristic U and U-series isotope distributions across a bone section as U is gained or lost in response to geochemical changes in the burial environment. Leaching or recent uptake of U lead to characteristic profiles which can be used to reject the bone as unsuitable for dating. In this case, the U profile is close to uniform, and the U-series date profile is È-shaped, confirming that uptake has happened under relatively constant conditions, giving us confidence in the date.

Our date of 93.0+8-5 ka is the first direct date of this human, confirming that Omo I is indeed one of the oldest examples of modern H. sapiens from Africa. This date also demonstrates the suitability of the technique to the direct dating of hominid fossils, and we expect that laser ablation U-series dating will lead to further critical insights into the timing of modern human evolution.

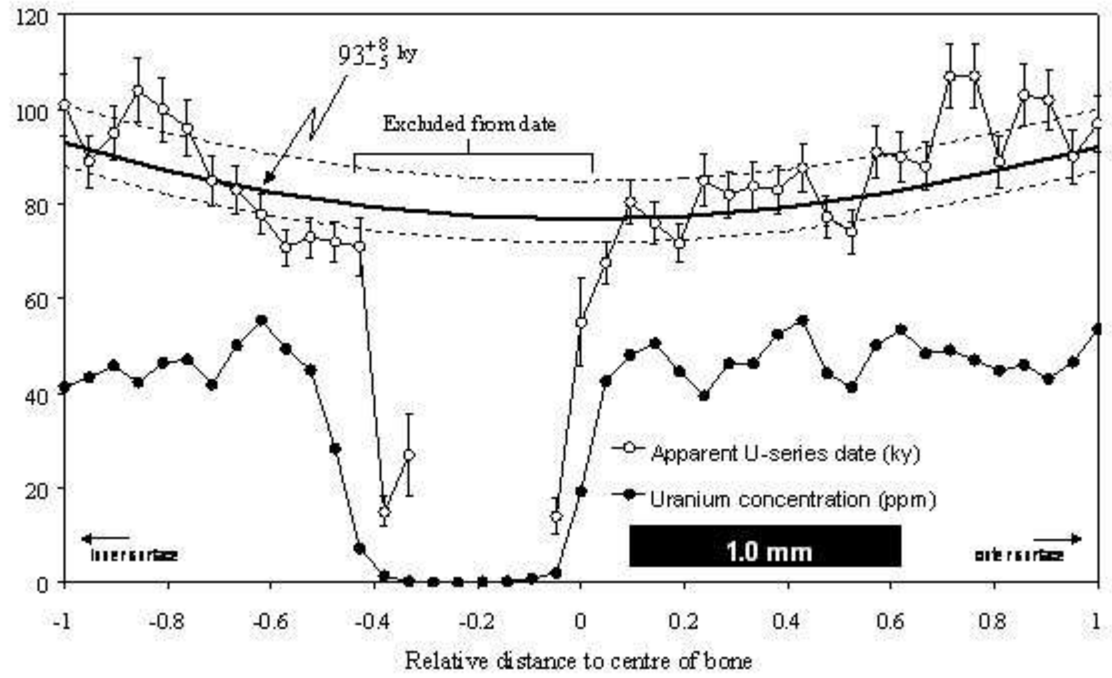


Figure 1: Laser ablation U and U-series date profiles measured across a section of the Omo Kibish I skull fragment. The bold curve represents the maximum likelihood date calculated using the D-A model, giving a date of 93+8-5 ka (at 95% confidence)3. The dates from the void in the centre of the bone have been excluded. Mean 230Th/232Th activity is 4800 across the bone and > 70 at all points in the bone. Error bars are at 1s.

1 Research Laboratory for Archaeology, University of Oxford, OX1 3QJ, UK.

2 Department of Palaeontology, The Natural History Museum, London, SW7 5BD, UK

3 Department of History and Ethnology, Democritus University of Thrace, P.O.Box 217, 69100 Komotini, Greece.

[Back to Contents]

New ages for Miocene hominid-bearing sediments at Haritalyangar, Indian Siwaliks

B. Pillans, M. Williams1, D. Cameron2 and R. Patnaik3

The Haritalyangar area (31º32’N, 76º38’E), in Himachal Pradesh, northern India, has yielded fossil hominid specimens for almost 100 years, but new dating of fossil-bearing localities significantly changes our perception of hominid evolution within this region. Previous work at Haritalyangar suggested that hominid fossils were between 6.3 and 7.7 million years old. However, subsequent paleomagnetic studies, and revisions to the Geomagnetic Polarity Time Scale (GPTS) have increased the ages to between 8.6 and 9.23 Myr. For the first time we provide an accurate age of 8.85 Myr for the rare, large ape, Indopithecus (more than 2 million years older then previously thought), while the primitive primate genus Sivaladapis occurs in deposits dating to 9.1 Myr. Specimens of Sivapithecus and Sivalhippus,believed to be an early, archaic member of the modern orang-utan lineage, are also revised to around 9 Myr. We also document the first appearance of ostrich in south Asia.

1 Research School of Earth Sciences, The Australian National University.

2 Mawson Graduate Centre for Environmental Studies, The University of Adelaide.

3 Department of Anatomy & Histology, The University of Sydney.

Upper second molar of a rare, Upper Miocene ape, Indopithecus giganteus von Koenigswald 1950, discovered at Haritalyangar in 2002, and dated to 8.85 Myr by magnetostratigraphy.

Back to Contents

A seven-year regulation of the El Niño-Southern Oscillation 3,700 years ago

D.Qu, M. K. Gagan, W.S.Hantoro1, B.W. Suwargadi1

The El Niño-Southern Oscillation (ENSO) is the dominant coupled atmosphere-ocean mode of interannual climate variability, affecting most of the tropics and subtropics and many mid-latitude regions of North America, South America, and eastern Asia. Recent research indicates that El Niño events have become more severe and more frequent in recent decades. Whether this change simply represents a mode of natural climate variability, or is a result of human-induced greenhouse forcing, is still debated. This debate highlights the importance of the need for understanding the long-term behaviour of this key climate system.

The oxygen isotopic composition of coral aragonite offers a robust proxy of ENSO variability because it is sensitive to both the oceanic and atmospheric components of ENSO. Corals from the island of Sumba, Indonesia, are well situated to record the sea-surface cooling and droughts brought about by El Niño events. A high-resolution oxygen isotope time-series for a modern coral from Sumba records all the major ENSO events between 1985 and 1996. During El Nino events, the skeletal d18O values increased both in winter and summer, in response to the cooler sea-surface temperatures (SSTs) and drier climate.

We have extended this approach to produce a high-resolution, 57-year-long coral d18O record of past ENSO variability from a fossil coral that grew within the fringing reef of Sumba 3,700 years ago (Fig. 1). The record was extracted from a 1.12 m long, high-quality Porites core (MS7) with an average annual skeletal extension rate of 1.6 cm/yr, which is typical for modern Sumba Porites. The fossil coral d18O record shows a remarkably regular interannual variability with a 7-8 year period. Each 7-8 year cycle terminates with the diagnostic signature of a strong El Niño, anomalously cool SSTs in winter accompanied by drought in the summer.

Our results suggest that El Niño events were less frequent and more regular 3,700 years ago, relative to the unpredictable 3-8 year periodicity for modern El Niño events. The seven-year regulation of El Niño is fascinating because it suggests that, under certain background climate states, El Niño events may be predicted years in advance. We are in the process of investigating the Holocene evolution of the Indo-Pacific Warm Pool climate for clues about the processes regulating ENSO.

1 Research and Development Center for Geotechnology, Indonesian Institute of Sciences.

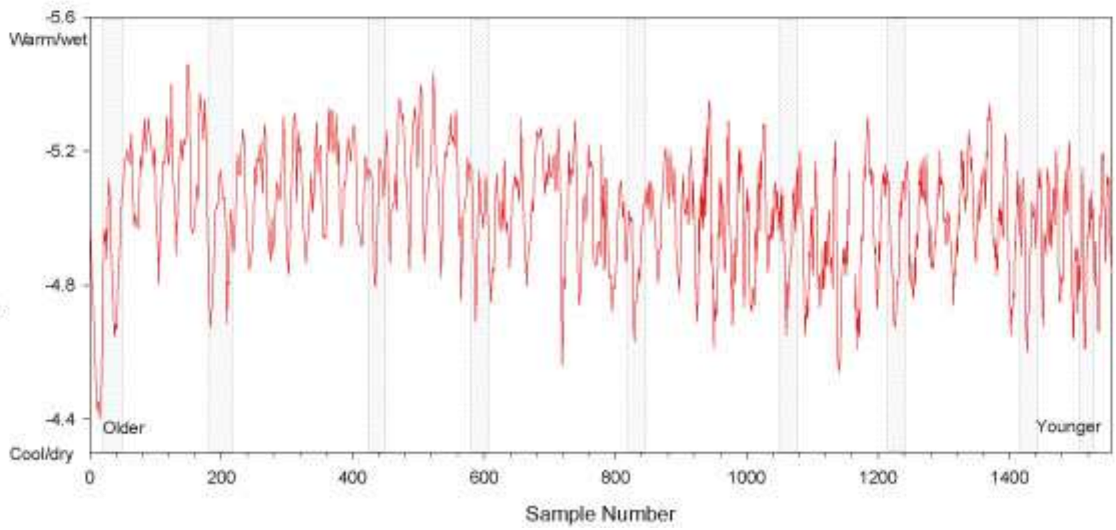


Figure 1: High-resolution skeletal d18O record for Holocene coral MS7. This coral has a uranium-series age of 3,700 years. The shaded areas indicate the diagnostic ocean-atmosphere signature of El Nino events, when anomalously cool SSTs in winter and the reduction of 18O-depleted rainfall in summer both produce higher skeletal d18O values. The Y-axis values are reversed to show warmer/wetter conditions toward the top.

Back to Contents

Geochemical Records of Bleaching Events from the Great Barrier Reef

B. Roark1, M.T. McCulloch, L. Ingram2 and J. Marshall

The health of coral reefs world-wide is increasingly threatened by a wide array of stressors. On the Great Barrier Reef (GBR) these stressors include increased sediment flux associated with land use changes, increased sea surface temperatures (SST) and salinity changes due to large floods, the latter two of which are factors in an increased number of bleaching events. The ability to document long-term change in these stressors along with changes in the number of bleaching events would help discern between natural and anthropogenic changes to this ecosystem. Here we present results of an initial calibration effort aimed at identifying bleaching events and the associated stressors using stable isotopic and trace element analysis in coral cores. Three ~15-year time series of geochemical tracers (d13C, d18O, and Sr/Ca) on Porites coral cores obtained from Pandora Reef and the Keppel Islands on the GBR have been developed at near weekly resolution. Since the d13C of the coral skeletal carbonate is known to be affected by both environmental factors (e.g. insolation and temperature) and physiological factors (e.g. photosynthesis, calcification, and the statues of the symbiotic relationship between corals and zooxanthellae) it is the most promising proxy for reconstructing past bleaching events. The first record (PAN-98) comes from a coral head that had undergone bleaching and died shortly after the large-scale bleaching events on Pandora Reef in 1998. A second core (PAN-02) was collected from a living coral within 10m of PAN-98 in 2002. Sr/Ca ratios in both cores track even the smallest details of an in situ SST record. The increase in SST that occurred three to four weeks prior to bleaching was faithfully recorded by a similar decrease in the Sr/Ca ratio in PAN-98, indicating that calcification continued despite the high SST of 30-31°C. The d13C values decreased by about 5 ‰ one week after the SST increase, and remained at this value for about 4 weeks until the coral died. In 1994 and 1995, there are decreases in the d13C values of 3 ‰. In 1994, a flood plume from the Burdekin River reached Pandora Reef and bleaching was reported. In 1995 we note a 4-5 week period of elevated SST based on the Sr/Ca results, which may have been sufficient to cause stress or bleaching of the coral. No clear decreases in d13C values associated with any bleaching event was evident in the PAN-02 record, however there is a clear growth hiatus that lasted several months during the 1998 bleaching event. d18O results in both records show many of the same details as the Sr/Ca and SST record, suggesting temperature changes as the dominant control. However, during flooding events (1996, 1997, and 1998), the d18O values were decreased by increased freshwater input to the reef. The associated salinity changes were determined by subtracting the temperature component from the d18O signal using Sr/Ca ratios and compared with the weekly average flow records from the Burdekin River and a Ba/Ca record (McCulloch et al. 2003) of sediment flux to the reef. Similar results were obtained in a third record from the Keppel Islands which included one of the largest floods of the century and a bleaching event in 1991.

1 Department of Geography, University of California, Berkeley, CA

2 Department of Earth and Planetary Science, University of California, Berkeley

Back to Contents

Geochronology of long-term landscape evolution, NW NSW

M. Smith, B. Pillans, S. Eggins, and J. Dunlap

The regolith geochronology and long-term landscape development history of north-western New South Wales is being investigated by dating regolith materials from a variety of locations, using an array of dating techniques. This region includes several distinct geological regions, the Broken Hill block, the Cobar Basin, the Eromanga and Surat Basins and the northern Murray Basin, from which several areas have been targeted for investigation, including Bourke, Broken Hill, Cobar, Parkes, Peak Hill, Tibooburra and White Cliffs. The use of multiple techniques is a key aspect of this study as each technique is capable of dating the products of different weathering and landscape forming processes, such as silcretes (Figure 1).

The main geochronological methods being used are palaeomagnetic dating, d18O dating of clay minerals, (U Th)/He dating and U Pb methods. Pilot palaeomagnetic analyses of samples from several sites have been carried out, and several iron oxides and apatites have been (U Th)/He dated. Clay minerals have been analysed by XRD to determine the clay content and suitability for d18O dating. Work is being undertaken to determine the applicability of U Pb geochronology to late stage anatase found in silcretes throughout the field area and in related sites from South Australia. Laser Ablation ICP-MS analysis of silcrete samples has been performed to determine their suitability for conventional high-precision U Pb dating, and to obtain preliminary U Pb dates (Figure 2).

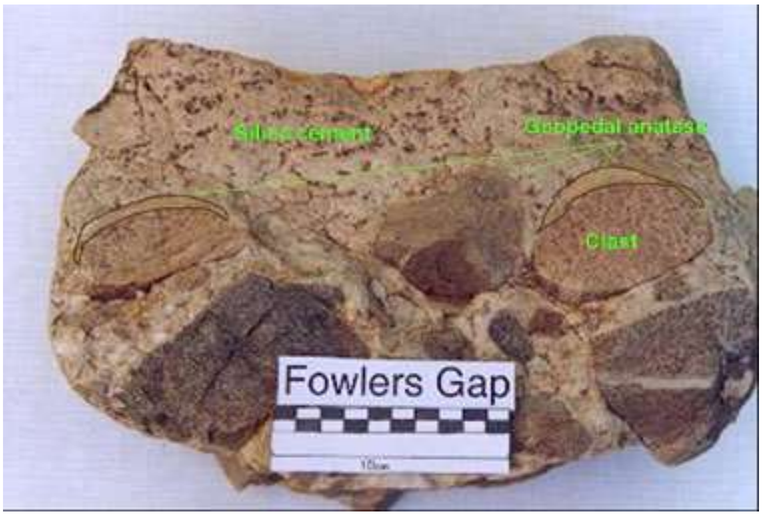


Figure 1

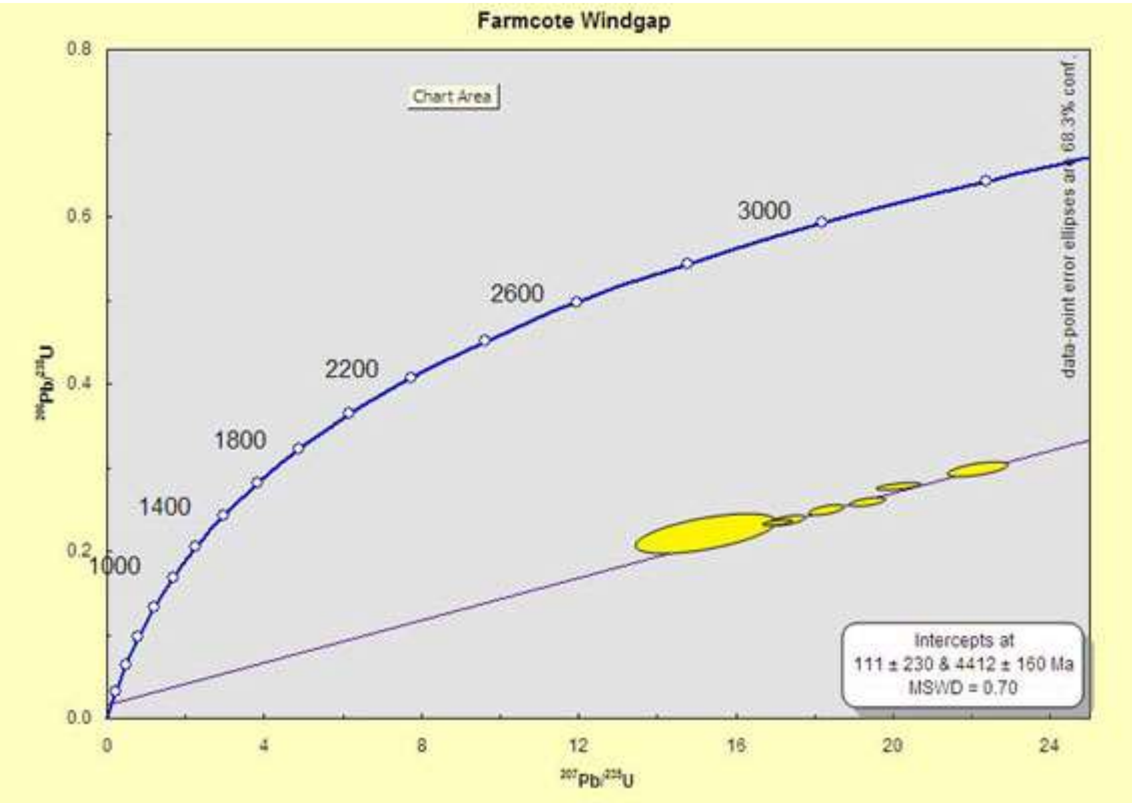


Figure 2
Back to Contents

Late Quaternary evolution of the Leeuwin Current, Western Australia
M. Spooner1, P. De Deckker1, M. K. Gagan

Australia is largely an arid continent and has a poor record of environmental change. Palaeoenvironmental histories extracted from Australian lake sediments are incomplete due to the lack of water and surface-sediment deflation. Therefore, the use of deep-sea cores to reconstruct past environmental change is advantageous as the deposition of sediment and microfossils is almost continuous.
We have recently completed a foraminifer faunal analysis and high-resolution d18O and d13C record for deep ocean core (MD002361) spanning at least the last 700,000 years from offshore north-western WA to investigate the late Quaternary evolution of the Leeuwin Current. This current is a warm, low salinity poleward flow originating from the Throughflow of water from the Pacific into the Indian Ocean. Today it runs southward along the western coast of Australia and has a significant impact on the climate of Western Australia. Past investigations of the Leeuwin Current so far have been inconclusive, especially in regard to the occurrence of this warm surface current during glacial periods. There is some evidence that the Leeuwin Current was absent during glacials, which may have resulted in the cold northbound Western Australian Current reaching the surface.
Initial investigations to ~ 425,000 years BP reveal that the Leeuwin Current was prevalent during all the marine isotopic stages (Fig.1). Tropical and subtropical foraminifer species, such as G. ruber and G. sacculifer, live in surface waters (0-75m). Comparison of all interglacial periods, such as the Holocene and Isotope Stages 7,9 and 11, shows that the relative abundance of G. ruber and G. sacculifer was equivalent to modern day abundances. However, the high abundance of the tropical species G. sacculifer indicates that the Leeuwin Current may have been enhanced during Isotope Stage 5. In addition, other tropical species such as P. obliquiloculata indicate warmer conditions and possible enhancement of the Leeuwin Current during Isotopic Stages 5 and 7.
There appears to be no evidence of dramatic upwelling events during glacial periods as indicated by the relatively low abundances of G. bulloides, G. glutinata and N. dutertrei. The only indication of nutrient-rich, cooler water is during Isotope Stages 12 and 10, given by the greater abundance of G. bulloides.
The species G. inflata resides in transitional waters between tropical and polar water masses. The relative abundance of G. inflata indicates a change in the water column during the glacial periods, with its greatest abundance during the last glacial maximum. This may indicate cooler waters during glacial periods and hence a reduced Leeuwin Current. This is also confirmed by the reduction of tropical and subtropical species, especially during the last glacial maximum.
We plan to reconstruct sea-surface temperatures using Mg/Ca ratios of G. ruber tests and possibly a transfer function using foraminifer assemblages developed by Dr T.T Barrows

(RSPhySE).

1Department of Earth and Marine Sciences, ANU.

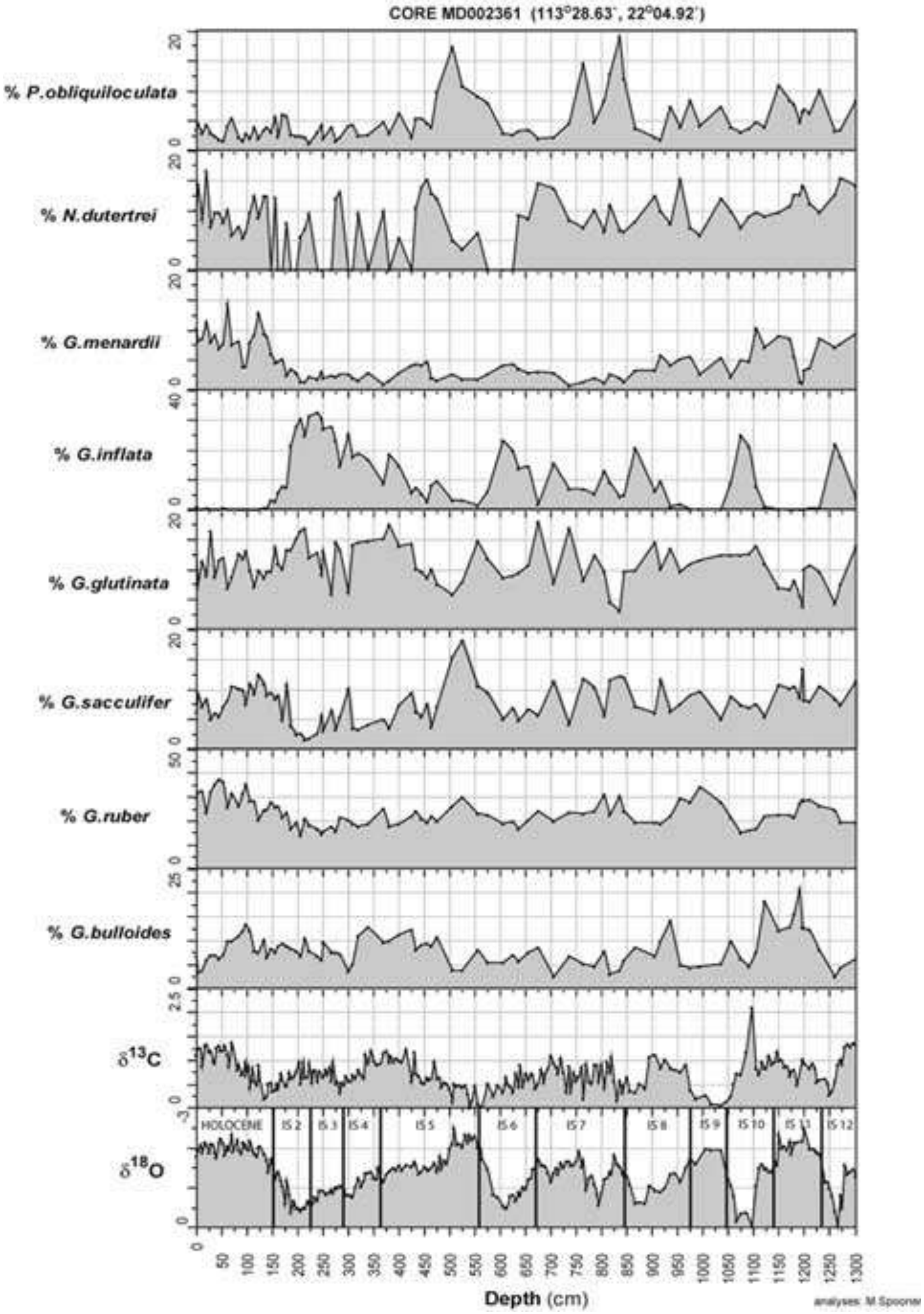


Figure 1: Diagram showing variations in core MD 002361 against depth for the relative abundance of planktonic foraminifera and skeletal d18O and d13C values. G. ruber, G. sacculifer, G. menardii and P. obliquiloculata are species which favour tropical-subtropical water conditions. G. bulloides, G. glutinata and N. dutertrei are species, which prefer cooler and nutrient rich water conditions. G. inflata prefers transitional water masses between subtropical and polar water temperatures.

Back to Contents

Conodont geochemistry proxies for understanding palaeoenvironments, bioevents and geoevents of the Palaeozoic

J.A. Trotter

A resurgence in studies using conodont apatite as a proxy for seawater composition has prompted a re-assessment of their suitability as geochemical tracers. This has not been adequately addressed in the past and requires clarification; an effective sampling protocol is also needed to ensure data integrity. Sample integrity is critical for determining primary geochemical signatures to evaluate environmental conditions and processes in Earth history.

This study is characterising the trace element & isotopic compositions of conodont apatite using high-resolution, in-situ, micro-analytical techniques (eg. laser ablation ICPMS). Compositional relationships to ultrastructure, taxonomy, and histology, have been recognised and are assessed in the context of sample integrity & diagenesis. Temporal variations are also recognised from conodonts extracted from continuous stratigraphic sections throughout the Ordovician and Early Silurian, which provide insights into ambient ocean conditions & environmental processes likely operating during this period.

The ubiquity and biostratigraphic significance of conodonts underscore their potential importance for geochemical studies, especially as potential recorders of ocean chemistry and environmental change during the Palaeozoic and early Mesozoic. Understanding extinction events and the processes controlling life during Earth history has immediate implications for present and future life on Earth.

Back to Contents

Biogeochemical cycling of trace metals in coastal seawater

T. Wyndham and M.T. McCulloch

The aim of this project is to use proxy records of seawater composition, incorporated in coral aragonite, to investigate the biogeochemical cycling of a selection of reactive trace metals (rare earth elements and bioactive transition metals) in the coastal waters of the Great Barrier Reef. Coral records of dissolved metal concentrations may reveal features of coastal marine processes that are difficult or impossible to identify using periodic sampling methods. In combination with direct measurement of dissolved and particulate metal concentrations, which can be used to aid in identifying specific cycling processes, this approach may provide a unique perspective upon the biogeochemical cycling of reactive trace metals. Based on these investigations, the application of trace element records in corals as proxies for biological, climate or anthropogenic changes in coastal seawater can also be explored.

Initial investigations of coral records of REE and Mn have produced a number of interesting results. The REE composition of coastal seawater inferred from the coral record at several coastal sites on the GBR appears to be dependant on seasonal factors. REE fractionation displays a strong seasonal cycle that correlates closely with Mn concentration. Higher Nd/Yb ratios and higher Mn concentrations in summer result from scavenging of heavy REE by particulate organic ligands and Mn reductive dissolution respectively, both processes occurring at higher rates during periods of high primary productivity. The Ce anomaly also displays a strong seasonal cycle showing an enhanced anomaly during summer and during flood events. This is consistent with the Ce anomaly being primarily controlled by the abundance of Ce oxidising bacteria. Based on these arguments, we suggest that the coral record of dissolved REE and Mn may be a useful proxy for biological activity in coastal seawater. Further investigations will be aimed at better characterising these changes in seawater composition and exploring the behaviour of other reactive trace metals using this approach.

Back to Contents

Soil Organic Carbon and Carbon Isotope Inventories of the Australian Continent

J.G. Wynn, M.I. Bird, L. Vellen, and E. Grand-Clement

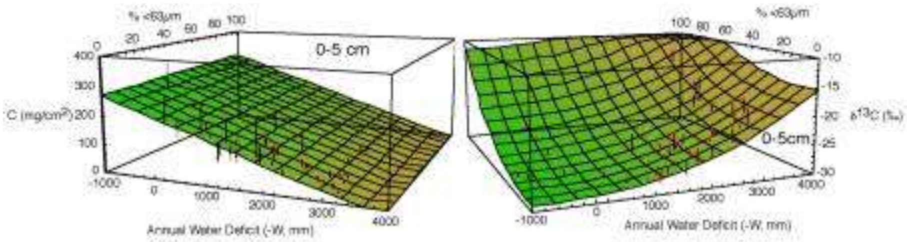
Research during 2003 has focused on extending the SOC inventories to soils of other textures along gradients in particle size (soil texture) within 4 climatic and ecological regions of Australia: desert shrublands near Birdsville, QLD; semi-arid subtropical savannas near Winton, QLD; tropical rainforests and woodlands near Cardwell, QLD; and temperate rainforests and heathlands in western TAS. With the extension to clay soils, SOC inventory and stable carbon isotope ratio values can be regressed with respect to two primary controlling factors, the annual water deficit and percent fine fraction (Figure 1). Annual water deficit is defined as the negative of mean annual availability of water (Berry and Roderick, 2002):

-W = -(MAP - Q / r L)

(where MAP is Mean Annual Precipitation, Q is annual solar radiation, and r and L are the density and latent heat of evaporation of water at 25°C.

Each of the 31 sand soil sites were analysed for 14C activity in the lab of Prof. John Chappell, RSES. 14C activity shows no pronounced relationship the annual deficit of water (-W). These 14C data explain much of the excess carbon in sites that are “overmeasured,” or “underpredicted.” These data indicate some proportion of stabilized pre-1950 carbon (pM, percent modern < 100), with a more dominant pool of labile carbon fixed since 1950 (pM between 100 and 165).

Organic matter from a selected set of sandy soil sites was respired and collected for AMS 14C analysis at the ANSTO Lucas Heights AMS facility (AINSE Grant 03/130). Samples were selected at sites along 2 climatic gradients of mean annual temperature and precipitation: two primary controls on carbon turnover. These results can be used to constrain the mixing ratio of stable pre-bomb carbon in “overmeasured.”



$$C_{0-5cm} = 209.5 - 0.0596(-W) + 0.229(\% < 63\mu m)$$

$$\delta^{13}C_{0-5cm} = -29.23 - 3.156\times10^{-8}(-W + 1000)^{2.3?} + 3.017\times10^{-4}(\% < 63\mu m)^{2.385}$$

Figure 1. Surface regression of SOC Inventory and stable carbon isotope ratio to annual water deficit and percent fine fraction (<63 µm). Centre point is mean of 5 transects with

gray “error bars” of variance between transects and vertical black line showing deviation of data from surface fit.

Berry S.L., Roderick M.L. (2002) Aust. J. of Botany, Vol 50, pp511-531.

Earth Materials

Experimental Petrology

Experimental Petrology Group

Annual Report 2003

The Experimental Petrology Group uses a laboratory-based experimental approach combined with field observations to study the Earth, its origin, evolution and mineral wealth. The group operates a wide range of experimental apparatuses for generating the high temperatures and pressures that are needed to reproduce the natural conditions within the Earth. The equipment includes: high temperature furnaces capable of reaching 1800ºC, several of which are equipped for precise control of oxygen and sulfur fugacities by gas mixing; eleven solid-media piston-cylinder devices for generating pressures to 6 GPa and temperatures in excess of 2000ºC, a multi-anvil apparatus, which can presently achieve pressures of 26 GPa; and, through collaboration with the Department of Earth and Marine Sciences, the Faculties, a well-equipped hydrothermal laboratory. These high-temperature, high-pressure apparatuses are complimented by an array of microbeam analytical techniques, including a Cameca SX100 electron microprobe, which was commissioned in Oct. 2002; laser-ablation ICP-MS, which is now being used regularly to analyse trace-elements in experimental run products; FTIR spectroscopy for the determination of H_2O, CO_2 and other volatile species in minerals and glasses; and visible-UV spectroscopy. A STOE STADIP powder X-ray diffractometer was installed in Sept. 2003; this instrument is particularly suited for the accurate characterisation of the often tiny samples produced in the group’s high-pressure research.

As well as the conventional 1/2 inch and 5/8 inch apparatus for use to 4 GPa, the group’s piston-cylinder laboratory also runs a high-pressure device that is now operating regularly at 6 GPa; the laboratory also has several large-capacity devices which take 30, 50 and 55 mm pressure assemblies, enabling pressure to be controlled extremely accurately, and which are capable of synthesising relatively large volumes of high pressure phases for detailed mineralogical studies. A novel diamond composite hard material, developed in these apparatuses and now under commercial production, offers promise as an anvil material to extend the pressure range of the multi-anvil apparatus above 26 GPa, thereby allowing detailed experimental exploration of the pressure-temperature regime of the Earth’s lower mantle. To further this research the multi-anvil apparatus has now been refurbished and provided with full computer control of pressure and temperature.

In recent years the group has become increasingly involved in developing methods to characterise geologic materials by X-ray absorption spectroscopy (XANES) and related techniques that use synchrotron radiation. Dr A. J. Berry has adopted a leadership role in this area, setting up a special interest group called GEOSYNC (to educate, advise and represent

Australian geoscientists), and is providing input into the design specifications of the planned microprobe and EXAFS beamlines. A special session on the use of synchrotron radiation in the Earth Sciences was held at the Australian Geological Congress in Hobart.

Much of the strength of the group derives from its Visiting Fellows, who bring an immense amount of intellectual diversity to the group's activities. Emeritus Prof. D. H. Green continues actively in the group. Dr A. Glikson, formerly of AGSO, continues his work on the investigation of impact structures in Australia. Prof. Thomas Sharp of Arizona State University, who is on a year's sabbatical with the group, is using the multianvil apparatus to investigate high-pressure minerals in shocked meteorites. Dr C. McCammon of the Bayerisches Geoinstitut is also visiting to continue her collaboration with members of the group on Fe oxidation states in minerals and melts.

Research Activities

The effect of temperature on the equilibrium distribution of trace elements between clinopyroxene, orthopyroxene, olivine and spinel in upper mantle peridotite

Hugh StC. O'Neill and G. Witt-Eikschen[1]

1. *Institut für Mineralogie und Geochemie der Universität Köln, Zülpicher Str. 49b, D-50674 Köln, Germany*

The abundances of 30 trace elements have been determined in the minerals of 16 well-equilibrated spinel lherzolite xenoliths by laser-ablation inductively-coupled-plasma mass-spectrometry (LA-ICP-MS). Major elements were analysed by electron microprobe. The xenoliths span a range of equilibration temperatures from 1150 to 1500 K (calculated at an assumed pressure of 1.5 GPa from two-pyroxene geothermometry), allowing the trace-element partitioning relationships among the phases (olivine, orthopyroxene, clinopyroxene, spinel, and in some lower temperature xenoliths, amphibole) to be quantified as a function of temperature. Most elements show smooth partitioning trends among all phases that depend primarily on temperature; the partitioning of the Rare Earth Elements between clinopyroxene and orthopyroxene is an excellent example (Figure 1). However, there is also some influence from bulk composition, particularly the amount of Na in clinopyroxene. Although most incompatible trace elements are concentrated into clinopyroxene, the effect of increasing temperature is to redistribute these elements into orthopyroxene and even olivine, such that these latter phases hold non-negligible proportions of many trace elements at the temperature at which peridotite would be in equilibrium with basaltic melts. The inter-crystalline trace-element partition coefficients reported in this study can be used to reconstruct the trace-element abundances in clinopyroxene at melting temperatures, and should also prove useful in elucidating the histories of more complex mantle peridotites with unequilibrated mineral compositions and textures.

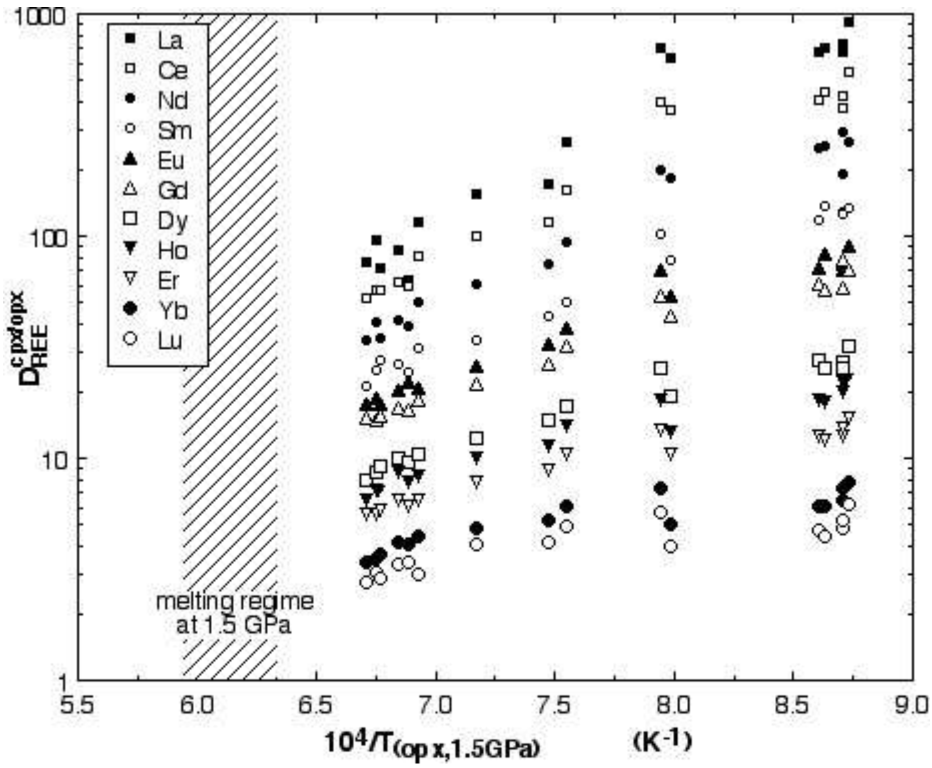


Figure 1: Partitioning of REEs between cpx and opx as a function of temperature. The region from the anhydrous peridotite solidus at 1.5 to an estimated cpx-out temperature at 1420ºC is shown shaded and labeled as the "melting regime". Note that much of the apparent scatter in the data is due to the effect of Na in cpx, which has not been accounted for in this two-dimensional representation.

The water site in mantle olivine

A.J. Berry, J. Hermann, H.St.C. O'Neill and G.J. Foran[1]

1. Australian Synchrotron Research Program, ANSTO

Nominally anhydrous mantle minerals such as olivine contain trace amounts of water and may accommodate the entire water budget of the Earth's upper mantle. This water is identified and quantified from the hydroxyl stretching region of infrared spectra. The spectra contain numerous bands which differ in number and intensity between samples. These bands are representative of different defect sites although there is no relationship between the bands and the tectonic setting. The nature of the defects and the mechanism of water incorporation remains unclear. In particular, the experimental synthesis of olivine samples under mantle conditions has hitherto not reproduced the hydroxyl spectrum characteristic of natural samples. This questions whether these samples retain the water content corresponding to equilibrium conditions in the mantle.

In piston-cylinder experiments simulating upper mantle conditions we have successfully reproduced the first-order hydroxyl features of mantle olivines. Intense, characteristic peaks at 3572 and 3525 cm^{-1}, which appear in essentially every natural sample, are associated with the presence of Ti. These Ti point defects are the lowest energy hydrated defect in olivine. Further experiments have allowed additional bands to be attributed to Ti line defects, Si vacancies, Mg vacancies, and Fe oxidation. This provides a means of fingerprinting natural samples for the conditions of water incorporation. Samples exhibiting complex spectra, which are frequently the most hydrous, do not reflect mantle chemistry or water content.

We suggest that the Ti content of mantle olivine provides a control or upper limit on the water solubility. The resulting maximum water contents of olivine in spinel and garnet peridotites are ~30 and ~100 ppm respectively. High water contents observed in some samples (~200 ppm) are anomalous and these values can not be extrapolated to the entire upper mantle. While it is likely that NAMs in garnet lherzolite are able to accommodate the expected mantle water budget, this may not be the case for spinel peridotites for which we estimate a water storage capacity of only 90-130 ppm. This suggests the release of water during decompression from garnet to spinel peridotite and the presence of H_2 as either a fluid, melt, or mineral phase.

[Abstract submitted to Goldschmidt Conference, Copenhagen, 5-11 June 2004]

The oxidation state of sulfur in silicate glasses and melt inclusions

A.J. Berry, H.St.C. O'Neill, N. Métrich[1], and J. Susini[2]

1. CEA/CNRS, Saclay, France
2. European Synchrotron Research Facility, Grenoble, France

Sulfur dissolves in silicate melts in at least two and possibly three oxidation states: S^{2-}, SO_4^{2-} and possibly SO_3^{2-}. The solubility of S in magmas is directly related to its oxidation state, and is important for understanding geological processes such as the origin of magmatic sulfide ores, sulfur degassing from volcanic eruptions and hence global climate change, and the geochemical behaviour of the chalcophile trace elements (Re-Os, PGE). Sulfur oxidation states can be determined by S K-edge X-ray Absorption Near Edge Structure (XANES) spectroscopy.

Thermodynamic analysis of sulfur solubility experiments undertaken as a function of fO_2 and fS_2 provide firm, unambiguous evidence for the S speciation at the conditions of the experiment, and also determine the fO_2 conditions where sulfide changes to sulfate. The oxidation of S^{2-} to SO_4^{2-} (i.e., S^{6+}) occurs over a very narrow fO_2 range and the probability of finding mixed S oxidation states in natural samples should be exceedingly low. Nevertheless, spectra indicating mixed oxidation states in natural glasses seem to be ubiquitous. Also, no sulfite (S^{4+}) is expected from the solubility experiments, however, there is good evidence for this oxidation state from the XANES spectra of natural melts. This raises the possibility that the spectra obtained for glasses may be recording processes that occur on cooling. For example, all natural silicate glasses contain Fe both as Fe^{2+} and Fe^{3+}, permitting the possibility of the electron exchange reaction: $S^{2-} + 4Fe^{3+} + 2O^{2-} = 4Fe^{2+} + SO_4^{2-}$. Since such a reaction essentially involves only a redistribution of electrons, it should proceed extremely rapidly, and may occur during quenching to a glass. The production of sulfite (SO^{3-}) may also derive from an electron exchange reaction on cooling.

XANES spectra were recorded at beamline ID21 of the European Synchrotron Research Facility. Sulfur was found to occur as either S^{2-} or S^{6+} in agreement with the oxidation states inferred from the thermodynamic analysis. These two species did not coexist in any sample and there is no evidence for a temperature dependent redox reaction with Fe. S^{4+} was only observed in samples saturated with anydrite and equilibrated at high pressure (piston cylinder experiments). It is possible that S^{4+} exisits as dissolved SO_2, rather than SO_3^{2-}, in these experiments. S^{4+} was also produced in some S^{6+} bearing samples by exposure to the X-ray beam.

The narrow fO_2 range over which sulfide and sulfate should coexisit, together with the finding that sulfate is not produced by reaction with Fe^{3+} on cooling, suggests that the commonly observed presence of both S^{2-} and S^{6+} in natural glasses may derive from post-quench modification. Future experiments will test if the spectra of natural samples can be reproduced by oxidation associated with the loss of water.

The oxidation state of Fe in melt inclusions

A.J. Berry, H.St.C. O'Neill, L. Danyushevsky[1], M. Newville[2] and S.R. Sutton[2]

1. School of Earth Sciences, University of Tasmania
2. Consortium for Advanced Radiation Sources, University of Chicago, USA

Melt inclusions are micron-sized droplets of magma trapped in a host crystal. These inclusions provide information about the origin and evolution of magmas at depth and may preserve the original volatile content of a melt prior to eruption. However, melt inclusions may be subject to modification after trapping. For example, inclusions of hydrous magmas may lose H_2O by diffusion of H_2, with the remaining O_2 oxidising Fe^{2+} to Fe^{3+}. A comparison of the Fe^{2+}/Fe^{3+} ratios of the inclusion with that of the erupted magma can test for this effect. While Mössbauer spectroscopy and wet chemical analysis are standard techniques for determining Fe^{2+}/Fe^{3+} in silicate glasses, they lack the spatial resolution necessary for typical melt inclusions. X-ray Absorption Near Edge Structure (XANES) spectroscopy utilises a micron sized beam and the spectra exhibit features which systematically vary with oxidation state. In previous work we calibrated the energy of the $1s \rightarrow 3d$ pre-edge transition against Fe^{3+}/Σ Fe determined by Mössbauer spectroscopy for a series of synthetic glasses equilibrated over a range of oxygen fugacities. The pre-edge energy exhibits a smooth trend with oxidation state indicating that $Fe^{2+}/\Sigma Fe^{3+}$ for unknowns may be determined with reference to calibration curves of this type.

The melt inclusions and their host crystals were prepared as free-standing doubly polished sections (c. 30 microns thick) in which the inclusion is exposed on both surfaces. This allows volatile contents to be determined by FTIR spectroscopy and XANES spectra to be recorded in both fluorescence and transmission modes. Fluorescence and transmission spectra were simultaneously collected, together with the transmission spectrum of Fe foil. The Fe reference spectrum enables the energy to be calibrated for each spectrum, allowing accurate absolute determinations of pre-edge energies, from which the oxidation states are determined. The samples were mounted on kapton tape held by a teflon frame. The experimental set-up comprises an ion-chamber, the sample, a second ion-chamber, Fe foil reference, and a third ion-chamber. A 16 element Ge fluorescence detector is positioned at ~ 45° to the sample. Location of the inclusions is facilitated by a long working distance microscope coupled to a CCD camera. Fe K-edge XANES spectra were recorded for a series of synthetic samples of

Mid-Ocean Ridge Basalt (MORB) composition which had been equilibrated at various values of oxygen fugacity. The Fe^{2+}/Fe^{3+} values of these samples can be estimated from the expression of Kilinc et al. 1983 and when related to the 1s→3d energy provide a calibration curve. XANES spectra were then recorded for a number of natural MORB inclusions and Fe^{2+}/Fe ratios determined using this calibration. The average value of 0.07 ± 0.01 is in excellent agreement with that of 0.07 ± 0.03 determined for MORB glasses (Christie et al. 1986). These results confirm the potential of the technique and validity of the approach. In future work we aim to similarly determine the oxidation state of Fe in komatiite inclusions. This should help resolve the controversy as to whether komatiites derive from high temperature or hydrous melting.

Silicate and carbonate melt inclusions associated with diamonds in deeply subducted carbonate rocks

J. Hermann and A.V. Korsakov

Deeply subducted carbonate rocks from the Kokchetav massif (Northern Kazakhstan) recrystallised within the diamond stability field (P 45-60kbar; T~1000°C) and preserve evidence for ultra high-pressure carbonate and silicate melts. The carbonates consist of garnet and K-bearing clinopyroxene embedded in a dolomite or Mg-calcite matrix. Polycrystalline Mg-calcite and polyphase carbonate-silicate inclusions occurring in garnet and clinopyroxene show textural features of former melt inclusions. The trace element composition of such carbonate inclusions is enriched in Ba and light rare earth elements and depleted in heavy rare earth elements with respect to the matrix carbonates providing further evidence that the inclusions represent trapped carbonate melt. Polyphase inclusions in garnet and clinopyroxene within a Mg-calcite marble, consisting mainly of a tight intergrowth of biotite + K-feldspar and biotite+epidote+titanite, are interpreted to represent two different types of K-rich silicate melts. Both melt types show high contents of large ion lithophile elements but contrasting contents of rare earth elements. The Ca-rich inclusions display high REE contents similar to the carbonate inclusions and show a general trace element characteristic compatible with a hydrous granitic origin. Low SiO_2 content in the silicate melts indicates that they represent residual melts after extensive interaction with carbonates. These observations suggest that hydrous granitic melts derived from the adjacent metapelites reacted with dolomite at ultra high-pressure conditions to form garnet, clinopyroxene a hydrous carbonate melt and residual silicate melts. Silicate and carbonate melt inclusions contain diamond, providing evidence that such an interaction promotes diamond growth. The finding of carbonate melts in deeply subducted crust might have important consequences for recycling of trace elements and especially C from the slab to the mantle wedge.

Titanium solubility in olivine in the system TiO_2-MgO-SiO_2: No evidence for an ultra-deep origin of Ti-bearing olivines

J. Hermann, A. Berry and H.StC. O'Neill

The finding of ilmenite rods in olivine from orogenic peridotites has sparked a discussion about the incorporation and exsolution of Ti in olivine. We experimentally investigated the Ti solubility in olivine as a function of composition, temperature and pressure in the synthetic TiO_2-MgO-SiO_2 system. Experiments at atmospheric pressure in the temperature range from 1200-1500°C showed that the highest concentration of TiO_2 is obtained when olivine coexists with spinel (Mg_2TiO_4). 1.25 wt.% TiO_2 was found in olivine in the assemblages olivine + spinel + periclase and olivine + spinel + ilmenite at 1500°C. Changes in the buffer parageneses and a decrease in temperature result in a significant reduction of the Ti solubility. Olivine coexisting with karooite ($MgTi_2O_5$) and a Ti-Si-rich melt at 1500°C displays a four fold lower TiO_2 content than when buffered with spinel. The experimentally determined phase relations are shown in Figure 1a. A strong decrease in solubility is obtained by a decrease in temperature from 1500°C to 1200°C. There is a negative correlation between the Ti and Si contents and no correlation between Ti and Mg in Ti-bearing olivine. Together with the established phase relations this suggests that there is a direct substitution of Ti for Si in these high temperature experiments. The unit cell volume of olivine increases systematically with increasing Ti content (Figure 1b). This demonstrates that the measured Ti contents in olivine are not caused by micro-inclusions but by incorporation of Ti in the olivine structure. Least square fitting of 20 olivine data yield the relation: V ($Å^3$) = 290.09(1) + 24.71(96) NTi. The partial molar volume of the Ti end-member (NTi=1) is thus 47.39±0.14 cm^3. The dependence of the Ti solubility in olivine coexisting with rutile and orthopyroxene with pressure has been investigated with piston cylinder experiments at 1400°C in the pressure range from 15 to 55 kbar. There is no increase in the TiO_2 content with pressure and in all the experiments olivine contains ~0.2 wt.% TiO_2 (Figure 1c). High Ti contents, leading to the exsolution of a Ti phase, are therefore the result of high temperature rather than high pressure as has been proposed previously. These data demonstrate that ilmenite exsolution observed in some natural olivine cannot be used as tracer for an ultra-deep origin of peridotite massifs. Olivine from garnet peridotites containing 200-450 ppm TiO_2 reach saturation on cooling to a temperature of 900-1050°C. Re-equilibration of garnet peridotites below this temperature will result in the exsolution of a Ti-rich phase. The experimental data were applied to the Alpe Arami garnet peridotite, for which an ultra-deep origin has been proposed. The 330 ppm of TiO_2 in structurally old olivines is likely to result from a high temperature stage between 1000 and 1150°C. During equilibration at 800°C, the 330 ppm TiO_2 in olivine is higher than the established saturation level and hence the formation of a Ti-rich phase such as ilmenite is likely. Therefore there is no need to assume an ultra-deep origin of the Alpe-Arami peridotite on the basis of ilmenite rods in olivine.

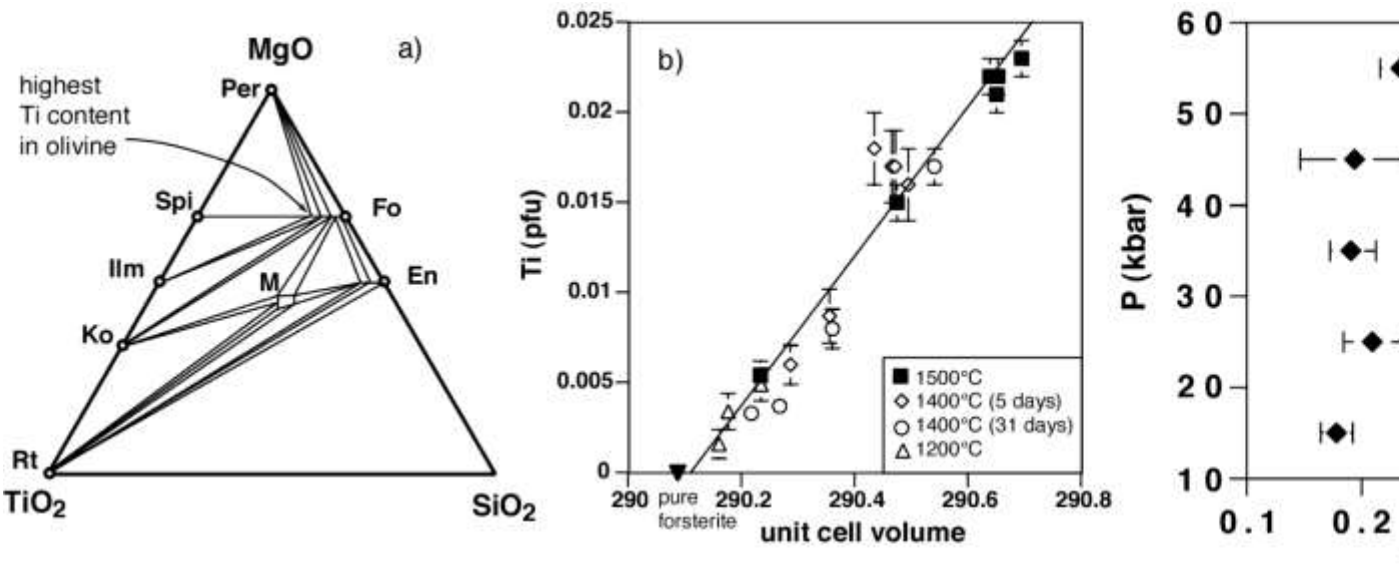


Figure 1: a) Schematic phase relations in the TiO_2-MgO-SiO_2 system at 1 atm and 1400°C. Note that the highest Ti solubility is not obtained when olivine (Fo) is buffered with pure TiO_2 but when it is buffered with a Mg_2TiO_4 spinel (Spi). Other abbreviations: Per = Periclase, En = Enstatite, Rt = Rutile, Ko = Korooite, Ilm = Ilmenite. b) Increase in the unit cell volume of olivine due to incorporation of Ti (given in atoms per formula unit). c) There is no increase in the Ti-solubility in olivine with pressure in the paragenesis olivine-rutile-orthopyroxene.

Petrological constraints on Mantle 'Plume' and Mid-Ocean Ridge Sources — Temperatures and Compositions

D.H. Green

The concept of deep-seated, high-temperature mantle plumes is well-embedded in geophysical and geochemical literature. The most direct method of investigation of the material nature of mantle plumes or 'hot-spot' sources is from their extrusive products i.e. the parental or most primitive magmas which can be identified at typical 'hot-spots'. Many models have attributed a density and buoyancy anomaly, and latterly, a seismic velocity 'anomaly', to abnormally high temperatures in a deep mantle plume, possibly originating in an inferred thermal boundary layer at the core-mantle boundary. Such models have postulated mantle potential temperature (T_p) differences ≥ of 200°C between upwelling plume and normal (MORB-source) mantle at depths below the crustal boundary layer. Geochemical characterisation of plume and MORB magma sources emphasises the relative heterogeneity and complexity of the former and greater global homogeneity ('well-mixed') of the latter. In particular, plume sources contain isotopic and geochemical signatures which are identified with mantle recycling of old oceanic crust. In addition, nobel gas isotopic signatures have been interpreted as signalling a component identified as degassing of old primitive mantle. Subduction of oceanic crust and lithosphere through Transition Zone to core-mantle boundary, re-heating and thermal and buoyancy instability leading to thermal plumes passing through Lower Mantle, Transition Zone and Upper Mantle is one hypothesis invoked to explain differences between ‘Hot-Spot’ and MORB volcanism.

Testing of this hypothesis by examination of the volcanics themselves provides no support but rather supports compositional rather than thermal causes of density/buoyancy plumes. Similarly T_p for MORB sources is similar to that for ‘hot-spot’ magma sources. The evidence for presence of old subducted oceanic crust and lithosphere in the ‘hot-spot’ sources is explained by re-fertilization of refractory, residual harzburgite by near-solidus melting of coesite eclogite and eclogite (subducted oceanic crust) and reaction and freezing of the dacitic to andesitic melts by reactive porous flow into the enclosing harzburgite.

The compositions of olivine phenocrysts in glasses and picrites, in both MORB and ‘Hot-Spot’ basalts have been used to define parental or primitive magmas in both settings and infer 1 bar liquidus temperatures of 1325±20°C. Furthermore, parental melts have compositions which are multiply saturated with olivine + aluminous enstatite + aluminous diopside + aluminous spinel (Cr#≤50) (MORB-type) at about 2 GPa or with olivine + enstatite + Cr-Al spinel (Cr#=60–75) at 1.5–2GPa (Hawaiian-type). These parental or primitive magmas define T_p ~ 1430°C. There is no evidence for a temperature contrast DT_p = 150–250°C between ‘plume’ sources and normal (MORsource) asthenospheric mantle.

Recent data from the Hawaiian Scientific Drilling Project include a large number of glass compositions from lava units of the Mauna Kea core-building stage. The most primitive (highest Mg#) of these provide two very clear compositional groupings, both defining harzburgite residue (ol+opx+Cr-spinel) trends. These data reinforce earlier work on Hawaiian picrites which similarly demonstrated harzburgite residue trends. The recent work confirms the absence of residual garnet at the melt extraction stage of magma genesis, with the corollary that incompatible elements (i.e. those elements not partitioning into olivine, enstatite or chrome-spinel) patterns are pre-set in the source composition or by the processes which preconditioned the source prior to the specific upwelling and melt extraction events for each ‘hot-spot’ volcano. The >,4 component mixing identified in the Hawaiian source in attributed to interaction between old subducted lithospheric slabs suspended or buoyant in the mesosphere, and surrounding ambient mantle (T_p = 1430°C), the redox contrast at the interfaces of the subducted slab providing a locus for increased aH_2O in the lherzolite–(C+H+O) system.

Early terrestrial maria-like impact basins: mineralogy and chemistry of Archaean and early Proterozoic asteroid impact ejecta, Pilbara and Transvaal, may imply existence of large oceanic impact basins on the early Precambrian Earth

A. Glikson

Asteroid impact fallout units, consisting of microkrystite (impact vapor condensate) spherules and microtektites, increasingly allow the deciphering of the early impact history of Earth. In a paper of key importance, B.M. Simonson, D. Davies, M. Wallace, S. Reeves, and S.W. Hassler, (1998, Iridium anomaly but no shocked quartz from Late Archie microkrystite layer: oceanic impact ejecta?, Geology, 26:195-198) point out the likely oceanic (mafic-ultramafic) crustal source of early Proterozoic impact ejecta in the Pilbara Craton, Western Australia. Studies of mainly chloritic microkrystite spherules from the Barberton greenstone belt, Transvaal, are consistent with a mafic derivation of impact condensates (Lowe et al., 1989; Byerly and Lowe 1994; Shukloyukov et al., 2000; Kyte et al., 2003; Lowe et al., 2003). Recent field and geochemical studies of Archaean to early Proterozoic impact units in the Pilbara Craton (Glikson and Vickers, 2003) lend support to Simonson et al.'s (1998) suggestion, on the following basis: [1] Siderophile element (Ni, Co), ferrous elements (Cr, V) and Platinum Group Element (PGE) patterns of least-altered microkrystite spherules and microtektites from Archaean and early Proterozoic impact fallout in the Pilbara Craton (northwestern Australia) and the Kaapvaal Craton (Transvaal) indicate a mafic/ultramafic composition of impact target crust; [2] No shocked quartz grains are observed in the impact fallout units.

Estimates of asteroid and crater sizes based on (1) Mass balance calculations of asteroid masses based on the flux of iridium and platinum as measured from impact fallout units, and (2) spherule size-frequency distribution using the method of Melosh and Vickery (1991), provide evidence for asteroids several tens of kilometer in diameter (Byerly and Lowe, 1994; Shukloyukov et al., 2000; Kyte et al.; Glikson and Vickers, 2003) and consequent oceanic (sima crust-located) impact basins with diameters on a scale of several hundred kilometers.

The implications of these observations for the nature of the early Earth crust and mantle are inconsistent with strict uniformitarian geodynamic models based exclusively on plate tectonic processes. It is suggested the evolution of the early crust represents the combined effects of mantle-driven convection, modified plate tectonic regimes, and large extraterrestrial impacts which triggered deep faulting and adiabatic mantle melting. The latter resulted, in turn, in a feedback mechanism which temporally and spatially controlled the onset and loci of long term dynamic plate tectonic patterns.

A picture emerges of a post-3.8 Ga early Precambrian Earth, i.e. postdating the Late Heavy Bombardment of 3.9-3.8 Ga, which consisted of sialic (SiAl-dominated) continental nuclei composed of multiple superposed greenstone-granite cycles interspersed within extensive tracts of simatic (SiMg-dominated) oceanic crust. The latter included maria-like impact basins on scales of up to several hundred kilometer, i.e. similar in size to the lunar Mare Crisium impact basin (~3.2 Ga; Ds ~ 400 km) or even Mare Serenitatis (Ds ~ 600 km).

Iridium anomalies and fractionated siderophile element patterns in impact ejecta, Brockman Iron Formation, Hamersley Basin, Western Australia: evidence for a major asteroid impact in simatic crustal regions of the early Proterozoic earth

A. Glikson and C. Allen

A stratigraphically consistent <20 cm-thick unit of microkrystite spherule and microtektite-bearing impact fallout ejecta overlying volcanic tuff of the 4th Shale Macroband (DGS4) of the Dales Gorge Member (2.47-2.50 Ga, A.F. Trendall, pers. com., 2003), Brockman Iron Formation, Hamersley Group, Western Australia, displays anomalous platinum group element (PGE) and other trace metal patterns. The unit has high Ir (13 ppb) and Pt (35 ppb), and low Pd (2.7 ppb) and Au (1.55-1.88 ppb). The low Pd/Ir ratios and low Cr/V suggest depletion in volatile PGE and metals relative to refractory PGE and V, contrasted to the ubiquitous high Pd/Ir of most terrestrial rocks. Marked depletion in the volatile REE abundances in stilpnomelane spherule cores is consistent with this model. The loss of volatile PGE, analogous to relations in 3.24 Ga impact fallout units of the Barberton greenstone belt (S3 and S4), suggests fractionation related to atmospheric spherule condensation.

A projected iridium flux of $5.3*10^{-6}$ $gr.cm^{-2}$ suggests impact by an asteroid on a scale of ~30 km diameter. The microkrystite spherule unit locally incorporate fragments and up to meter-scale boulders of banded chert and stromatolite carbonate, suggesting tsunami transport postdating spherule deposition. DGS4 microkrystite spherules are dominated by stilpnomelane mantled by K-feldspar shells, which consist of inward-radiating fibrous feldspar aggregates suggestive of devitrification. The K and REE enrichment of spherule margins are contrasted to flat REE patterns of the stilpnomelane cores, suggesting adsorption of lithophile elements during settling of the spherules through the hydrosphere. K-feldspar shells contain submicron-scale Ni metal, oxide, sulphide and arsenide grains and euhedral needles of feldspar-exsolved ilmenite. Associated magnetite may have high nickel (<1.25% NiO). The generally mafic composition of the spherules and high Ni/Cr and Ni/Co are consistent with a target mafic-ultramafic crust, consistent with the lack of shock-metamorphosed quartz. Mixing calculations suggest a contribution of 2.5-3 percent projectile component to the impact-generated volatile cloud. Conservative mass balance estimates derived from the Ir and Pt flux, assuming global extent of a 10 cm-thick spherule unit and chondritic projectile composition, suggest an asteroid diameter on the scale of ~30 km. Similar estimates are obtained from spherule sizes, which in DGS4 reach a mean diameter of ~2.0 mm in aerodynamically elongate spherules. The evidence implies formation of an impact basin on the scale of 400 km in simatic/oceanic regions of the early Proterozoic crust.

Multiple 3.47 Ga-old asteroid impact fallout units, Pilbara Craton, Western Australia

A. Glikson, C. Allen and J. Vickers[1] 1. Geology Department, ANU

A new microkrystite spherule-bearing diamictite is reported from below the impact spherule-bearing 3.47 Ga Antarctic Chert Member (ACM) at the base of the Apex Basalt, central Pilbara Craton, Western Australia. The diamictite, defined as ACM-S2, consists of 0.6-0.8 meter-thick spherule-bearing pebble to cobble-size chert-intraclast conglomerate separated from the main ACM-S3 by a ~200 meter-thick dolerite and ~30 meter-thick felsic hypabyssals. The microkrystite spherules are discriminated from angular to subangular detrital volcanic fragments by their high sphericities, inward-radiating fans of sericite pseudomorphs after K-feldspar, relic quench textures and Ni-Cr-Co relations. Scanning Electron Microscopy coupled with E-probe (EDS) and laser ICPMS analysis indicate high Ni and Cr in sericite-dominated spherules, suggesting mafic composition of source crust. Ni/Cr and Ni/Co ratios of the spherules are higher than in associated Archaean tholeiitic basalts and high-Mg basalts, rendering possible contamination by high Ni/Cr and Ni/Co chondritic components. The presence of multiple bands and lenses of spherules within chert and scattered spherules in arenite bands within S3 may signify redeposition of a single impact fallout unit or, alternatively, multiple impacts. Controlling parameters include (1) spherule atmospheric residence time; (2) precipitation rates of colloidal silica; (3) solidification rates of colloidal silica; (4) arenite and spherule redeposition rates, and (5) arrival of the tsunami. The Presence of spherule-bearing chert fragments in S3 may hint at an older spherule-bearing chert (?S1). Only a minor proportion of spherules are broken. The near-perfect sphericities of chert-hosted spherules and arenite -hosted spherules constrains the extent of shallow water winnowing of the originally delicate glass spherules. It is suggested that the spherules were either protected by rapid burial or, alternatively, disturbance was limited to a short term high energy perturbation such as may have been affected by a deep-amplitude impact-triggered tsunami wave.

The age and origin of Australian opals

K. Dowell

Australia produces over 90% of the worlds opal, it is the name of our Olympic medal winning basketball team and it is our official National Gemstone. Yet the question remains; How are they formed? By answering this question, we can further the understanding of low temperature silicification and develop an exploration technique to better Australia's economy.

Australia has several different precious opal types, within sedimentary (crystal, boulder, white and black opal) and volcanic environments (usually white opal). During two separate field trips to Lightning Ridge (NSW) and Quilpie (QLD) sediment and water samples. Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS) and electron microscopy were used to determine trace and major element compositions. X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) were used to determine bulk major elements and opal states present within the opal host sediment, again respectively. Infra red analyses provided water and CO_2 concentrations within opal. Radiocarbon dating techniques (AMS, Research School of Physics) were used to date opal samples. The opal dated is Holocene aged, opposing the previously accepted age in the Cretaceous. We are trying to find an independent dating technique but U-series dating has so far been an unsuccessful tool.

Comparing two different opal morphologies, seam and nobbie, using trace elemental analyses, different environmental conditions were distinguished. Using Transmitted Electron Microscopy (TEM), small inclusions were found within and around the micro-silica spheres in precious opal. The TEM imagery has provided a new path for understanding trace element anomalies previously unknown. The chemistry of opal and their environments has been analysed and this information is critical in understanding opal genesis and low temperature silica mobility.

Dislocation microstructures in deformed olivime displaying the C-type and B-type fabrics

T.G. Sharp and J.D. Fitz Gerald in collaboration with S.-i. Karato and H. Jung

Because seismic anisotropy in the upper mantle is commonly a result of lattice preferred orientations (LPOs) of minerals as a result of mantle flow, seismic anisotropy is used to probe fabrics and therefore flow directions in the mantle. Jung and Karato, (2001) have shown that the fabrics developed in experimentally deformed olivine are dependent on H_2O fugacity and stress, suggesting that olivine fabric in the upper mantle can provide a means of probing H_2O content and stress. Olivine fabrics, known as B-type and C-type, occur in olivine deformed under high H_2O fugacity and high stress. In order to extrapolate these experimental deformation fabrics to the mantle, one must understand how H_2O changes the mechanisms of plastic deformation in olivine.

Experimentally deformed olivine samples with C-type and B-type fabrics have been examined by TEM at ANU to determine dislocation microstructures, core structures and active slip systems. In the C-type sample, we examined a relatively large olivine grain with its b axis normal to the TEM foil and the a and b axes approximately 45° from the slip direction. Tilt boundaries along (100) and (001), consisting of edge dislocations with **b** = [100] and **b** = [001], respectively, indicate that the dominant slip systems are (001)[100] and (100)[001]. HRTEM imaging of the **b** = [100] and **b** = [001] edge dislocations along [010] shows no dissociation for **b** = [100], whereas the **b** = [001] dislocations are dissociated into 1/2[-101] and 1/2 [101] partial dislocations separated by 3 nm along the (-101) plane (Figure1). The C-type fabric, which occurs in wet olivine deformed at low stress, results from the domination of the (100)[001] slip system over the (010)[100] slip system that produces the A-type fabric. The B-type sample, which was deformed under higher stress than the C-type sample, has a more complicated microstructure with poorly organized subgrain boundaries. Slip systems and core structures in the type-B sample are currently under investigation.

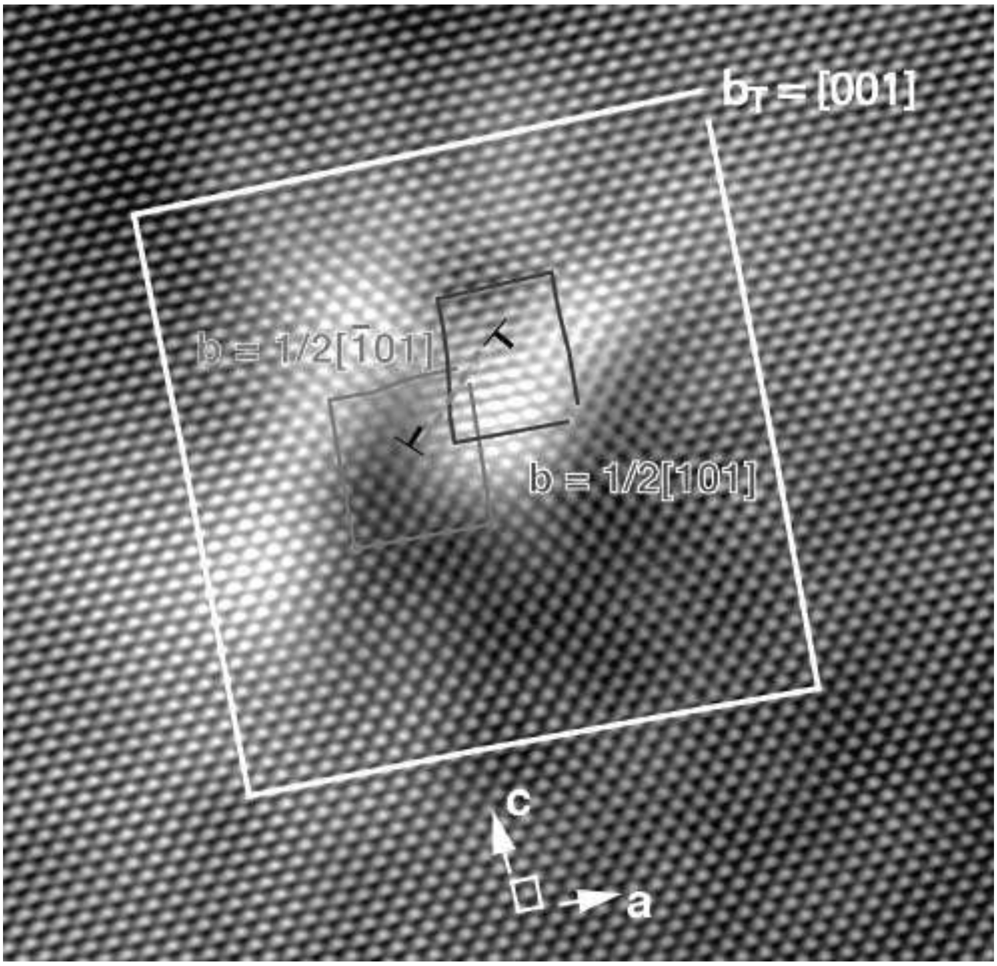


Figure 1: Fourier-filtered high-resolution TEM image of a **b** = [001] edge dislocation along [010] viewed down the [010] zone axis of olivine. The large Burgers circuit shows the total Burgers vector **b** = [001] whereas the smaller Burgers circuits show that the dislocation is dissociated into **b** = 1/2[-101] and **b** = 1/2[101] partial dislocations. The unit cell of olivine is shown at the bottom of the image.

Partial melting at Broken Hill, Australia: Evidence from sulfide melt inclusions

H. Sparks and J. Mavrogenes

Although contentious, a number of features within the Broken Hill orebody are consistent with a sulfide partial melt forming during peak metamorphism. First proposed by Brett and Kullerud (1966; 1967) and Lawrence (1967), the idea that the formation of a sulfide neomagma derived from partial melting of pre-existing ore, has largely been ignored due to the difficulty in finding direct field evidence. This study identified the existence of abundant polyphase sulfide melt inclusions (SMINCs) within the manganese (garnetite) halos and quartz veins surrounding areas of remobilised ore (droppers). Homogenisation experiments determined re-equilibration of SMINCs as low as 720ºC at 5 kbar, well below peak metamorphism at Broken Hill (820°C, 5kbar). An average SMINC bulk composition of Pb 51.4 wt%, Cu 10.3 wt%, Zn 1.3 wt%, As 7008 ppm, Sb 7031 ppm and Ag 5656 ppm was calculated from LA-ICP-MS data. This indicates more than an order of magnitude enrichment in Ag relative to average lead lodes. Compositional trends reminiscent of igneous fraction trends were observed in populations of SMINCs from both garnetite and quartz hosts. All of the above evidence strongly supports the existence of a sulfide partial melt during peak metamorphism at Broken Hill. If we are to understand how these world-class ore deposits form we must first learn to distinguish primary from secondary features. This work has helped delineate an important process in ore remobilisation, which is probably more prevalent than had been previously thought.

Hydrous sulfide melting in the Fe-Pb-Zn-S-H-O system at 1.5 GPa

J. Wykes

The effect of H_2O on the melting temperature of the FeS-PbS-ZnS system was investigated at 1.5 GPa using the piston-cylinder apparatus. A novel capsule technique, involving cold-pressed, polycrystalline galena capsules was developed to overcome problems related to interaction between sulfide melt and noble metal/graphite capsules inherent in high-pressure sulfide melting experiments (Naldrett and Richardson, 1967). The eutectic of the H_2O-free FeS-PbS-ZnS system was determined to be at 900 ±5 °C, with a composition of 48 mole % FeS, 48 mole % PbS and 5 mole % ZnS. Experiments performed with the eutectic composition + H_2O demonstrated that the addition of H_2O depresses the melting temperature by 35 ±5 °C relative to the dry FeS-PbS-ZnS eutectic. Vesicles in quenched sulfide melt confirmed the presence of dissolved H_2O. Sulfide-oxide experiments performed at 1.5 GPa demonstrated that the addition of ZnO, Fe_3O_4, or Fe_2O_3 did not depress the melting temperature of the FeS-PbS-ZnS system. Comparison between Fourier Transform infrared (FTIR) spectra obtained from hydrous granitic glasses produced in platinum and polycrystalline galena and troilite capsules reveals that cold-pressed polycrystalline galena capsules are capable of preserving the initial H_2O as well as a Pt capsule.

The results of this study indicate that H_2O is soluble in sulfide melts. However, the study was performed at a pressure of 1.5 GPa, which is represents a significantly higher pressure than typically experienced by magmatic sulfide deposits or high-grade metamorphic terranes. Should the solubility of H_2O in sulfide melts behave in a similar manner with respect to pressure as silicate melts behave, then it could be expected that the depression of the solidus, and hence the solubility of H_2O will be less in crustal environments. Indeed, experiments into the solubility of halogens in sulfide melts (Mungall and Brenan, 2003) demonstrated increasing halogen solubility with increasing pressure.

In magmatic sulfide deposits, sulfide-silicate melt partitioning is expected to concentrate H_2O in the silicate melt. However, melting of massive sulfide orebodies in high-grade metamorphic terranes may lead to the formation of a sulfide melt through partial melting of existing sulfides, rather than saturation of a parent silicate liquid, permitting increased amounts of non-chalcophile components, including H_2O to dissolve into the anatectic sulfide melt. Extensive crystallisation in response to retrograde cooling may result in H_2O-saturation and the exsolution of a hydrous fluid from the sulfide melt. The exsolved hydrous fluid may appear as a post-peak hydrothermal overprint. The intimate association between ore and alteration from the exsolved hydrous fluid may be incorrectly interpreted as reflecting a post-peak hydrothermal origin of the ore.

Structure and Tectonics

PDF is no longer available.

Rock Physics

Seismic Properties and Interpretation

Seismic Properties and Interpretation

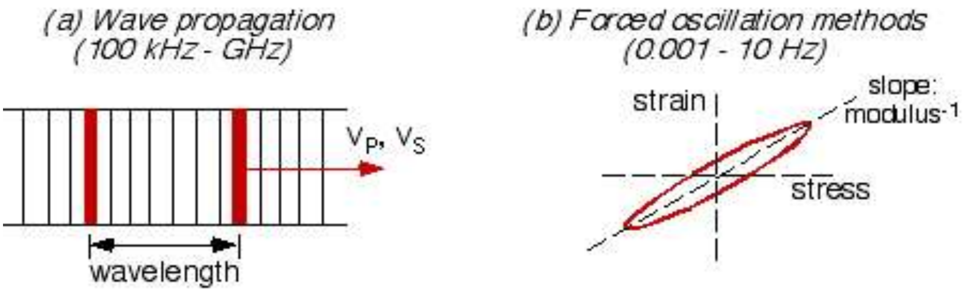
The structure of the Earth's mantle interpreted through laboratory measurements of seismic wave speeds and attenuation: background and techniques

Seismic wave speeds typically increase with increasing depth in the Earth's mantle – the generally smooth variation evident in global average models being punctuated by discontinuous increases of 5-10% at depths near 410 and 660 km. Superimposed upon this radial variation is substantial lateral variability especially in the uppermost 300 km of the mantle and near the core-mantle boundary.

Are the discontinuities near 410 and 660 km depth simply the result of known pressure-induced changes in crystal structure or is the mantle sharply stratified in chemical composition? What causes the marked lateral variability of the shear wave speed and attenuation in the upper mantle? Variations in temperature? Compositional heterogeneity? Partial melting?

These questions are central to an understanding of the internal dynamical processes represented at the Earth's surface by continental drift and plate tectonics. Answers require measurements on appropriate materials performed under controlled laboratory conditions of pressure and temperature.

The variation of elastic wave speeds with pressure and temperature, like thermal expansion, arises from asymmetry of the interatomic potential energy. Such ‘anharmonic' variations of elastic wave speeds can be conveniently measured in the laboratory on mineral or rock specimens of ~0.1 mm to cm size at sufficiently high frequencies (MHz-GHz) by ultrasonic interferometry and opto-acoustic techniques, (see figure a. below). During the past decade, both single-crystal and coherent polycrystalline specimens of most of the major mantle minerals (including high-pressure phases) have been characterised with these high-frequency methods. Much has been learned about the pressure, and more recently temperature, dependence of their elastic wave speeds. However, substantial uncertainties remain – especially as regards the combined influence of pressure and temperature.



At the much lower frequencies of teleseismic wave propagation (< 1 Hz) the shear modulus and hence both shear and compressional wave speeds may be profoundly altered at high temperature, and in the presence of fluids, by viscoelastic relaxation. The stress-induced migration of crystal defects (vacancies, dislocations and grain boundaries) and/or redistribution of interstitial fluid results in additional strain and hence lower wave speeds accompanied by attenuation.

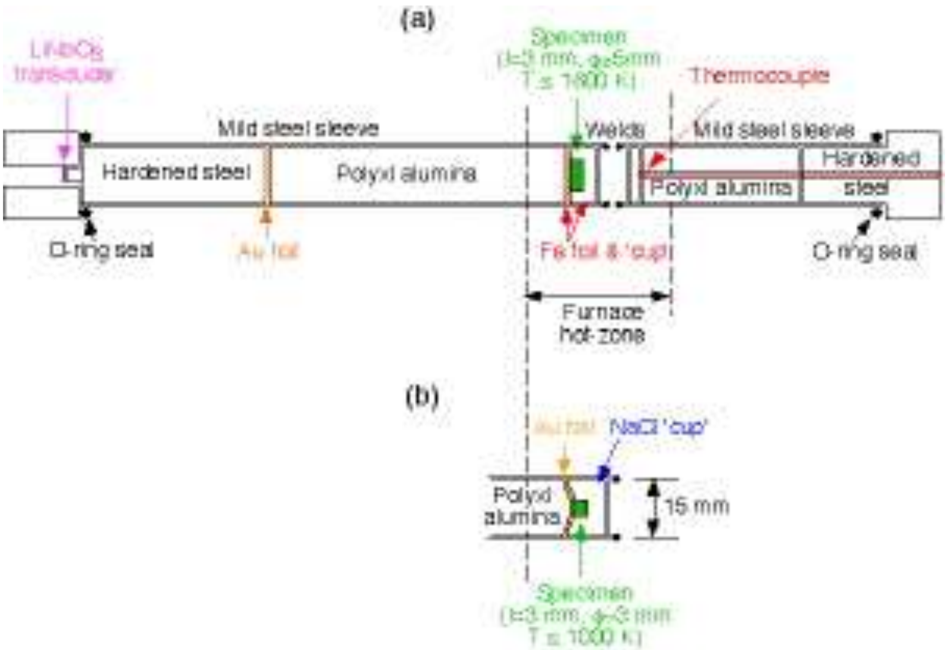
These effects have only recently become amenable to laboratory study through the methods of ‘mechanical spectroscopy' – the testing of cm-sized cylindrical specimens at mHz-Hz frequencies with sub-resonant torsional forced-oscillation and microcreep methods (see figure b. above).

The following are 2003 highlights of our ongoing long-term commitment to the development and application of both ultrasonic and forced-oscillation/microcreep methods.

High-temperature ultrasonic interferometry: polycrystalline MgO and pyrope garnet

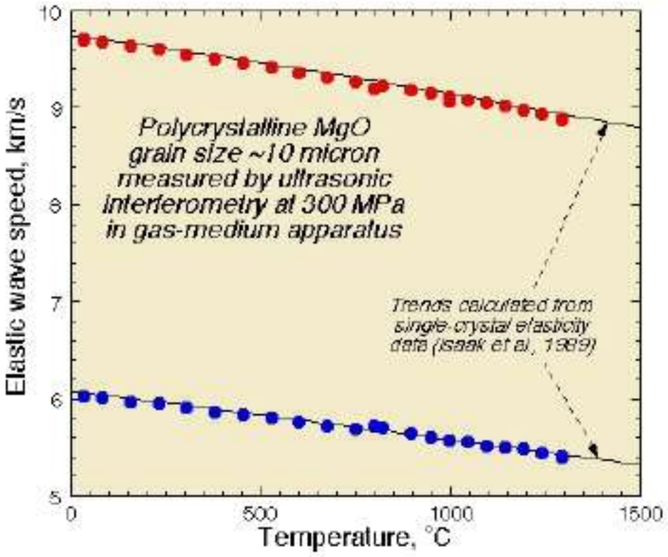
Granville, Gwanmesia, Jackson, Saint and Weston

Further progress was made during 2003 on the refinement of our procedures for ultrasonic measurement of elastic wave speeds at high temperature and moderate pressure (300 MPa) in gas-medium high-pressure apparatus. For small specimens and temperatures < 1000 K an alumina buffer-rod tapered to roughly match the specimen diameter and an NaCl pressure-transmitting ‘cup' has been proved (see figure below), whereas, for higher temperatures (to 1600 K), a simple cylindrical buffer-rod and soft Fe cup are employed (see figure a. below). In both cases a dual-mode transducer now provides for the measurement of both compressional and shear wave speeds within a common P-T cycle. (Jackson, Webb, Weston & Boness, Phys. Earth Planet. Interiors, in review)



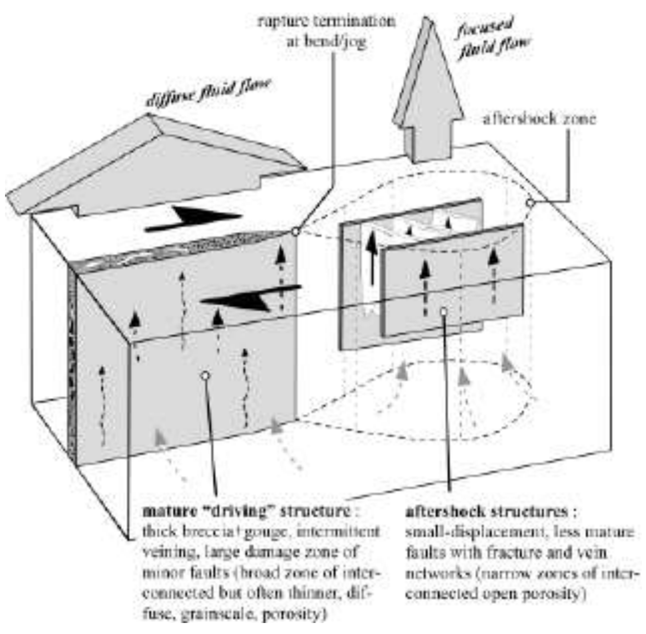
Experimental assemblies for elastic wave speed measurements at high temperature by ultrasonic interferometry.

As part of the preparatory work for a major new project on high-temperature viscoelastic relaxation and grain-boundary sliding in MgO, a dense polycrystalline specimen of ~10 mm grain size was fabricated and tested by ultrasonic interferometry (assembly of figure a. above). The measured temperature-dependent wave speeds correspond closely with the trends expected from single-crystal elasticity data (see figure below) - confirming the quality of the hot-pressed polycrystal.



Comparison of measured temperature-dependent P and S-wave speeds for polycrystalline MgO with single-crystal trends.

Subsequently, two small specimens of pyrope garnet hot-pressed and characterised at Stony Brook by visiting Professor Gwanmesia from Delaware State University were measured in the ANU gas apparatus (assembly of figure b. above), again with results closely consistent with expectations based on single-crystal data. In the next phase of this work, partially funded by an ARC Linkage International award, we will compare the temperature sensitivities of elastic bulk (K) and shear (G) moduli measured at the vastly different pressures accessible in gas (300 MPa) and solid–medium apparatus (~10 GPa) to constrain the mixed pressure derivatives d2M/dPdT (with M = K, G).



In addition healing and sealing of faults is a rapid process in fluid-rich systems. Thus the extended period that after-shocks occur over implies those zones that are repeatedly activated attain high cumulative fluid fluxes relative to the major through-going fault. In this way we have been able to explain the location and clustering of mineralised small displacement structures around non-mineralised major structures.

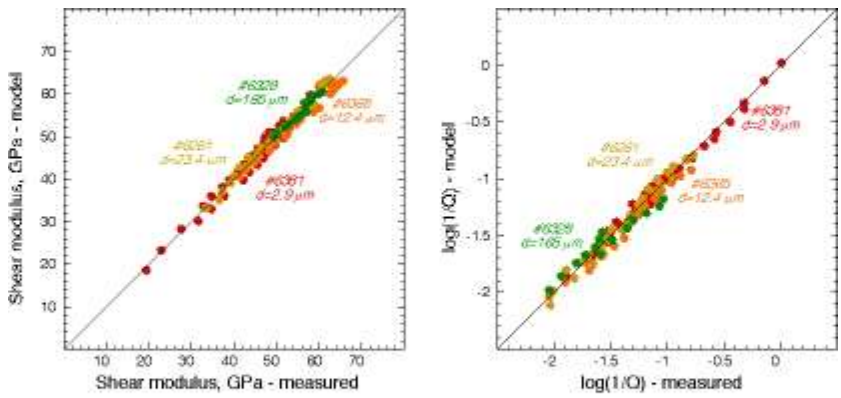
High-temperature viscoelastic relaxation in olivine-dominated upper-mantle materials and its seismological implications

Faul, Fitz Gerald, Jackson, Kokkonen & Saint

In recent years we have applied torsional forced oscillation/microcreep methods (techniques Fig. b below) in seismic- frequency studies of the high-temperature viscoelastic behaviour of fine-grained materials based on the dominant upper-mantle mineral olivine. Initially we fabricated and tested a suite of dense, high-purity olivine polycrystals – establishing the 'base-line' behaviour in the absence of melt. The variations of both shear modulus G and strain-energy dissipation 1/Q with oscillation period, temperature and mean grain size were quantified. The behaviour is of the type commonly referred to as 'high-temperature background' in which 1/Q varies smoothly and monotonically with period and temperature without any resolvable dissipation peak. Qualitatively different behaviour was observed for a second suite of olivine specimens containing basaltic melt fractions ranging between 0.01% and 4%. For these specimens, a broad dissipation peak superimposed upon a melt-enhanced background is consistently observed. The high-temperature dissipation background and associated modulus dispersion are attributed to grain-boundary sliding with diffusional accommodation, whereas the peak seen only in the melt-bearing materials is thought to be caused by elastically accommodated sliding facilitated by the rounding of olivine grain edges at triple-junction melt tubules (Jackson, Faul, Fitz Gerald & Tan; Faul, Fitz Gerald & Jackson, J. geophys. Res., in press).

In order to clarify key aspects of the interpretation of these experimental data, we plan to repeat the measurements on additional suites of olivine specimens containing melts of substantially lower viscosity or different wetting behaviour. Extensive trials have identified suitable compositions expected to be of substantially lower viscosity.

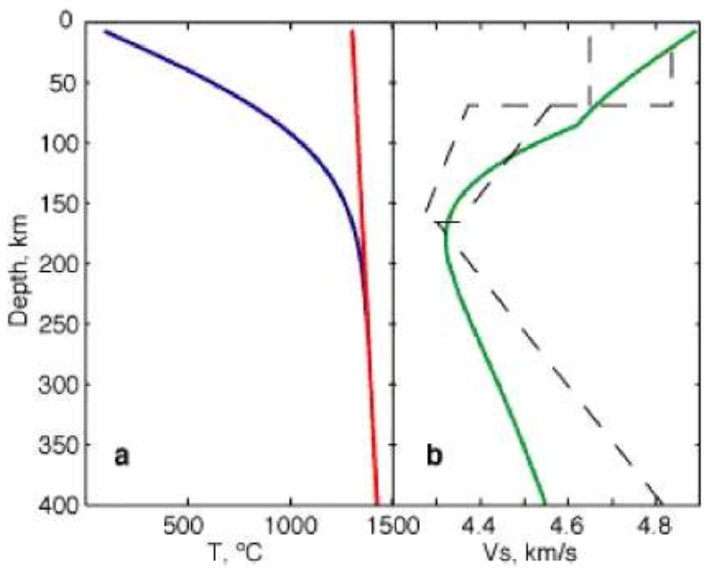
Another major focus during 2003 was the development of a comprehensive and internally consistent description of both strain energy dissipation and the associated modulus dispersion by specifying of the creep function. This function, which is the time-dependent strain resulting from unit step-function application of stress, can be used to calculate the response of linear viscoelastic material to sinusoidally time-varying stress and hence G and 1/Q. A creep function based on the simple Burgers spring-and-dashpot model has been developed that provides an excellent description of the observed variations of both modulus and dissipation for our melt-free olivine aggregates (see figure below).



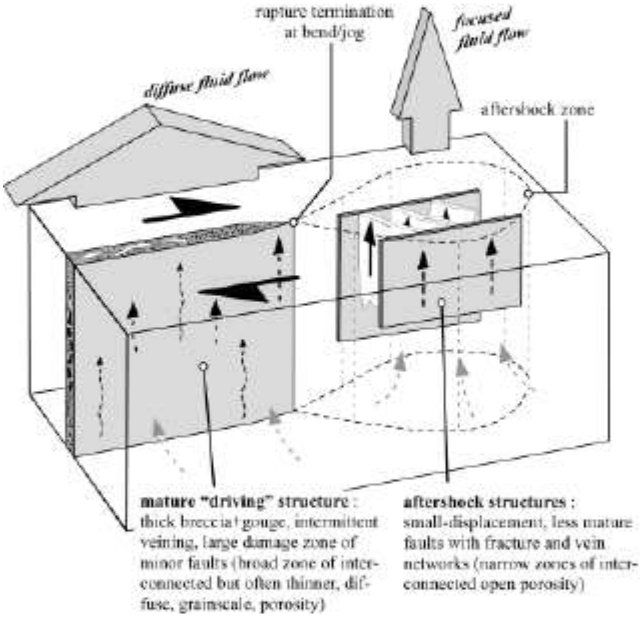
A comparison of measured shear modulus (a) and strain energy dissipation (b) with the predictions of the extended Burgers model.

Such a model provides a robust framework for application of the insights gained in the laboratory to teleseismic wave propagation in the upper mantle. Calculations for oceanic lithosphere of varying age and for the most ancient continental regions indicate that many features of the upper-mantle wave-speed-attenuation-depth models can be explained by the effects of solid-state viscoelastic relaxation in different thermal regimes without recourse to widespread partial melting (see figure below).

The further development of this creep-function approach to describe the more complicated behaviour of melt-bearing olivine is underway.



Shear wave velocity-depth models for oceanic lithosphere. (a) calculated from the laboratory-based extended Burgers model for olivine of 1 mm grain size. (b) inferred from surface wave studies (Faul & Jackson, Nature, in review).



In addition healing and sealing of faults is a rapid process in fluid-rich systems. Thus the extended period that after-shocks occur over implies those zones that are repeatedly activated attain high cumulative fluid fluxes relative to the major through-going fault. In this way we have been able to explain the location and clustering of mineralised small displacement structures around non-mineralised major structures.

Coupline Between Fluid Flow, Deformation Processes and Reaction

Experimental, field-based, microstructural and numerical modelling approaches are being used to explore several aspects of coupling between deformation processes, fluid transport, chemical reactions and the strength of earth materials in crustal and subduction zone environments.

Experimental studies have focussed on measuring changes in permeability of serpentinites during dehydration reactions in isostatic stress regimes, as well as during deformation. Fluid generation and associated reaction-enhanced permeability in devolatilising serpentinite in subducting slabs is likely to be a key factor influencing nucleation of intermediate depth earthquakes, as well as metasomatism and melt generation in the overlying mantle wedge. Analysis of chemistry of fluids generated during serpentinite devolatilisation has provided surprising implications for boron budgets in the mantle.

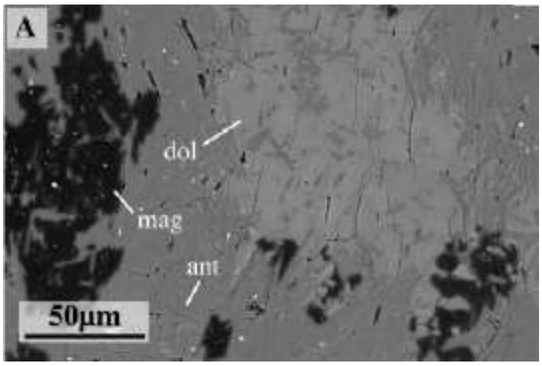
A new project, funded by ARC and a consortium of minerals industry sponsors, is examining why fluid flow tends to be localised within particular parts of crustal-scale fault networks. This research is aimed at understanding controls on the distribution of lode gold systems in fault networks. New field and modelling studies of a major goldfield north-west of Kalgoorlie in WA have shown that the distribution of gold deposits is consistent with the deposits forming in low displacement faults that were repeatedly reactivated following mainshocks on a nearby large displacement fault. The distribution of gold deposits formed in aftershock networks is found to be predictable if mainshocks are repeatedly arrested at large scale fault jogs or bends. Ongoing research is testing these concepts elsewhere in the Eastern Goldfields province of the Yilgarn Craton.

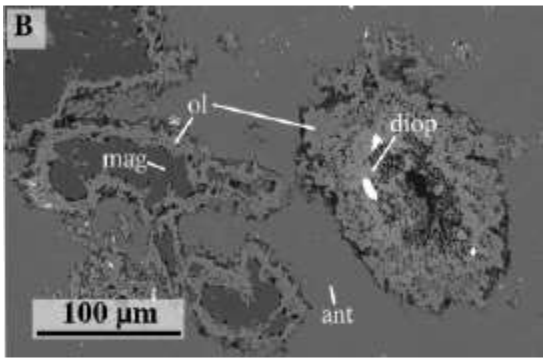
Field-based studies have used C/O stable isotope studies of vein systems to explore growth of fracture-controlled fluid pathways during low temperature deformation of a limestone sequence. Systematic variations in d18O in veins and altered wall-rocks within the carbonate sequence indicate growth of fracture networks was driven by upwards invasion of pore fluids into the sequence. The work highlights the role that high pore fluid pressures, rather than stress states, can have in driving both the growth of fault systems, and repeated slip events on these structures.

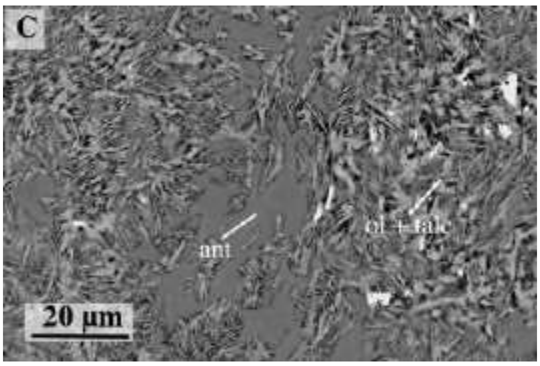
Reaction Enhanced Permeability and the Generation of Intermediate Depth Earthquakes

E. Tenthorey and S.F. Cox

Serpentinites are hydrated rocks that usually form during the interaction of seawater-derived fluids with ultramafic rocks of the deep oceanic lithosphere. During subduction, the serpentinized portion of the lithosphere heats up and eventually the mineralogy reverts back to a anhydrous assemblage dominated by olivine. In recent years, there has been speculation that the liberated fluids may result in overpressures, which nucleate the puzzling earthquakes observed deep in subduction zones. Using natural cores of serpentinite, we conducted high-pressure experiments in which we monitored permeability and strength during dehydration. Our main observation was that the serpentinite did not fail by fluid assisted shear failure because rapid generation of an interconnected pore network allowed the fluid to drain efficiently and maintain initial stress conditions. During the various dehydration reactions, pore space was generated (see figure below) and maintained with the permeability increasing by more than 3 orders of magnitude in some cases. The results of this work provide important data, which is needed to model fluid flow in the deep Earth.







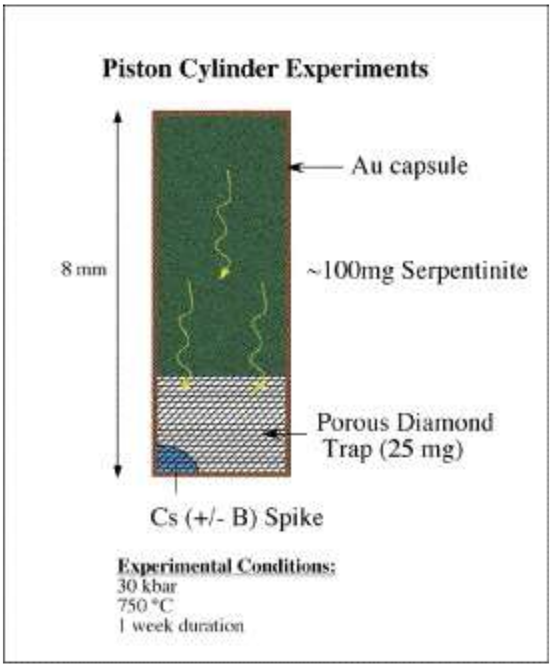
Scanning electron micrographs of starting serpentine and reaction products after dehydration reactions. A: Starting serpentinite specimen with pods of dolomite (dol) and magnesite (mag) within a matrix of antigorite (ant). B: Experiment at 600°C showing coronal reaction textures between magnesite, dolomite (reacted out), and antigorite resulting in olivine (ol) and diopside (diop). C: Experiment at 650°C showing partial breakdown of antigorite to olivine + talc.

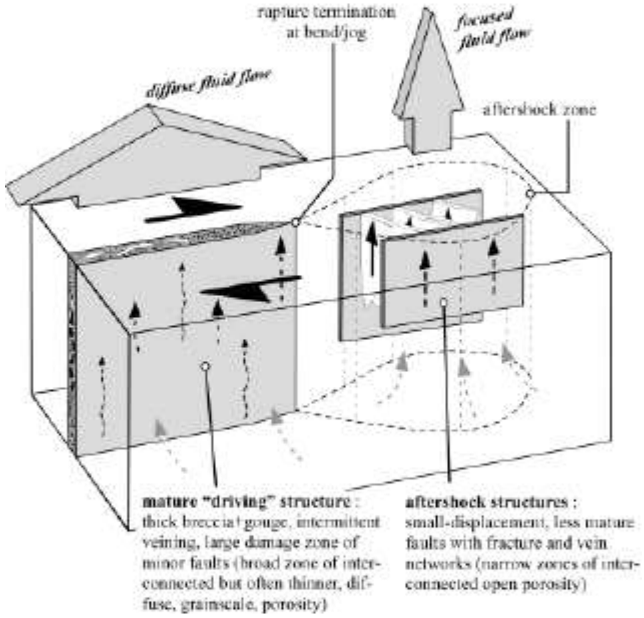
Trace Element Composition of Fluids during Serpentinite Dehydration

E. Tenthorey & J. Hermann

It is currently believed that island arc magmas are generated when H 2 O migrates from subducting lithosphere into the overlying wedge. The addition of H 2 O lowers the melting temperature of the ultramafic rocks and also acts as a medium for transport of various trace elements. Although serpentinites are probably the most important reservoir for H 2 O in subduction zones, little is known concerning the role of serpentinites in magma genesis. Determining the sources of the fluids is contingent on understanding the trace element behaviour during mineral reactions and also their partitioning behaviour into the breakdown fluids.

To this end, we have conducted a series of piston cylinder experiments to characterize trace element mobility during serpentinite dehydration. These novel experiments involved capping our serpentinite specimen with a porous diamond aggregate so that the fluids liberated during dehydration were separated from the sample and trapped in the diamond (see figure below). The olivine-rich residue and the quench precipitates in the diamond were then analysed using laser ablation ICP-MS so that partition coefficients could be determined for various elements. The most surprising result was that boron, an element long thought to be highly mobile, was far less mobile than other elements such as Cs and As. Since serpentinites contain high concentrations of B, our results have significant implications for B recycling into the deep mantle and indirectly for the dynamics of fluid flow in the mantle wedge.





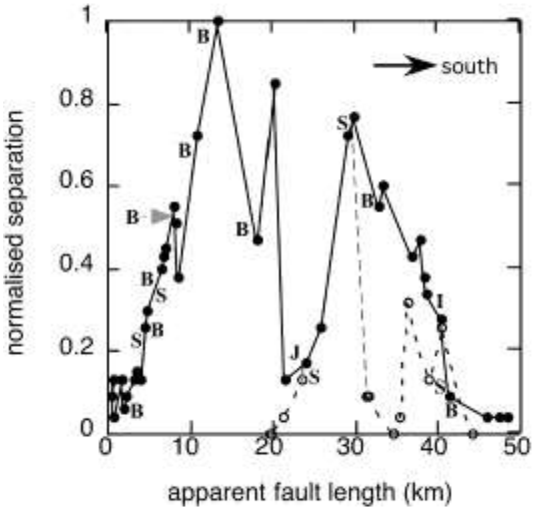
In addition healing and sealing of faults is a rapid process in fluid-rich systems. Thus the extended period that after-shocks occur over implies those zones that are repeatedly activated attain high cumulative fluid fluxes relative to the major through-going fault. In this way we have been able to explain the location and clustering of mineralised small displacement structures around non-mineralised major structures.

Stress transfer modelling for area selection in mesothermal gold systems

S. Micklethwaite and S.F. Cox

A critical understanding of fault and fluid interactions is absolutely necessary for the prediction of many types of mineral deposits, the evolution of crustal strength, the triggering of earthquakes and crustal mass transport. It is well known that fault rupture enhances permeability, particularly in low porosity rocks. Fluid migration and chemical fluid-rock reaction are often a direct consequence, resulting in mineralisation or rock strength softening processes. We are concerned with the dynamics of seismogenic fault zones, their effect on fluid migration in mid to upper crustal conditions and the implications for gold mineralisation.

In this project we are using a combination of field observations and stress transfer modelling (STM), where parameters in the model are constrained by field data. Stress transfer modelling is a technique developed in California for earthquake hazard assessment. In response to an earthquake on a fault, the rock volume around the rupture undergoes changes in stress. Those volumes that are brought nearer to failure are closely associated with aftershocks and can be predicted using STM. Three separate case studies, through 2003, were carried out on gold deposit mine sites from the Kalgoorlie terrane, Western Australia.



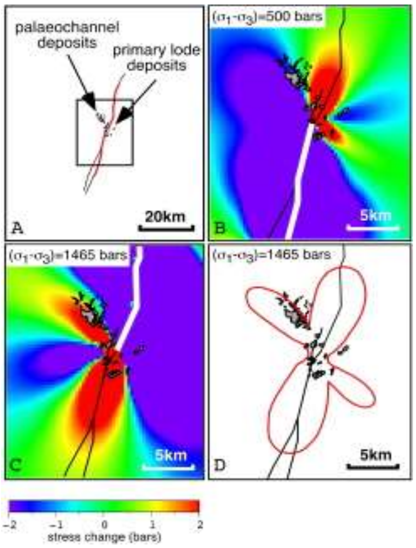
One highlight of the field studies was to identify segmentation and a major jog along the Archaean Black Flag Fault, using net-slip distribution (Fig 1). Segmentation and jog zone linkage of faults is known to control the maximum size of earthquakes that are generated and the location of earthquake termination. On this basis we were then able to rigorously apply STM to the ancient fault.

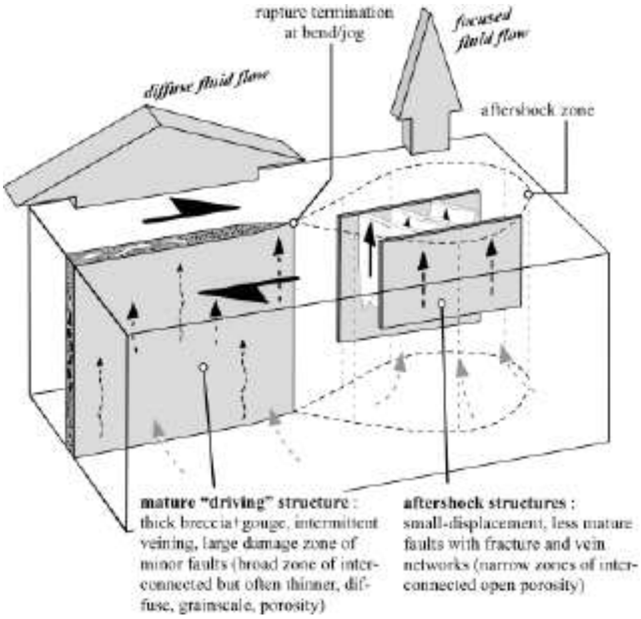
Our results indicate that gold deposits in the Kalgoorlie terrane are located on structures that repeatedly hosted aftershock ruptures (see figure below).

We are now able to argue that during seismic deformation on a fault system, fluid flow and/or mixing is focused in specific sites determined by the location of aftershock networks. Dilation at jogs and bends along the larger fault does not matter so much as the fact that networks of aftershocks are located adjacent to such sites. This arises because jogs and bends are sites for EQ rupture arrest. Thus, contractional jogs or bends on large faults are just as likely to lead to transiently permeable zones of crust as a dilational jog. We predict that crust between 2 underlapping segments will be subject to the highest fluid fluxes. Equally, the distribution of aftershocks can lie not only between interacting fault segments in jogs but also off-fault, where lobes of positive stress change are generated laterally (see lateral positive stress lobes in (see figure below).

During the coming year we will begin to apply STM to more “greenfield” sites, where less is known about the local geology. The suitability of STM for prediction of mineral deposit targets is a potential application that we wish to directly test. In addition we are compiling an atlas of ideal fault-rupture scenarios. It is hoped this will provide a template for exploration geoscientists trying to predict fault-hosted targets in the field, without the need for individual STM case studies.

Showing modelling of the Black Flag Fault. B&C: Example calculations of maximum Coulomb failure stress predicting aftershock distribution that results from ruptures on southern (B) and northern (C) segments of Black Flag Fault. D: Summary of predicted zone of aftershocks resulting from ruptures on the BFF, which correlates with distribution of gold deposits.





In addition healing and sealing of faults is a rapid process in fluid-rich systems. Thus the extended period that after-shocks occur over implies those zones that are repeatedly activated attain high cumulative fluid fluxes relative to the major through-going fault. In this way we have been able to explain the location and clustering of mineralised small displacement structures around non-mineralised major structures.

Evolution of Fluid Pathways During Deformation

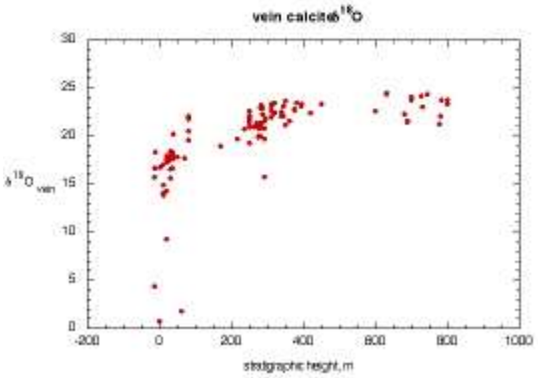
Structural and stable isotope studies of a one kilometre thick, Lower Devonian carbonate sequence (Murrumbidgee Group) in the Taemas area of the Lachlan Fold Belt (south-eastern Australia) indicate that externally-derived fluids migrated through the sequence during upright folding and associated reverse faulting at depths of several kilometres and temperatures in the range 150ºC to 200ºC. The evolution of fluid pathways during crustal shortening was controlled by growth of fault-related and fold-related vein networks at transiently supralithostatic fluid pressures (see figure below).

Extension vein arrays in competent massive limestone unit (Currajong Limestone). Such units have been stretched and fractured at various stages during progressive fold growth.

Systematic changes in O-isotope compositions of veins up through the carbonate sequence are related to buffering of externally-derived fluid compositions by progressive reaction with the host rocks along the structurally-controlled fluid pathways. At the base of the carbonate sequence, calcite veins are ^{18}O depleted by up to 23‰ relative to unaltered host-rock limestones. ^{18}O-depleted alteration haloes up to 20 metres wide in wall-rock in areas of intense vein development are related to fluid discharge from faults and associated vein arrays. Higher in the carbonate sequence, fault- and fold-related veins typically exhibit progressively less depletion relative to the distal host rocks (see below). In the upper parts of the sequence, vein d ^{18}O is usually less than 1-2‰ less than unaltered host rocks. Systematic depletion of vein ^{18}O by up to 23‰ also occurs immediately adjacent to the high displacement Warroo Fault, which bounds the eastern side of the carbonate sequence.

Decreasing ^{18}O depletion within faults upwards through the carbonate sequence indicates vein formation was associated with upwards infiltration of fluids having an initial d ^{18}O of -8‰. These fluids are interpreted to be evolved meteoric fluids or formation waters which migrated through the Black Range Group, a volcanic sequence underlying the Murrumbidgee Group. Reactive transport modelling of this flow system indicates time-integrated fluid fluxes of approximately 10^2 moles H_2O cm^{-2}.

Variation in vein d 18 O as a function of stratigraphic height in the Murrumbidgee Group.



At the eastern boundary of the area, fluids which percolated through parts of the Warroo Fault also had an initial d 18 O of -8‰. This fault is interpreted to have tapped fluids from the same reservoir which supplied fluids that migrated through faults at the base of the Murrumbidgee Group during contractional deformation.

Within-site variations in d 18 O between veins are interpreted in terms of variations in (1) relative timing of formation of veins during progressive migration of the geochemical front through the sedimentary sequence, (2) changes in connectivity between the backbone part of the fracture-controlled flow network and developing fracture arrays, and (3) local variations in stable isotope compositions of host rocks along fluid pathways.

Systematic variations in stable isotope compositions of veins indicate that most faults were well-connected to an external fluid reservoir. This suggests that growth of fault and fracture networks has been driven largely by invasion of high pore fluid factor fluids.

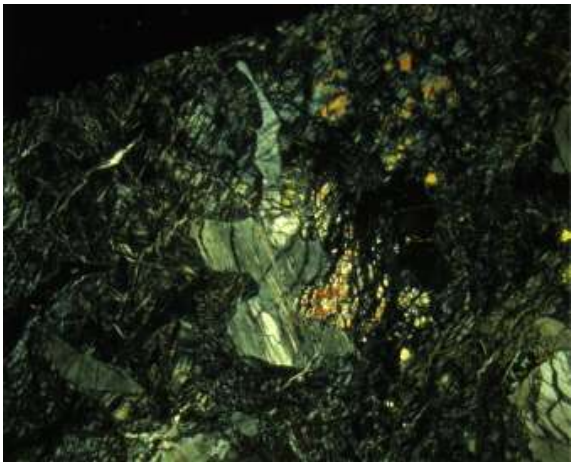
Deformation and Melt Transport at Slow Spreading Ridges: Initial Results from Ocean Drilling Program Leg 209.

Ulrich Faul and Leg 209 Shipboard Scientific Party

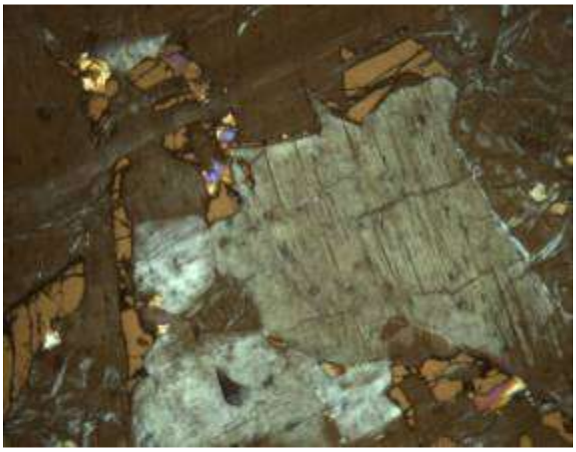
Our understanding of how mid-ocean ridges work are in large part based on observations from obducted bodies of mafic and ultramafic rocks called ophiolites. Models of mid-ocean ridges derived from these observations predict that the mantle upwells and undergoes decompression melting beneath the ridge, before the flow turns horizontal away from the ridge axis. This type of flow should result in distinct deformation patterns in the mantle rocks. Leg 209 was one of the first legs of the Ocean Drilling Program to directly test this hypothesis by drilling a series of holes along strike of the Mid-Atlantic Ridge between 14 and 16ºN. Previous observations from this area from dredges and submersible sampling had shown numerous peridotite outcrops at the sea floor.

During Leg 209 a total of 20 holes at 8 sites were drilled in the target area. Of those, two sites were drilled in basalt; one site on top of a "Megamullion" (thought to be the surface of a long-lived detachment fault) yielded gabbroic rocks and impregnated dunites, while peridotites with some interlayed gabbroic rocks were recovered from five sites. Initial analysis of the gabbroic rocks indicates that they crystallised at depths between 12 and 20 km. Gabbroic veins in the peridotites indicate continuously evolving compositions that were intruded as the host rock cooled in the thermal boundary layer.

Most of the deformation during uplift and emplacement was taken up by relatively large shear zones, up to several metres thick in the recovered cores. Surprisingly, no signs of the expected high temperature deformation in the peridotites are observable, for example foliation, subgrain boundaries or trails of spinel grains are absent. Scanning electron microscope (SEM) based electron-backscatter diffraction will be used to investigate whether signs of deformation were simply annealed, but a lattice preferred orientation of olivine and pyroxene is still present. The results will shed light on the dynamics of slow spreading ridges.



Peridotite textures from Leg 209, Hole 1274A are characterized by interstitial orthopyroxene grains with elongate "fingers" protruding between adjacent olivine grains.



Spinel grains (brown) show complex shapes and are often associated with clinopyroxene (blue-yellow-red). This assemblage could be due to exsolution and/or open system crystallisation of migrating melts.

Earth Physics

Introduction

Research into the structure and dynamics of the Earth uses a range of modern physical and mathematical techniques grouped into four themes of Geodynamics, Geophysical Fluid Dynamics, Seismology and the Centre for Advanced Data Inference.

There are considerable interactions between these areas particularly through common use of computational methods. Work in Earth Physics spans observational, theoretical, computational
laboratory and data oriented studies that are all directed to understanding the structure and processes in the solid and fluid Earth and their environmental consequences.

Funding for the Terrawulf PC-cluster was secured from the ARC LIEF process at the end of 2002 and the machine was commissioned during the year, with results beginning to emerge in a number of different areas, as can be seen from the detailed reports.

An RSES strategic initiative linked to the Terrawulf was the establishment of the Centre for Advanced Data Inference in July 2003 under the joint direction of Malcolm Sambridge and Jean Braun.

The observational component of work in Earth Physics in 2003 has continued to be varied, with geodetic studies in Papua New Guinea, a broad-scale seismic experiment surrounding edge of the Precambrian shield and both geodetic and seismic deployments in Antarctica (with
some co-located sites).

Laboratory work is mostly in geophysical fluid dynamics and is frequently coupled to computational studies as in studies of the fluctuations in the thermo-haline circulation of the oceans.

Research in computational geophysics has taken many forms in 2002, with studies of the evolution of mountain belts, development of techniques for adaptive inversion of data sets and new dynamic models for the behaviour of the mantle in 3-D.

Data oriented work has seen the development of new methods for surface wave tomography with a consequent improvement of resolution of seismic structure beneath the whole Australian region with the incorporation of data from western Australia and a reanalysis of all available surface wave paths.

Work on the development of ice-models for the last European and North American glaciations continues with incorporaion of new sea level information.

GEOPHYSICAL FLUID DYNAMICS

INTRODUCTION **RESEARCH PROJECTS**

Geophysical Fluid Dynamics is the study of fluid flows and their roles in transporting heat, mass and momentum in the oceans, atmosphere and Earth's deep interior. In RSES, the research in this field is focused on the exploration of physical processes of importance in three different areas:

• convection, mixing and circulation in the oceans,
• magmatic and volcanic processes, and
• convection of the solid silicate mantle, with its implications for plate tectonics.

Geophysical Fluid Dynamics (GFD) emphasises the importance of dynamical modelling. At the ANU much of the research program in this area is anchored strongly in experimental fluid dynamics and relies on the excellent facilities of a recently constructed 400 sq. m laboratory and workshop area. This is the premier GFD research group and experimental facility in Australia and is well known around the world for its contributions across fluid dynamics, oceanography and 'solid earth' geophysics. The research relies also on advanced computing facilities within the Research School and the Australian Partnership for Advanced Computing (APAC) located at ANU.

Figure 1: Work in progress in the GFD laboratory

The research topics in GFD this year included two key aspects of ocean circulation driven by the surface winds and the global thermohaline circulation of the oceans. Numerical modelling of the wind-driven circulation by A.E. Kiss (an Australian Postdoctoral Fellow, ARC) continued to focus on the nature of instabilities that cause western boundary currents to produce large eddies and separate from the continental boundary.

The dynamics of the global thermohaline circulation of the oceans was addressed by Prof. R.W. Griffiths, Dr G.O. Hughes and PhD student J.C. Mullarney. In this study, attention turned to the purely thermally-driven case, using laboratory experiments with convection forced by a horizontal gradient of surface heat flux (Figures 2 and 8), along with numerical solutions developed on the APAC supercomputing facility. The most important result is a demonstration that heating and cooling, with zero net heat input, at the same horizontal boundary (such as the ocean surface) can drive a vigorous and turbulent overturning circulation. The resulting temperature distribution involves a stably stratified boundary layer (or thermocline) and a very small vertical gradient through much of the interior. Exciting new theoretical ideas on the dynamics and forcing of the ocean overturning circulation were developed based on insights obtained from the experiments.

Figure 2: A movie clip of passive dye tracer in “horizontal convection” in a long box of water. The box is cooled through the right hand half of the base and heated through the left hand half of the base, and has reached thermal equilibrium in which there is zero net heat input. The box is 1.2 m long and 0.2 m high, but only the left 1/3 of the length is shown. Features include small-scale convection in a mixed layer along the heated base of the tank, a narrow turbulent plume ascending on the left hand wall, and a turbulent outflow at the top. (see also Figure 9)

In mantle dynamics, Dr G.F. Davies began work with a three-dimensional code for simulation of mantle convection, in which he has implemented passive tracers in order to follow material parcels as they move around, disperse or congregate in the flow. This well-developed parallelised code represents a major expansion of our capacity to model the dynamics and chemical evolution of the mantle. He also began a major overhaul of his existing two-dimensional code.

Dr R.C. Kerr and Dr C. Meriaux completed a series of experiments that explored the stirring of tracers by sheared mantle plumes when they draw on chemical heterogeneities in their source region (Figures 3 and 4).

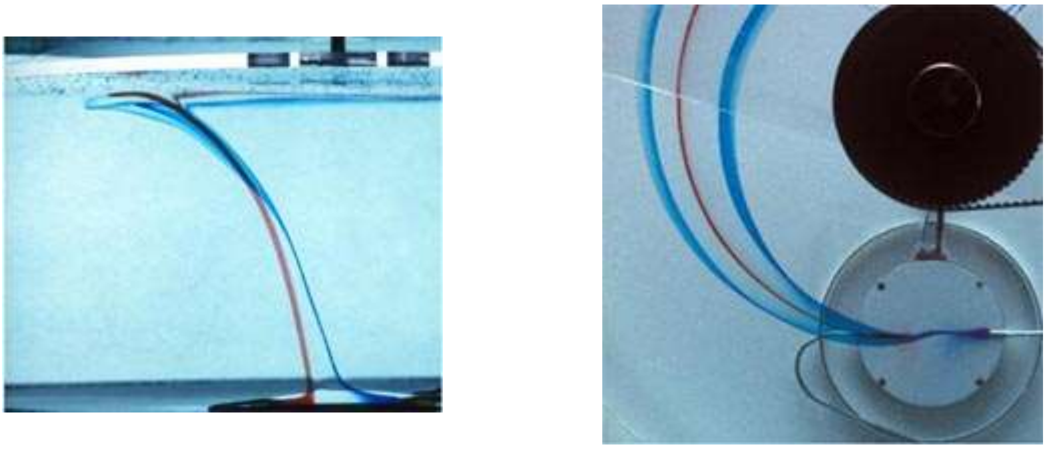


Figure 3: Front and overhead views of a strongly sheared thermal plume, with a high viscosity ratio.

The results of laboratory experiments with the subduction of lithospheric slabs into the mantle, carried out by Prof. C. Kincaid (Visiting Fellow from the University of Rhode Island) and Prof R.W. Griffiths in 2002, were analysed and published in Nature. They showed marked differences in the temperature-depth trajectories for the model slab surface (implying different melting histories for mantle slabs), depending on the relative rates of slab sinking and slab rollback (or trench migration) and are related to the differing patterns of three-dimensional flow in the surrounding mantle.

In volcanology, modelling of lava flow dynamics continued, in collaboration with volcanologist Prof. K.V. Cashman from the University of Oregon. An experimental study of the patterns of solidification of (basaltic lava) flows in simple uniform, sloping channels was completed and the data interpreted to reveal the combined (and somewhat opposing) effects of downstream flow and thermal convection. The flow surface solidified to form either a lava tube containing well-insulated internal flow or only a relatively small amount of mobile solid crust on its surface. Thus a criterion for lava tube formation was established. In other experiments a PhD student, A.W. Lyman, used rapid releases of solidifying viscous and Bingham (yield-strength) fluids to determine the stopping time and distance and the conditions under which these are controlled by yield strength or solidification.

The group continued to benefit from the presence of Emeritus Professor J.S. Turner and enjoyed a 6-month stay by Ms C. Menesquen (a Masters student from ENS, Paris, France). Mr T. Prastowo, from Indonesia, commenced his PhD program in GFD and is working on mixing in exchange flows through straits. Ms M.A. Coman was enrolled in the inaugural year of the Physics of the Earth Honours program at RSES and carried out her thesis project on convection flows in two connected chambers.

Mr D.I. Osmond completed and graduated from the PhD program. PhD student Ms J.C. Mullarney was awarded a Geophysical Fluid Dynamics Summer Fellowship by the Woods Hole Oceanographic Institution, USA, to study at the Woods Hole GFD summer program. Prof. Griffiths and Drs Hughes and Kiss taught the "Dynamics of Ocean Circulation" unit in the new RSES Physics of the Earth Honours program. Prof. Griffiths again taught an undergraduate course on fluid dynamics and ocean-atmosphere dynamics in the Department of Physics and Theoretical Physics, ANU.

The staff, students and visitors all acknowledge the vital contributions of our technical support staff, A.R. Beasley and C.J. Morgan, to our research program. Collaboration continued with Australian Scientific Instruments in commercialisation and sales of the 'Geophysical Flows Rotating Table', and we were awarded funds by the ANU Major Equipment Committee to purchase and equip a new rotating table in 2004. Three new ARC Discovery grants, including two Australian Postdoctoral Fellowships to commence in 2004, were awarded to members of the group.

Dynamical evolution of the mantle in two and three dimensions

G.F. Davies

This has been a year of investment and consolidation, with the acquisition of the numerical code Terra for modelling mantle dynamics in three dimensions and an overdue renovation of my two-dimensional code Conmg. Terra was made available by its authors, Professor Peter

Bunge, now in Munich, and Dr. John Baumgardner of the Los Alamos Scientific Laboratory, who I visited in April and May. The code is capable of including simulated lithospheric plates and of accommodating heavy tracers that can be used to simulate the stirring and settling of subducted oceanic crust. Plates require large viscosity gradients, which the code handles readily, while tracers were already implemented, though they will require adaptation for the long runs planned. Adaptation of the code has proceeded to the point of achieving a preliminary four-plate planet and demonstrating that the tracer implementation will be stable with minor modifications. The code will be used to do three-dimensional simulations of long-term geochemical and isotopic evolution of the mantle, of the kind published last year in two dimensions.

Conmg, having grown over the course of more than three decades, was overdue for a substantial rewrite in order to make it more simple to understand and use and thus to make it less prone to users' error. The major task has been completed, which was to convert it from Fortran 77 to Fortran 90, which permits a much more modular and transparent structure. The code will now be much easier to maintain and modify. In due course other revisions awaiting implementation will be to convert to dimensional equations, to convert to a more robust multigrid flow solver, and potentially to parallelise the code.

Both codes will be used to study the chemical evolution of the mantle. The two-dimensional code has already accomplished preliminary models of the hotter Archean mantle, and these will be extended into a full thermal evolution model. Terra will be used to extend such modelling into three dimensions, either to confirm or extend the results. These fairly ambitious plans will be substantially boosted by the award of ARC funding, to begin in 2004.

The dynamics of thermal plumes in viscous shear flow, with application to sheared mantle plume

R.C. Kerr and C. Mériaux [1]

This year we completed a very extensive series of laboratory experiments aimed at understanding the dynamics of sheared viscous thermal plumes. In the experiments, the plumes were generated by electrical heating of a circular hot plate on the base of a cylindrical tank filled with either glycerol or glucose syrup. The plumes were then sheared by a rotating a Perspex lid at the surface of the fluids. To observe the flow, two small tubes released dyed fluid at opposite sides of the hot plate: either on the upstream and downstream edges of the plate, or on the inner and outer edges of the plate. The flow is characterised by 5 dimensionless parameters: the Rayleigh number, the Prandtl number, the aspect ratio, the viscosity ratio, and the ratio of the lid velocity to the rise velocity of an isoviscous plume. Our experiments have systematically varied these parameters to determine how each parameter affects the flow field.

Our experiments have identified and delineated 3 distinct convective flow regimes. First, at low shear velocities, there is a regime in which the plume is slightly tilted and some of it is able to spread upstream before being advected downstream (Figure 4). Second, at moderate shear velocities, there is a regime in which the plume is moderately tilted and all of it is advected downstream. Third, at high shear velocities, there is a regime in which strong tilting of the plume leads to cross-stream circulation and thermal entrainment of ambient fluid (Figure 3).
Measurements of the steady state profiles of the plumes have shown that they follow a parabolic trajectory as they rise through the linearly sheared fluid, with a vertical rise velocity

that depends on the buoyancy flux and ambient viscosity but is almost independent of the plume viscosity. Measurements have also been made of the upstream and lateral spreading of the plume fluid under the lid. These observations have been compared with similarity solutions derived for the spreading of viscous gravity currents on a rigid surface.

When applied to the Earth, our research provides a host of geophysical and geochemical predictions about the behaviour of mantle plumes. In particular, we demonstrate that geochemical heterogeneities in a plume's source region will result in a heterogeneous plume and in an asymmetrical geographical distribution of geochemical heterogeneities in the erupted ocean island basalts, as is seen in both the Hawaiian and Galapagos Islands. We are also able to predict the convective flow regime and vertical rise velocity of each mantle plume, as well as the extent of upstream spreading and the rate of lateral spreading under the lithosphere.

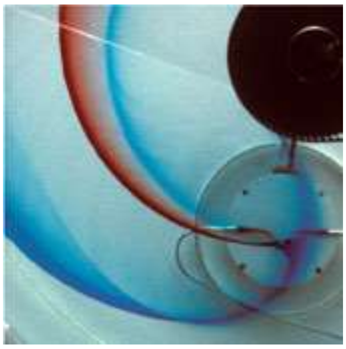



Figure 4: Front and overhead views of a weakly sheared thermal plume, with a high viscosity ratio (see also Figure 3).

1 Institut de Physique du Globe de Paris, France

Patterns of solidification in long lava channels

R.W. Griffiths, R.C. Kerr and K.V. Cashman

In a collaborative project with volcanologist Professor K.V. Cashman of the University of Oregon, and funded by both the ARC and the National Science Foundation, we have explored the behaviour of basaltic lava flowing through long channels, with the aim of understanding the factors influencing the cooling of the flow, and the resulting flow behaviour. Basaltic lava from large eruptions on volcanoes such as Hawaii is often channelled into rivers of melt. Channels are commonly 10-100 m wide and of the order of 10 km in length, with the flow being 2-10 m deep during its active period. Much longer channels, up to 750 km, were important in transporting lavas from large prehistoric flood basalt eruptions and spreading them over broad areas of the Earth. Lava tubes are also common. Tubes arise when the lava surface solidifies and forms a connected roof over the flow. The roof greatly reduces the rate of heat loss and hence enables the lava to flow much greater distances then would be possible if the roof were continuously disrupted or if there were little solid on the surface. These dynamics may be central to the interpretation of the rates and volumes of prehistoric eruptions.

The physical processes that govern the formation of channels and the cooling of continued flow through them are complex. To model lava channels, we use laboratory experiments in which polyethylene glycol (PEG) flows under cold water down a 3m-long, inclined channel. Our flows are laminar, having Reynolds numbers of 0.2 – 70 based on flow depth and centreline speed, thus covering the range estimated for basalt channels. For a constant source volume flux we have found two steady state regimes, depending on the flow velocity and the temperatures of the flow and water relative to the freezing temperature of the PEG flow.

Our results indicate a critical condition for tube formation, dependent on both the rate of down-slope flow and the Rayleigh number (or rate of convective overturn) of the lava. For rapid flows, solid can form a raft along the channel centre-line on the flow surface, with open shear zones along the edges (Figure 5). This is the first time that convective overturn has been shown to be an important process in the behaviour of lava flows. We showed that convection occurs as two organised rolls with axes aligned along the channel and carrying surface material from the centreline toward (and down) the walls. In basalt channel flows, the sidewall shear zones expose incandescent material at the surface (Figure 6) and much of the heat loss is from these zones. The work was published in the Journal of Fluid Mechanic

Figure 5: Time-lapse video movie of a steady state regime of solidification in a sloping channel flow of PEG cooled from above. The flow is viewed from above far downslope (0.8 m to 1.1 m) from the vent. Channel is 8 cm wide. Solid wax is white, liquid PEG is transparent and the base of the tank is black. Flow is from left to right.

Figure 6: Basaltic lava channels active at Puu Oo, Hawaii, in 1983. The red regions along the edges of the channels indicate exposure of hotter melt, whereas the dark surface along the centre of the channels is cooler solid. The channels are typically about 20 m wide.

Modelling the runout time and distance for rapid eruptions
A.W. Lyman, R.W. Griffiths and R.C. Kerr

Motivated by the question of how rapidly large andesite flows may have erupted, novel experiments were designed to explore the behaviour of lava flows having high effusion rates and intermediate composition. Earlier laboratory modelling using slurries having a yield-strength as well as surface cooling and solidification were focussed on slow effusion rates and the formation of highly silicic lava domes. In the new experiments we have worked at the opposite extreme, with polyethylene glycol (PEG) and mixtures of kaolin clay and PEG suddenly released to flow under cold water by removing a dam wall at the end of a horizontal or inclined channel (Figure 7). The distance travelled and the elapsed times can be compared with theoretical scaling law predictions, and we are particularly interested in the final runout length of flows. Experiments in a horizontal channel have been completed, and experiments have begun in sloping channels. We find that the final runout distance can be controlled by either solidification at the flow surface or by the yield strength of the material in the interior of the flow. We have determined scaling laws for the stopping times and distances in the cases of 1) viscous flows that solidify due to surface cooling and 2) isothermal Bingham flows with no cooling, and we have found the transition between these two classes of flow in the general case, from solidification controlled stopping to yield strength controlled stopping. The results will be helpful in placing bounds on the durations of eruptions of large prehistoric andesite flows.

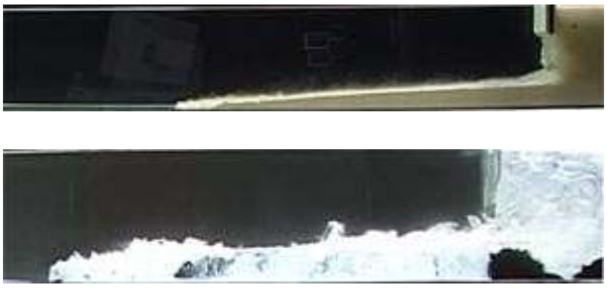


Figure 7: Solidifying gravity currents of a) PEG-kaolin slurry (which has a yield strength) and b) viscous PEG, both under cold water that provides heat loss and solidification at the flow surface.

The dynamics of the ocean thermohaline circulation
R.W. Griffiths, G.O. Hughes and J.C. Mullarney

Laboratory and numerical models are being used to examine critical physical processes that control the global ocean thermohaline circulation. In a simple model designed to examine the balances between buoyancy forcing at the ocean surface, poleward flow near the surface, sinking at high latitudes and vertical diffusion in the interior, a long shallow channel is forced by heating over one half of the base and cooling over the other half the base, resulting in a large-scale ‘horizontal’ convective flow (for practical reasons it is inverted when compared to the oceans). This circulation involves a stable ‘thermocline’ which breaks down to deep convection only near one end of the basin.

A two-dimensional numerical simulation of the thermally driven case has been developed, using the software package FLUENT running on the ANU supercomputing facility (Figure 8). The numerical solutions show excellent agreement with flows observed in the laboratory and the simulation is useful for more complete exploration of the behaviour than is possible in the experiments alone.

We find that at large Rayleigh numbers (strong forcing) the thermocline contains a vertically mixed layer in which small-scale convection is driven by the destabilising boundary heat flux. This mixed layer deepens toward the poleward end of the basin, where its waters feed into the region of bulk vertical flow (a turbulent plume) against the end of the tank (Figure 9). The return flow is the plume outflow, which is turbulent and fills approximately one third of the depth. We conclude that thermal forcing at the one horizontal boundary is capable of driving a vigorous and turbulent circulation that shows many of the key features of the ocean thermohaline circulation.

In parallel, and based on insights from these experiments, we have developed a new model for the ocean circulation that gives preliminary predictions of Antarctic Bottom Water formation rates in close agreement with previous field estimates. From the model we also predict a thermocline thickness and density profile through the ocean depth close to the measured global averages, and we find that the rate of supply of available potential energy from thermal buoyancy forcing alone (neglecting wind and tidal energy sources) can induce an interior diffusivity due to vertical mixing of order 105 m2s-1. This value is consistent with direct measurements by others in the open oceans, but is an order of magnitude less than the diffusivity required by theories for the circulation that impose a uniform vertical upwelling velocity and thereby neglect entrainment of water from all levels into the downwelling regions. Our model represents a major departure from current thinking and suggests that the widespread search for sites of high rates of mixing in the oceans may not yield basin averages as high as previously expected.

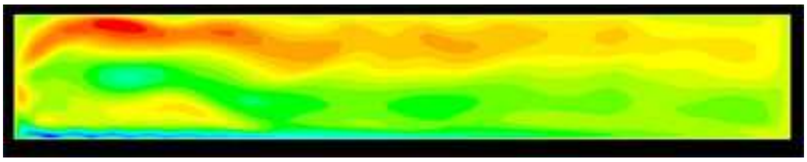


Figure 8: A two-dimensional numerical solution (showing horizontal velocity – red to the right and blue to the left) for the convective circulation in a long box of water which is cooled through the right hand half of the base and heated through the left hand half of the base. Features include small-scale convection above the heated base of the tank, with a narrow plume ascending on the left hand wall, as seen in our laboratory experiments (Figure 9).

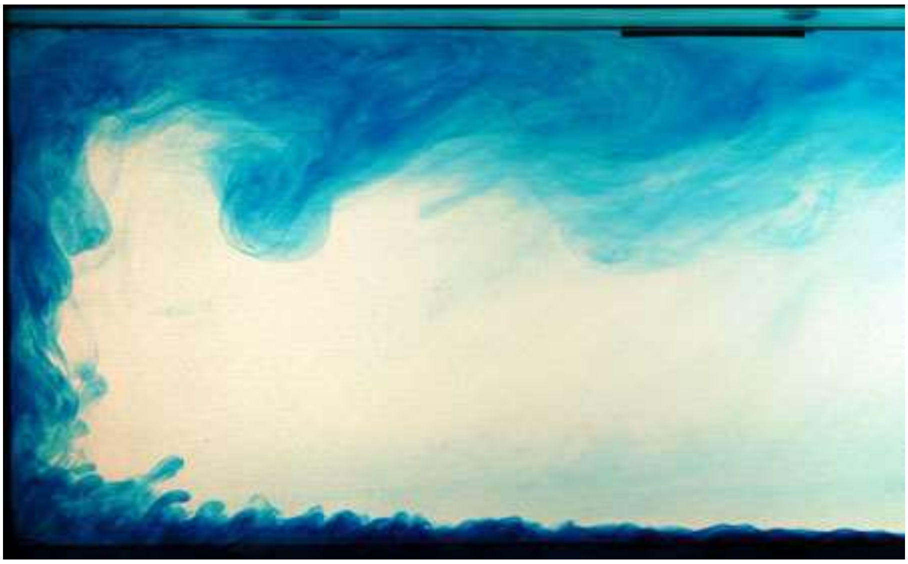


Figure 9: A photograph of dye tracer in the convective circulation in a long box of water

which is cooled through the right hand half of the base and heated through the left hand half of the base. The box is 1.2 m long and 0.2 m high, but only the left 1/3 of the length is shown. Features include small-scale convection above the heated base of the tank, with a narrow plume ascending on the left hand wall. (see also movie clip in Figure 2)

Convection in complex geometries

G.O. Hughes, R.W Griffiths and M.A. Coman

Convection drives flows throughout the atmosphere and oceans, and in many engineering and industrial applications. These flows are driven by buoyancy forces that arise from locally destabilising variations in temperature and/or chemical composition within a fluid. The convective processes are the primary mechanism by which heat, mass and chemicals are transferred between parts of the fluid domain. In many practical situations the confining geometry is complex and has a dramatic influence on the flow. We have examined two such flows this year.

The first project (M.A. Coman, G.O. Hughes and R.W. Griffiths) studied the convection in a two-chamber cavity that was heated and cooled on opposite end walls (Figure 10). The flow was forced to pass through a relatively small gap connecting the chambers. This geometry is relevant to the flow over a sill between ocean basins, or through doorways in buildings. The introduction of the barrier between the two chambers severely disrupts the flow. Our measurements have quantified the reduction of mass exchange and heat transfer through the gap for a range of gap sizes and heating conditions.

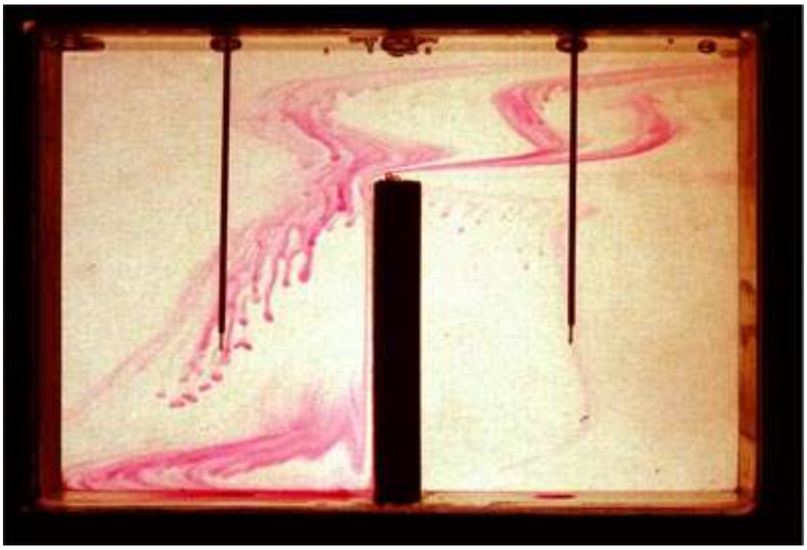


Figure 10: Dye visualization of the convective exchange flow between two connected chambers driven by heating and cooling of the left and right end walls, respectively. A highly asymmetric and complicated flow structure is seen.

The second project (T. Taumoefolau2, S. Paitoonsurikan2, G. Hughes and K. Lovegrove2) examined the convective flow driven by a heated, inclined cylinder that was closed at its upper end. This geometry models the heat loss due to turbulent convection from a cavity receiver placed at the focus of a paraboloidal solar dish that concentrates the solar radiation onto the receiver. The convective flow becomes stronger and more turbulent, with an accompanying increase in heat loss from the receiver, as the cavity axis approaches the horizontal (Figure 11). An understanding of the flow will provide design pointers for improving the efficiency of solar energy collection.

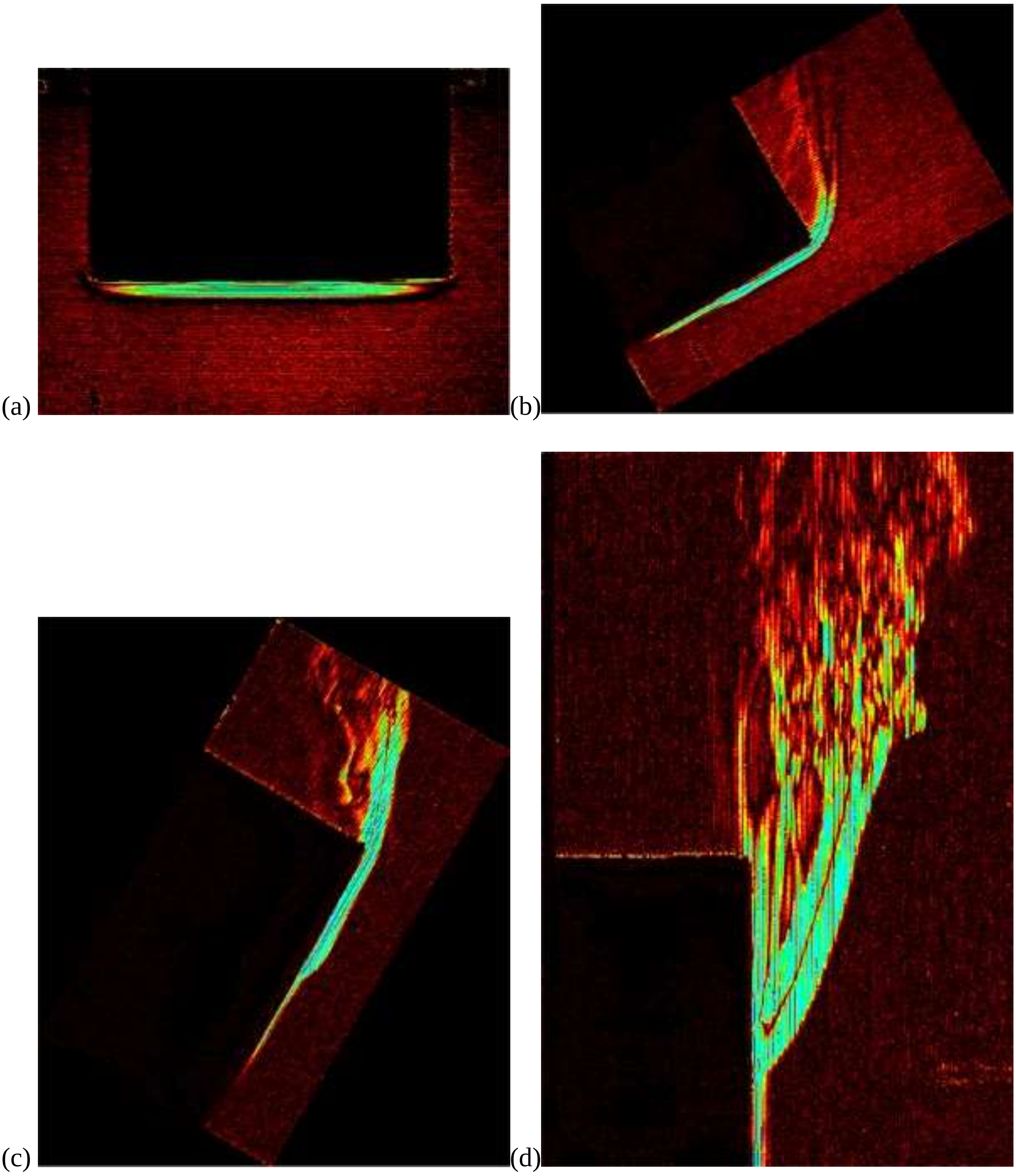


Figure 11: Synthetic-schlieren visualization of the turbulent convective flow out of a model solar cavity receiver (the dark rectangle) for a range of angles (a) 90º, (b) 60º, (c) 30º and (d) 0º between the cavity axis and the horizontal.

2 Centre for Sustainable Energy Systems, Department of Engineering, ANU

'Optimal' vortex rings and aquatic propulsion mechanisms
J.S. Turner and P.F. Linden

A theory of vortex ring production, using the technique of forcing fluid impulsively through a pipe, has previously been presented in the fluid dynamics literature. As the length to diameter ratio L/D of the injected plug is increased, the diameter of the vortex core also increases, and a unique core size is identified for each L/D. These results have now been used to explain the mechanisms of propulsion of various marine organisms; a paper in press is aimed at testing the model using recently published observations and bringing these ideas to the attention of marine biologists. Fish swim by flapping their tail and other fins. Other sea creatures, such as squid and salps, eject fluid intermittently as a jet. We have discussed the fluid mechanics behind these propulsion mechanisms, and have shown that both produce optimal vortex rings, which give the maximum thrust for a given energy input. Fish optimise both their steady swimming and their ability to accelerate and turn by producing an optimal ring with each flap of the tail or fin. Salps produce vortex rings directly by ejecting a volume of fluid through a rear orifice, and these are also close to optimal in our sense; squid, on the other hand, produce a long backward jet that uses more energy but enables them to achieve more rapid acceleration. An important implication of this work is that the repetition of vortex production is not necessary for an individual vortex to have the 'optimal' characteristics.

Dynamics of ocean circulation driven by surface wind stress
A.E. Kiss

At mid-latitudes the large-scale mean horizontal circulation of the upper ocean takes the form of large recirculations ("gyres") spaning the width of each ocean basin. In subtropical gyres the recirculation consists of a slow equatorward drift driven by the surface wind stress, which is returned by a narrow, rapid boundary current at the western side (the Gulf Stream in the northern Atlantic is the best-known western boundary current, but similar currents are found in all ocean basins, such as the East Australia Current in the southwest Pacific). The western boundary currents (WBCs) of subtropical gyres form an important part of the global climate system by carrying a large amount of heat from subtropical to subpolar latitudes.

Dr Kiss is utilising simplified laboratory and numerical models to investigate the essential physical processes that control the wind-driven circulation and its variability. Models with and without bottom topography are being used in order to study the influence of continental slopes on WBC behaviour. Numerical modelling is implemented using a modified quasigeostrophic formulation (Kiss, Ocean Modelling, 2003) that remains valid when depth variations are large.

Dr Kiss has continued to investigate the dynamics of WBC separation. Oceanographic observations and the output of high-resolution ocean models suggest that the potential vorticity "crisis" mechanism identified in a highly idealised model (Kiss, Journal of Marine Research, 2002) may have relevance to separation in the real oceans, and capturing this process may be a crucial requirement for realistic WBC separation in numerical models.

Investigation continued (in collaboration with C. Menesguen) into the instabilities of WBCs and the way in which they are affected by periodic changes to the wind forcing. This employed both laboratory work (using DigImage particle-tracking software) and numerical modelling. The basic flow displayed periodic eddy-shedding under steady wind forcing, and a survey was undertaken of the parameter space defined by the frequency and amplitude of the periodic forcing perturbation. The survey revealed instances of nonlinear resonance in which the response of the flow was locked onto a rational multiple of the forcing period. These resemble the “Arnol’d tongues” arising in forced nonlinear oscillators, but differ in important ways due to the presence of additional oscillatory modes in the fluid system.

The role of continental shelves in the overall potential vorticity balance has also been investigated. The recovery of potential vorticity lost to the wind occurs via lateral or bottom friction in rapid currents along the boundary in regions where depth contours intersect the boundary (or equator). However this recovery cannot happen in a basin encircled by continental slopes, since all depth contours are closed loops which do not intersect the boundary. Dr Kiss has used numerical modelling to investigate the way in which an overall potential vorticity balance is achieved in this case (Figure 12), and also developed a general theory for finding the lowest-order flow in such geometries. These insights were used to explain the laboratory observations of Griffiths and Veronis (1997). A manuscript detailing this work has been submitted to the Journal of Marine Research.

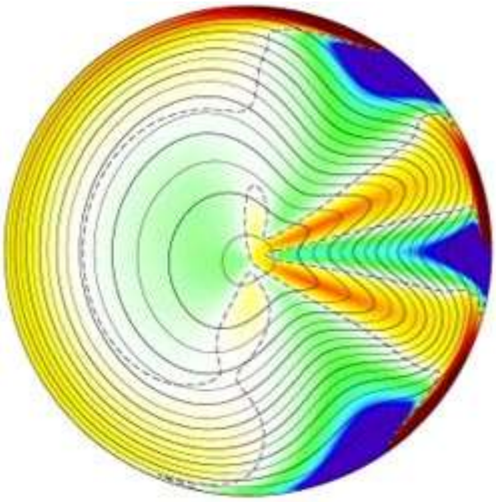


Figure 12: Loss (green/blue) and recovery (orange/red) of potential vorticity in wind-driven flow over closed depth contours. The black lines are streamlines, which are closely aligned with isobaths; the dotted lines separate regions of potential vorticity loss and recovery.

Earth Physics - Geodynamics

RESEARCH CONTRIBUTIONS - GEODYNAMICS GROUP

With the formation of the Centre for Advanced Data Inference (CADI) in Earth Physics, the Geodynamics Group’s research now focusses on two principal areas. (i) the geodetic monitoring of crustal deformation and the study of the underlying tectonic processes, and (ii) the interactions between ice sheets and sea level during recent glacial cycles.

The crustal deformation studies involve two long term observation projects, both partly funded by ARC Discovery Grants. One is in Papua New Guinea where the initial goal is to develop a comprehensive model of the kinematics of the crustal motion using GPS. 2003 fieldwork included the reobservation of a transect along the western border and results include estimates of shortening across the highlands. A substantial basic network has now been established and repeat observations at two or more epochs are now available from many sites that give a quite detailed picture of the deformation of PNG in response to the convergence of the Australia-Pacific plates (Figure 1). From the equator to the pole, the second observation program is the monitoring of the time dependence of geodetic rock-sites in Antarctica, in and around the Lambert Glacier, with the objective of determining the glacial rebound signal. This project is also partly funded by the Australian Antarctic Division. The fourth site, at Mt Komsomolsky, some 800 km inland, was installed in the 2002–2003 season and preliminary site-velocity estimates were obtained for 2002–2003.

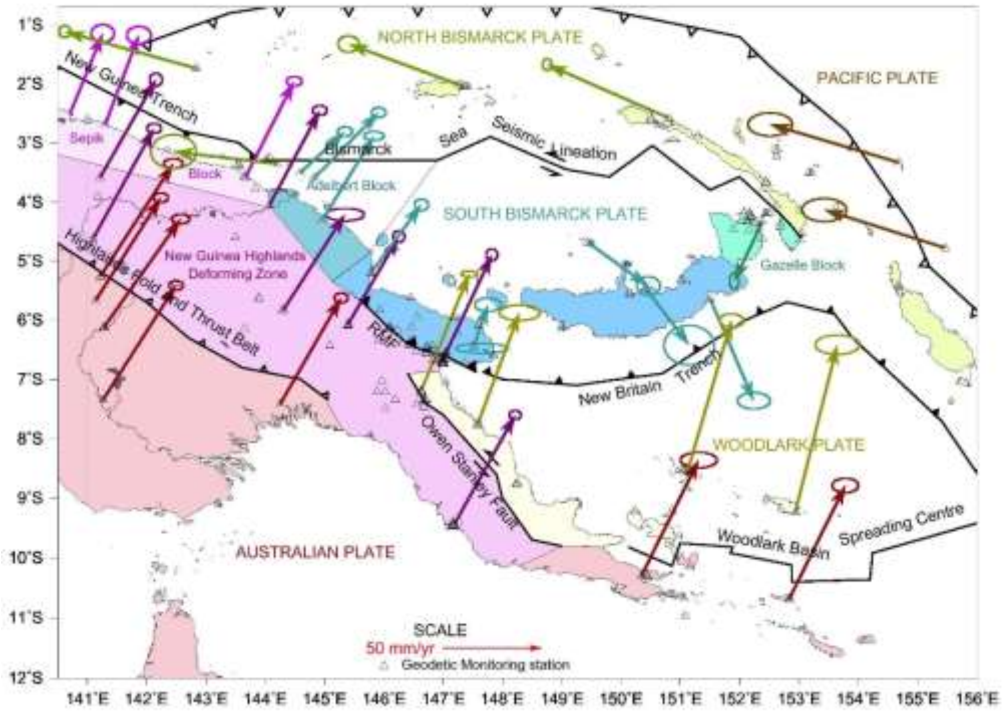


Figure 1: Plot of the velocity field and tectonic setting of PNG. The velocity fields in the Gazelle Block and the Ramu-Markham Fault Zone have been omitted for the sake of clarity.

Another long-term observing program is the measurement of the time-dependence of gravity in a joint experiment with the National Astronomical Observatory of Japan at Mizusawa using a superconducting gravimeter. The instrument located at the ANU’s Mount Stromlo Observatory survived the destruction of the January 2003 fires but, despite the destruction of the building in whose basement it was housed and the loss of power, the instrument sensor continued to function throughout and loss of recorded data was minimal.

The sea level and isostatic rebound research focussed on three areas in 2003: the development of new ice models for the last European and North American glaciations, the establishment of the change in ocean volumes from Late Holocene to the present, and constraining sea levels and ice sheets during the period between the last two major glaciations, including recent time. This research is also partly funded by ARC Discovery Grants and by the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE-CRC). This latter work includes the analysis of speleothems from now-submerged caves to establish the timing of marine and terrestrial growth. This work, using uranium series dating and trace element analyses, is being carried out by Dr Andrea Dutton and Mr Giovanni Scicchitano, in cooperation with the environmental Geochemistry Group in RSES. The samples worked on are from two caves in Italy and the project is a cooperative one with ENEA and the University of Catania.

Work on recent sea level change includes collaboration with scientists from the ACE-CRC in analysing and interpreting instrumental measurements (tide gauge and satellite altimetry). The RSES contribution includes evaluation of geological, glaciological and hydrological contributions to present ocean volume and is being carried out by Ms Gisela Estermann.

In 2003, Dr Douglas Christie returned to RSES from the Comprehensive Nuclear Test Ban Treaty Organisation, in Vienna, to continue his infrasonics research.

The following short reports represent a cross-section of the group's activities for 2003.

Tectonic Studies in Papua New Guinea

P. Tregoning, R. Stanaway, H. McQueen and K. Lambeck

In 2003, a major GPS field campaign was undertaken in Papua New Guinea spanning most of the mainland. There were several objectives of the work:

1. To reobserve a transect of sites running along the western border of PNG from the coast, across the highlands to the southern flood plains. The objective is to measure the distribution of shortening through the highlands caused by the collision of the Australian Plate with the New Guinea land mass.

2. To reobserve a network of sites in the Schouten Islands and in the region of Wewak. Some of these sites were affected by co-seismic displacement after the September 2002 Wewak earthquake, while other sites had been observed only once before.

3. To continue the monitoring of the post-seismic motion in the New Ireland/New Britain regions.

4. To reobserve a network in the Lae regions as part of monitoring deformation across the Ramu-Markham Fault.

There is ongoing relaxation occurring after the November 2000 New Ireland earthquakes. The co-seismic displacements estimated from GPS analyses have been inverted to model the slip distribution on the Weitin Fault strike-slip event and the two subsequent thrust events that occurred on the New Guinea Trench. The inversion for fault location and slip distribution is non-unique for the two thrust events because the GPS co-seismic offset data are not able to separate the contributions of each thrust event (both occurring south of the GPS network). Aftershocks were relocated using the Arrival Pattern method developed at RSES (Nicholson et al., 2002) in an attempt to better constrain the locations of the thrust earthquakes. The research is ongoing.

Antarctic Glacial Isostatic Rebound

P. Tregoning, K. Lambeck, H. McQueen and R. Decrevel

In the 2002/03 Antarctic summer season one new remote GPS site was installed at Komsomolsky Peak (75.2S 63.6E) and the equipment at Dalton Corner was upgraded. Both these sites were equipped with Iridium satellite modems provided under the US Iridium Project to permit data transmission back to RSES while the sites were unattended. This has worked successfully. The sites at Beaver Lake and Landing Bluff were serviced but remain essentially the same, with satellite phone communications continuing via the Inmarsat Satcom-B system.

All four sites recorded GPS data until early May 2003 and all four sites successfully awoke from hibernation in early spring. The two sites equipped with Ashtech microZ receivers recommenced recording GPS data in late September and were operating when revisited in the 2003/04 summer season. We have now demonstrated that it is possible to record GPS observations over 200 days per year with our solar-powered systems.

The analysis of the recorded data shows temporal height variations of up to 20 mm, with the signals at all sites showing significant correlation. Furthermore, it was found that receiver firmware changes at the GPS receivers at Mawson and Davis in 2000 (operated by Geoscience Australia) have increased the number of low elevation observations, which has subsequently introduced a bias in the height estimates (Tregoning et al., 2003). Relative heights calculated between sites have a much smaller scatter and are more likely to provide useful estimates for geophysical interpretation. At this stage it appears that there is less than 1 mm/yr relative vertical movement between Davis, Beaver Lake, Landing Bluff and Dalton Corner, but Mawson appears to be uplifting at around 2 mm/yr relative to all of these sites.

A Dynamic Geodetic Datum for Papua New Guinea

R. Stanaway and P. Tregoning

Significant advances have been made in the accessibility and accuracy of positioning technology in recent years, especially with GPS. Tectonic deformation impacts on the use of geodetic datums in tectonically active countries, such as PNG. We have developed a strategy whereby national geodetic datums and survey networks in tectonically active regions can include a geodetic velocity field, strain models and other non-secular offset data in order to maintain the integrity of the datum. A least-squares datum adjustment program has been developed which includes these dynamic elements, to enable geodetic surveyors to reduce geodetic measurements made in dynamic local networks to a reference epoch. The program has applications for the monitoring of geophysical hazards and localised crustal deformation.

RSES's ongoing geodetic monitoring of crustal deformation in PNG has been closely allied with geodetic activities conducted by other PNG institutions, including the National Mapping Bureau, the PNG University of Technology, and the Rabaul Volcanological Observatory. GPS observations from a network of over 200 geodetic stations in PNG gathered by RSES and these institutions, have been collated and analysed in order to examine the effects of tectonic deformation on the PNG Geodetic Datum. The availability of geodetic observations from these institutions has proved to be highly beneficial in the understanding of the complex tectonic setting in PNG, particularly across the Highlands Fold and Thrust Belt, the Lae urban area, and the region encompassed by the Gazelle Peninsula and Southern New Ireland. The rugged and inaccessible nature of much of PNG supports a collaborative approach for the gathering of geodetic data, as the data are useful for both geophysical and practical geodetic applications, including land surveying, mapping, and navigation. RSES has funded several large GPS campaigns in PNG, and the physical infrastructure, data archive and analysis resulting from these campaigns forms an ideal basis for a Geodetic datum and geodynamic monitoring network for PNG (See Figure 1).

Improved ice sheet model for Scandinavia for the last glaciation

K. Lambeck and A. Purcell

The last ice age of Fennoscandinavia continues to have geological and geodetic repercussions across the region despite the ice having retreated almost 10,000 years ago. The most obvious consequences are the land uplift along both sides of the Gulf of Bothnia and the concomitant retreat of the sea. More subtle changes include the present day tilting of large inland lakes and sea shorelines and the vertical and horizontal displacements of the earth’s crust, measured with geodetic techniques, and the associated changes in crustal stress. The geological and geodetic signals provide constraints on two important classes of parameters that define (i) the Earth’s rheology, and (ii) the repeat history of the Scandinavian ice. Through a careful exploration of the combined parameter space, exploiting the spatial and temporal variability of the response signals (sea-level change, tilting, strain) it is possible to establish constraints on both groups of parameters and to develop physically plausible models that are not just descriptive but that also have a predictive capability.

Mantle rheology. From inversions of an improved geological observational data set (including the Baltic Ice Lake shorelines), the mantle rheology can be adequately represented by a three-layer model of lithospheric thickness Hl, upper mantle viscosity hum, lower mantle viscosity hlm (with realistic radial dependence of density and elastic moduli) with values of

Hl ¼80–90 km
hum (2.5–3)1020 Pa s
hlm ¼(7–30)1021 Pa s.

Curiously, the inversion of geodetic data (including tide gauges, lake tilting and GPS) yields somewhat higher values for hum (4.25 ± 0.25) 1020 Pa s. These values represent "effective" values and if substantiated by the next-iteration solution, points to possible non-linear behaviour of the mantle response.

Crustal Stress. The state of stress of the planet’s surface is the sum total of many processes but the one that, in areas subject to glaciation, changes on relatively short time scales is that induced by the changes in the surface loads of ice and water. The rebound model-development has reached a stage where it is possible to predict realistic regional stress patterns. We use as a measure of the incremental stress the change in the Fault Stability Margin (FSM), ÐFSM, resulting from the change in surface load. In the absence of other force fields, the crust beneath the ice is stabilized but it becomes less stable in regions outside of the loaded area. When the ice retreats the crust beneath the former ice becomes less stable and existing faults may be reactivated. Detailed modelling has been carried out for Finland and for much of the central area the deviatoric FSM reaches its maximum values at about 10,000 years ago but the magnitudes relax with time and today are only about 20% of their peak values (See Figure 2). Thus any failure within the crust triggered by glacial loading and unloading will have occurred preferentially when the region first became ice free and the potential for reactivating faults today must be considered as negligibly small.

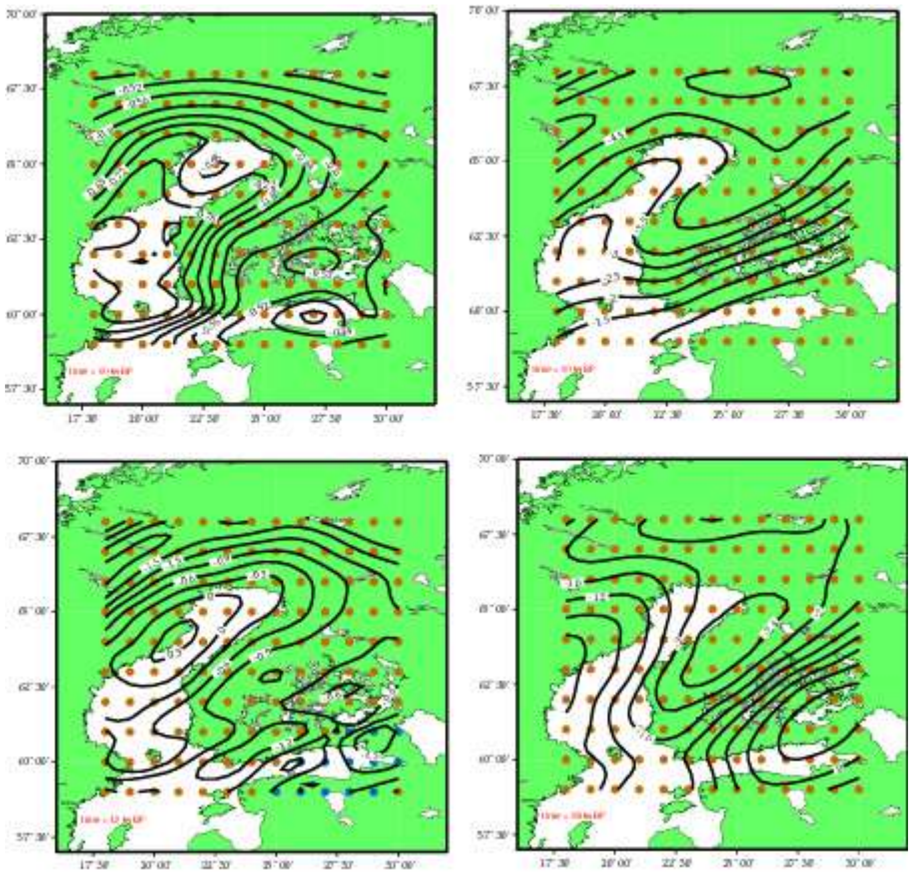


Figure 2: The ΔFSM at the surface for four epochs (kaBP = 1000 years Before Present). The magnitudes are given by the contours and the style of faulting is given by the colour coding (orange-brown thrust; blue normal). Only for T = 12 ka BP are there regions where the style of faulting is different from thrusting.

The Revised Ice Sheet. Figure 3 illustrates the ice thickness at three epochs as inferred from the inversion of the geological data with the ice margin locations constrained by field data. The maximum ice, at the time of the Last Glacial Maximum (LGM) occurred over the northern part of the Gulf of Bothnia with a value of ~2700 m. A secondary maximum of ~2400 occurred over southern-central Sweden. By 18.8 ka BP considerable thinning of ice occurred over the Gulf of Bothnia and we speculate that this caused the late ice advances over the northern European Plain and Denmark. This rapid decrease in ice volume at ~19 ka BP appears to be a robust feature all the inversions.

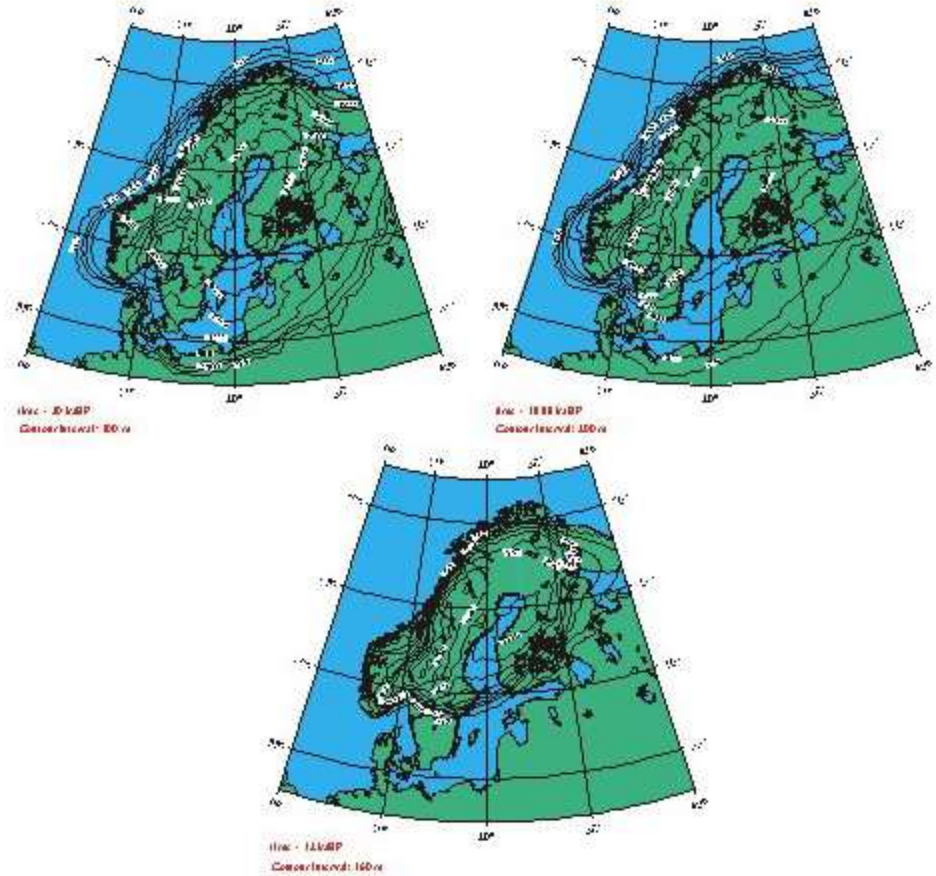


Figure 3. Ice thickness maps for three epochs: (a) the time of the Last Glacial Maximum at 20 ka BP. (b) at ~19 ka after the occurrence of a substantial thinning of the ice, (c) at the time of the Younger Dryas between about 12.8 and 12ka BP.

Ancient Roman fish tanks and present-day sea level change

K. *Lambeck, A. Purcell, M. Anzidei and F. Antonioli*

An issue of some importance is whether the present-day observed sea level change is representative of the past century, the typical duration of the instrumental record, or whether it is representative of a longer interval. If the latter, then the causes could be human-induced. A recent re-evaluation of tide gauge records by Church et al. (J. Climate, in press) indicates that the sea-level rise globally has been ~1.8 ± 0.2 mm/year for the past 50 years. A few isolated tide gauge records suggest that this rise may have started towards the end of the 19th century but the data is limited. As part of our global sea level studies we have searched for sea level indicators for the first few millennia that may be used to constrain ocean volumes. Archaeological remains of fish tanks from the Roman epoch (100 BC to 100 AD) have provided particularly useful indicators because water exchange between the tanks and the sea is tidally controlled and because the tidal range in the Mediterranean is small (see Figure 4).

A substantial number of fish tanks have been examined south and north of Rome and they provide a consistent estimate of local sea level for 2000 years ago. Control on any tectonic component is provided by the observed height of the Last interglacial Shoreline and the glacio-hydro isostatic contribution (the remnant signal from mainly the Northern European deglaciation) is constrained by geological data extending back to ~14,000 years ago in Italy. The result provides an estimate of eustatic sea level at 2000 BP.

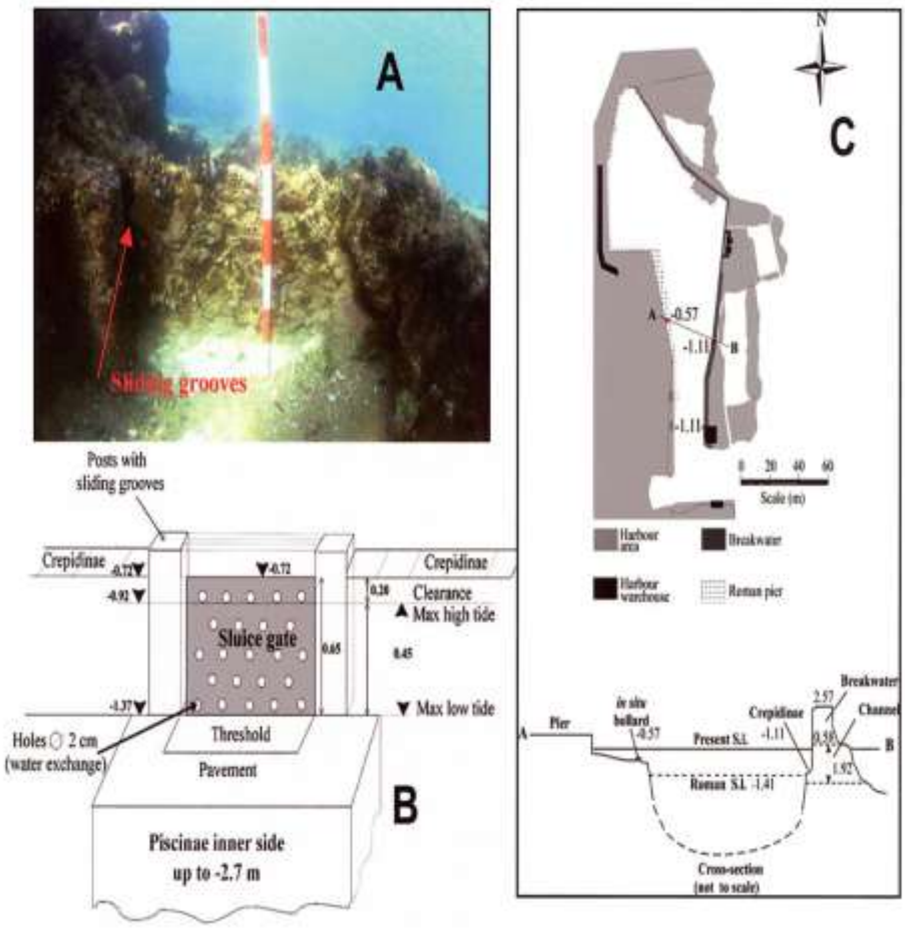


Figure 4 : (A) underwater photo of the in-situ sluice gate at La Banca. The complete gate consist of: (i) a horizontal stone surface that defines the threshold with a groove to receive the gate; (ii) two vertical posts with grooves to guide the movement of the gate; (iii) an upper stone slab with horizontal slot to extract the gate; and (iv) the gate itself, ~65 cm high, with small holes for water. In this illustration the gate is partially covered by sand and the bright zone is that part of the gate that has been cleaned of sand and biological growth. The threshold, covered by sand, lies ~10 cm below the measuring rod that is calibrated at 10 cm intervals. (B) Sketch of the channel sluice gate with sliding posts, threshold and lowest level crepidinae as viewed from within the fish tank. The top of the sluice gates coincides with the elevation of the lowest level foot-walks and corresponds to a position above the highest tide.11 In this example, the lowest foot-walk is now 0.72 m below the sea surface at the time of measurement and the threshold is 1.32 m below present sea level. (C) Plan and cross-section of the Ventotene Roman harbour indicating structures that identify limiting values to sea level (s.l.), including the lowest level foot-walks and bollards carved into the rock. Roman time s.l. is ~1.40 m below present mean sea level (m.s.l.), the now-submerged bollard would have been at ~0.85 m above m.s.l. and the lowest level foot-walks are estimated to

have been ~0.30 m above m.s.l. The channel through the breakwater at B for flushing the harbour remained operational at all tidal levels.

Four tide gauge records exist for the same section of coast from which a composite record of modern local sea level change has been constructed. Corrections for the isostatic and tectonic signals then lead to an estimate of the present-day eustatic change (the change in sea level due to changes in ocean volume, caused either by addition of water into the oceans or by changes in water temperature). Extrapolation of this rate back in time results in the Roman sea levels being reached only after about 100 years and the conclusion is that the present-day eustatic sea level change is a recent phenomenon and is not part of a longer-term "natural" background signal.

Infrasound and the Comprehensive Nuclear-Test-Ban Treaty

D.R. Christie

The infrasound component of the International Monitoring System (IMS) is used to detect and locate atmospheric nuclear explosions as part of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty. In contrast with seismology and hydroacoustics, research in the field of atmospheric infrasound has largely been neglected during the last 30 years. This situation has changed dramatically with the on-going establishment of the 60-station IMS global infrasound-monitoring network. The prospect of data of unprecedented quality from a global network, coupled with the recognition that the field of infrasound can profit greatly from recent advances in electronics and computing, has led to a renaissance in the field of infrasound. New infrasound research programs have been established at a large number of universities and other institutions around the world. Fundamental problems in the field of infrasound that originally appeared to be intractable can now be tackled with confidence and the results can be applied to a wide variety of geophysical studies in the atmosphere.

Work on the 60-station IMS infrasound-monitoring network is proceeding rapidly. Approximately 40% of the stations in the network have been completed and are transmitting continuous data via satellite to the International Data Centre in Vienna Austria. Work has started at nearly all of the other stations in the global network and it can be anticipated that 60% of the stations will be in operation by the end of 2004.

The IMS infrasound-monitoring network is far larger and much more sensitive than any previous infrasound monitoring network. The global coverage of the IMS infrasound network provides a unique opportunity for high-resolution time-dependent tomographic studies of atmospheric dynamics and structure, studies of acoustic wave propagation on a global scale and detailed studies of atmospheric transport processes.

While there has been considerable progress during the last few years in the technology of infrasound monitoring, a number of important problems remain unresolved. All of these problems have a potentially serious detrimental influence on the performance of the IMS monitoring system. The detection and location capability of the infrasound monitoring system needs to be improved significantly. Work needs to be undertaken to develop optimal array designs and reliable detection algorithms. Many of the stations that will be installed in the next few years are located in high-wind environments. These stations will be subject to unacceptably high background noise levels. In addition, high levels of background noise during the daytime seriously limit the performance of a substantial number of existing stations in the IMS infrasound network. Further fundamental research needs to be carried out to identify all components in the infrasound noise spectrum and techniques need to be developed to reduce background noise levels to acceptable levels. The source of most infrasound signals observed at IMS stations is largely unknown. Research needs to undertaken to develop procedures that can be used for the reliable identification and discrimination of infrasonic signals. This research should include the development of propagation models that can accurately describe the complex evolution pattern of infrasonic waves at regional distances. The research on infrasound in Earth Sciences will be largely focussed on an attempt to resolve these problems in support of the CTBT monitoring program.

Data from the global infrasound monitoring system can also be used in a number of practical applications. Perhaps the most important application at the present time is the use of infrasonic data to provide a timely warning to the aviation community of the presence of volcanic ash clouds in the lower stratosphere. Ash deposited in the lower stratosphere by a volcanic explosion represents a very serious hazard to aviation. The early identification of areas with hazardous volcanic ash clouds remains an unresolved problem. Even after nearly a decade of work on this subject, it is recognized that complete avoidance of areas with potential ash clouds is the only guaranteed way of ensuring aircraft safety. Earlier work carried out in Earth Sciences on this subject indicated that data from the IMS infrasound network could be used to provide a timely advisory warning of all significant volcanic explosions that may inject volcanic ash into the lower stratosphere. Negotiations between the Comprehensive Nuclear Test-Ban-Treaty Organization and the International Civil Aviation Organization have been underway for some time to provide IMS infrasound data for a timely volcanic ash advisory warning system for aircraft. It is planned to extend the earlier work on the volcanic ash problem to establish a realistic measure of the effectiveness of the use of infrasound as a means for reliably monitoring global volcanic activity and also to provide a preliminary model that will allow a direct assessment of volcanic ash hazard as determined from the morphology of observed infrasound signals from volcanic explosions.

Estimating neotectonic movement in southern Victoria using cosmogenic burial dating

Fabel, D., Gardner, T., Webb, J., and Fink, D.

The aim of this project is to determine the age of several tectonically displaced sedimentary deposits in the Cape Liptrap area of southern Victoria using cosmogenic burial dating.

The geomorphology of this region testifies to the profound influence of faulting in shaping the landscape. While quantitative constraints on the displacement history of these faults are not yet available, dramatic evidence for recent movement is indicated by kink-bands in ~125,000 year old cemented dune limestone near Cape Liptrap. There are no numerical ages for tectonically offset older sedimentary deposits that could provide further constraints on the age and rate of neotectonic movement. We are using a relatively new chronological technique, cosmogenic burial dating, utilising the radioactive decay of cosmic-ray produced Be-10 and Al-26 in buried quartz, to estimate these ages. Based on the differential decay of the in-situ produced cosmogenic nuclides Be-10 (radioactive half-life = 1.51 ± 0.03 m.y.) and Al-26 (0.705 ± 0.02 m.y.) in quartz, the technique is widely applicable to dating up to approximately 5 million year old quartz-rich sediments. The ratio Al-26/Be-10 in quartz is dominated by the nuclide production rate ratio for all but the very slowest erosion rates where radioactive decay starts to become significant. Because Al-26 and Be-10 are produced at a constant ratio, independent of absolute production rates, the Al-26/Be-10 ratio in quartz is robust against temporal production rate variations. In a steadily eroding landscape, quartz grains within the soil and sediment contain Al-26 and Be-10 concentrations in this predictable ratio. If these quartz grains are subsequently buried, for example deep within a sedimentary deposit, then cosmogenic nuclide production within those grains is attenuated by the overburden and inherited Al-26 and Be-10 concentrations diminish by radioactive decay. Because Al-26 decays more rapidly than Be-10, the Al-26/Be-10 ratio decreases exponentially with time. By measuring the Be-10 and Al-26 concentrations using accelerator mass spectrometry, the current Al-26/Be-10 ratio in the sample can be determined, and the burial time calculated.

Preliminary results indicate that coarse sand and gravel overlying horizontally cut marine platforms at elevations ranging from 4 – 18 m above present mean sea level were deposited between 630 ka and 1.15 Ma. Although the results are intriguing, they are complicated by post burial cosmogenic nuclide production. We are currently evaluating methods of obtaining reliable ages for samples with complex burial histories.

Tracing the post-Younger Dryas retreat of the northern Fennoscandian Ice Sheet using cosmogenic radionuclide exposure ages

Fabel, D., Stroeven, A., Dahlgren, T., Harbor, J., Hättestrand, C., and Kleman, J.

The aim of this project is to determine the rate of retreat of the Fennoscandian ice sheet from the Younger Dryas limits in northern Norway to the terminal limits in the northern Swedish mountains (Figure 5). The north to south retreat history is poorly constrained due to a lack of datable material. We are working to provide new constraints on the timing and pattern of deglaciation using cosmogenic nuclide apparent exposure ages.

The work involves mapping and dating depositional and erosional geomorphological features related to the former ice sheet margin. Because the ice sheet initially had warm-based conditions close to its margin, the dominant morphology is one of eskers and aligned lineation systems, such as crag-and-tails. Abundant meltwater eroded bedrock locally to considerable depth and deposited fans or deltas perched above current local base levels (Figure 5). However, subglacial conditions during final deglaciation were generally cold-based, inhibiting the formation of eskers and lineation systems, although there are widespread (lateral) meltwater channel erosional imprints and occasional plucking scars.

Each geomorphological setting was examined for its value in providing deglaciation ages, testing the initial assumption that, (i) abundant erosion on crags of crag-and-tails, across transverse erosional scarps, and in meltwater channels has exposed bedrock surfaces without a prior exposure history and (ii) depositional features contain embedded boulders without a prior exposure history (on the surfaces of eskers and deltas, and erratics). Preliminary results indicate that meltwater channels, transverse erosional scarps, and erratics yield deglaciation ages that are consistent with the limited ages provided by other methods, but that crag-and-tails yield apparent exposure ages that are too old, presumably because of a prior exposure history that was not fully removed by glacial erosion.

Figure 5. (A) Crag and tail. Ice flow was from right to left. (B) Perched glaciofluvial delta dissected by meltwater channels. (C) Esker

Basal thermal regimes of former ice sheets constrained using cosmogenic nuclides

Fabel, D., Stroeven, A.P., Harbor, J., Kleman, J., Clarhäll, A., Elmore, D., Fink, D.

The motion of ice sheets occurs as a result of internal deformation and basal sliding, which includes direct sliding of ice over its substrate, internal deformation in the substrate, and enhanced deformation in basal ice (Paterson, 1994; Benn and Evans, 1998). Basal sliding is ineffective where basal ice is below the pressure melting point (cold based, or frozen bed conditions) and most effective where basal ice is at the pressure melting point (warm based, or thawed bed conditions), so that water is present (Cuffey et al., 2000). Reconstructions of the last glacial maximum Fennoscandian and Laurentide ice sheets are extremely sensitive to assumed basal thermal patterns (Kleman and Hättestrand, 1999; Marshall et al., 2000), resulting in estimates of ice thickness that vary on the order of 1 km (Clark et al., 1999).

Recognition of subglacial boundaries between sliding and frozen-bed areas for former ice sheets is typically based on distinct morphological contrasts between areas with glacial landform assemblages and relict areas showing little alteration of pre-existing features. However some of these boundaries, especially on continental shield areas, are clearly visible from air photos but have minimal topographic expression (Figuure 6). Understanding the chronology and erosional development of such boundaries is important to provide insight into the pattern and persistence of basal conditions under ice sheets.

Geomorphic evidence and cosmogenic radionuclide concentrations of bedrock outcrops on either side of sliding boundaries on low-relief upland plateaus in northern Sweden (Figure 6) are consistent with negligible erosion in relict landscape (frozen bed) areas due to the last glaciation, but also indicate very limited erosion in the sliding areas. This pattern and magnitude of landscape modification indicates that sliding was short lived in these areas, likely as a transient phase during deglaciation. These sites demonstrate that short periods of sliding are in some cases sufficient to produce landscapes that are recognized as ‘glacial’ from air photos. Thus regions of sliding identified on shield areas must be viewed as the cumulative total area that has experienced sliding at any time during a glaciation. The actual extent of sliding areas during most ice sheet phases is presumably considerably less than this cumulative total, which has important implications for establishing appropriate basal boundary conditions for ice sheet reconstructions.

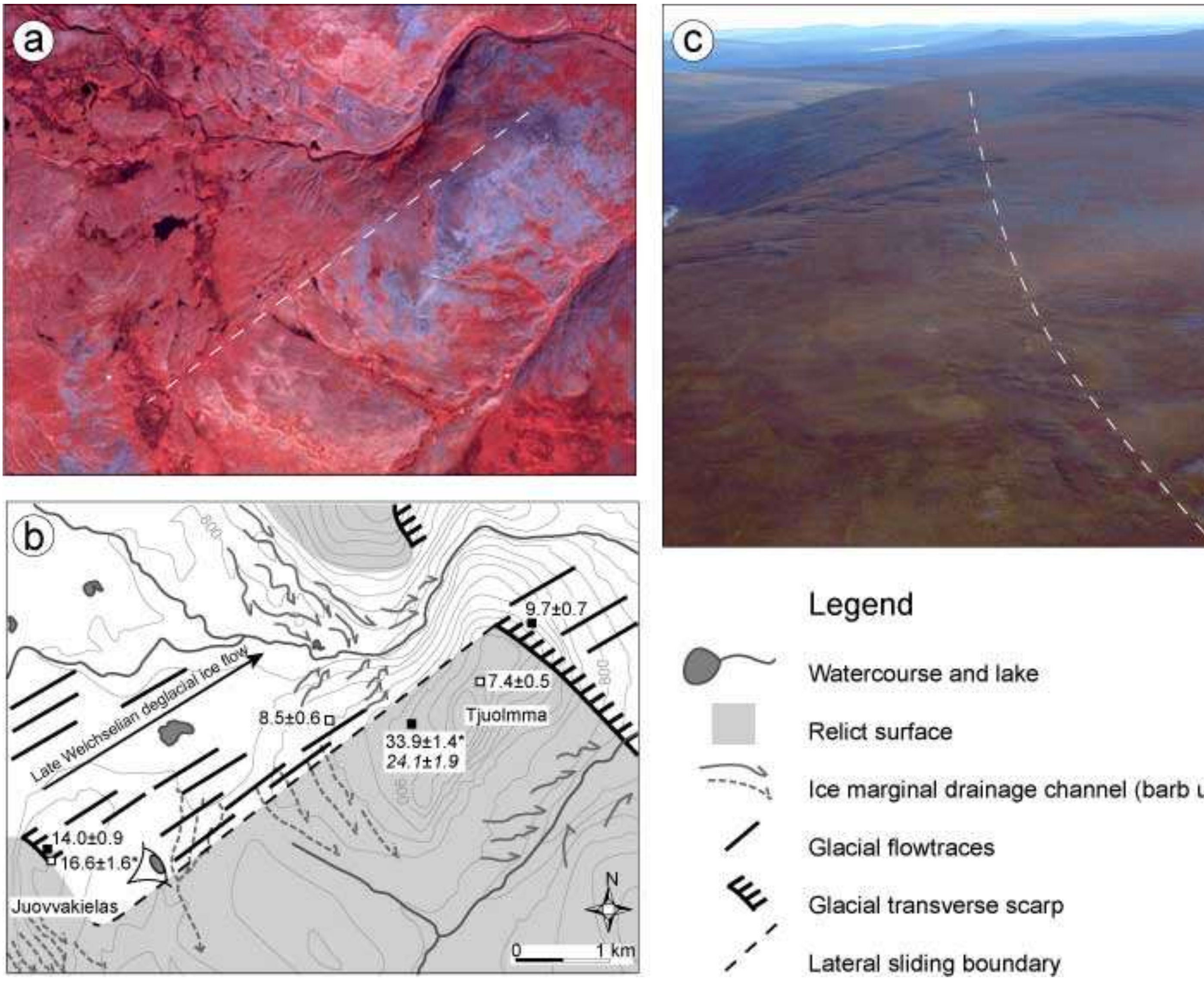


Figure 5. Infra-red air photo (a), geomorphological map (b) and oblique airphoto (c) of Mt. Tjuolmma and Juovvakielas on Ultevis. The oblique air photo (c) is taken from the point shown by the eye symbol in (b). Pre-Late Weichselian lateral meltwater channels are crosscut by till lineations and the lateral sliding boundary. The channels can be traced on the glacially eroded side of the boundary as water-filled depressions aligned with the down-stream continuation of the lateral channels. The lateral sliding boundary itself appears as a sharp feature on air photos and terminates in transverse lee-side scarps. Sample locations are marked by open squares (erratic samples) and closed squares (bedrock samples). 10Be and 26Al (italics) apparent exposure ages with uncertainties are given in thousands of years. An asterisk indicates a weighted mean age.

Seismology and Geomagnetism

This report is no longer available

Earth Physics - CADI

CENTRE FOR ADVANCED DATA INFERENCE 2003

The establishment of CADI

A result of the Research School of Earth Sciences' 2003 strategic planning exercise was to provided funding for a new Centre for Advanced Data Inference (CADI). The Centre's main goal is to develop and use state-of-the-art computational methods to analyze complex datasets and model Earth processes combining forward and inverse modelling techniques. On August 12th CADI was launched together with the TerraWulf computational facility which was built by CADI directors Jean Braun and Malcolm Sambridge during the year (see below).

Figure 1: CADI launch on 12th August 2003.

The Centre's operations are based on collaborative projects with other groups/centres in the Earth Sciences which are supported through partial funding of doctoral and post-doctoral fellowships, and an extensive visitor program. The Centre also provides access to parallel processing on a large cluster of performance PC's (called TerraWulf) funded by an Australian Research Council LIEF grant.

The main body of the report provides a survey of the strands of work in CADI. The first 5 months has seen establishment of projects in the areas of geodynamical modelling, seismology; airborne geophysics, and environmental studies. Work on computational simulation and inversion continues in CADI with strong links to other groups in the school such as Geodynamics and Seismology, within the Earth Physics area.

Building of the TerraWulf Cluster

The TerraWulf cluster, jointly funded by the ARC, the ANU MEC, RSES and collaborators from the University of Melbourne, MacQuarie University, the University of Western Australia, Geoscience Australia and Dalhousie University in Canada, was purchased and built during the first six months of 2003.

The cluster is made of 128 Pentium IV PCs running at 2.4 GHz, each with 1 Gbyte of fast access memory (1066 MHz). The PCs are connected by a 1Gbit Ethernet network. It operates under Linux RedHat 7 and performant compilers such as the Intel Fortran90 and C++ compilers.

Figure 2: The TerraWulf cluster.

The cluster has been operational since June 2003 and has been used in a large number of research projects, including the modelling of thermochronological ages to constrin the tectono- geomorphic evolution of active mountain belts and passive escarpment margins, global tomographic inversion and the solution of the Stokes equation in 3D to study deformation of the Earth's crust and flow in the underlying mantle.

Low temperature themochronology to constrain the tectono-morphic evolution of the Southern Alps of New Zealand

Frederic Herman, Jean Braun and Jim Dunlap

Temperature-time histories of rocks can be used to constrain tectonic and/or geomorphic scenarios of tectonically active areas. However, this inference is not always straightforward and relies on several interdependent mechanisms such as heat conduction, horizontal and vertical heat advection, tectonic kinematics, transient topography, etc, that must be taken into account while interpreting thermochronological datasets. Using a 3D finite element code (Pecube) that solves the transient heat transfer equation with an evolving topography, one can define accurate Temperature-time histories to interpret thermochronological datasets. Proper inversion methods (Monte Carlo type, e.g. Neighborhood Algorithm) can in turn be used to constrain the tectono-morphic development of a tectonically active area. This approach has been applied to the continental collision that occurs in the South Island in New Zealand. Existing thermochronological datasets (K-Ar in Biotite and Muscovite, Fission tracks in apatite and zircon) complemented by recent low-T termochronometer data ((U-Th)/He in apatite and zircon) are used to derive information on the tectono-morphic development of the orogen: changes in tectonic regime, apparition of relief, geometry of major oblique-thrust and influence of glaciations.

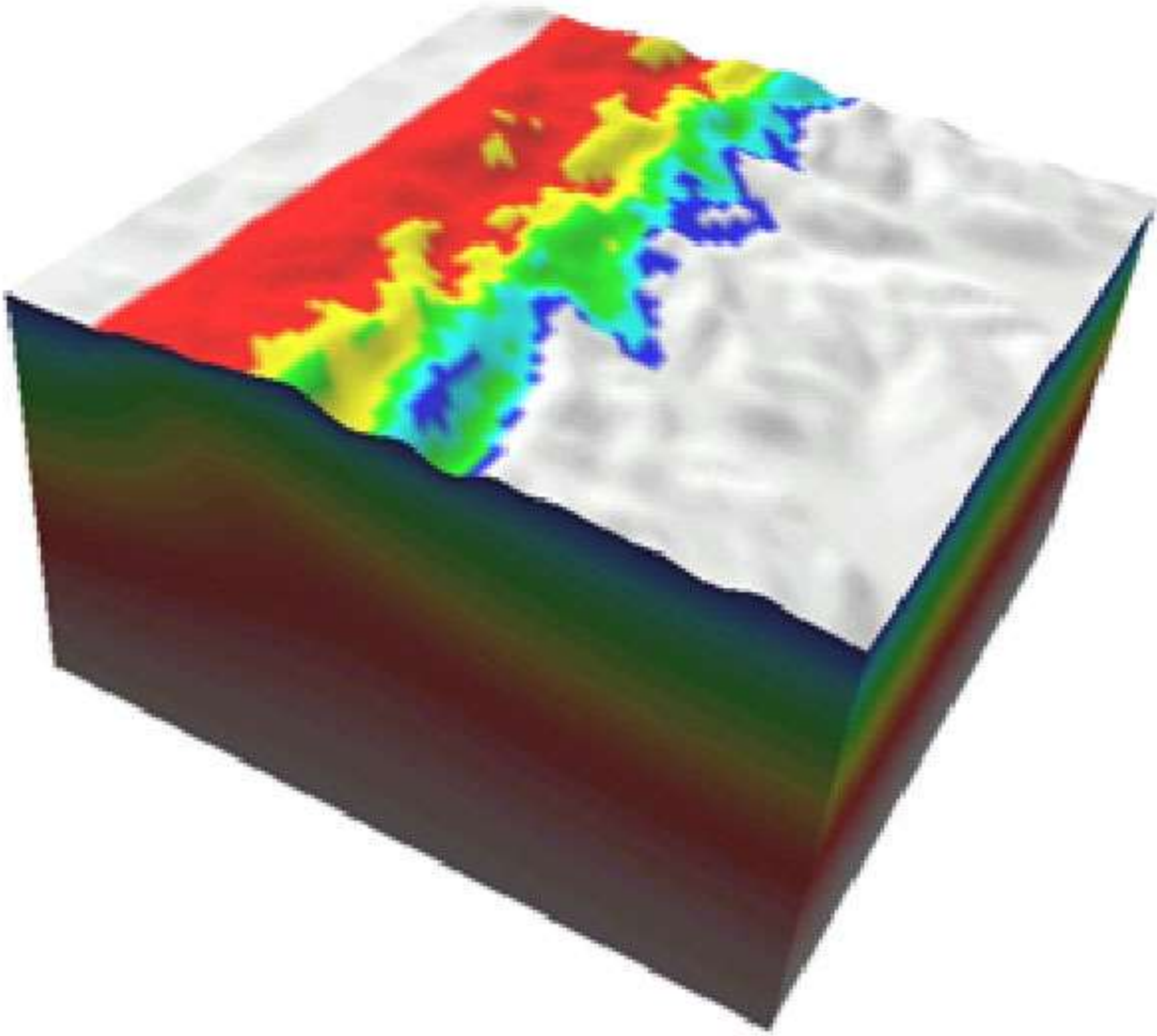


Figure 1: Predicted thermal structure beneath the Southern Alps of New Zealand as derived by inverse modeling of thermo-chronological data.

Constraining the erosion history of ancient mountain belts by thermochronology: the effect of flexural isostasy.

Xavier Robert and Jean Braun

Much work has recently been done to understand the coupling between tectonic and erosion. Regions characterized by a finite amplitude relief are subject to erosion, leading to rock exhumation and cooling. We can therefore obtain information about rock exhumation and the evolution of the relief from thermochronological data, especially when considering the relationship between age and elevation at a range of lengthscales. In post-orogenic settings, exhumation is driven by the isostatic response to erosion. Using a coupled thermo-isostatic model, we demonstrate that the distribution of cooling ages at the surface of an ancient mountain belt is not only determined by the rate at which the ancient topography has evolved through time but also by the nature of the isostatic rebound which is, in turn, controlled by the flexural strength of the underlying lithosphere. Using published low-temperature thermochronological data from the Dabie Shan in eastern China, we demonstrate that a careful quantitative analysis of the age distribution and its relationship to present-day surface topography provide information on the rate at which the surface topography of the mountain belt has evolved through time to reach its present-day morphology but also on the elastic thickness of the underlying lithosphere. The data suggest that, over the last 60 to 70 Myr, relief has decreased almost linearly by a factor of 4 to 5 and that the lithosphere is characterized by an effective elastic thickness of 20 km. The data also provide constraints on the thermal structure of the crust beneath the Dabie Shan.

Constraining passive margin escarpment evolution by low-temperature thermochronology

Peter vanderBeek (Univ. of Grenoble) and Jean Braun

Passive margin escarpments are major geomorphic features that separate low-relief, high elevation plateaux from near sea-level coastal plains. Their initial development is often linked to a base level drop associated with the episode of continental rifting that leads to the opening of an adjacent oceanic basin. How they migrate from their original coastal position to their present-day location sometimes several hundred kilometers inland, remains a matter of debate. Do escarpments retreat while maintaining their shape, or do they evolve from their original position to the location of a pre-existing inland divide by downwearing of the continental plateau. Recent thermo-chronological studies across the Great Escarpment of Southeastern Australia and the escarpment flanking the southern margins of the African continent have provided some constraints on the rate and nature of escarpment migration. Here, we use a complex three-dimensional thermal model of the crust coupled to a surface processes model to demonstrate under which circumstances thermochronological data can be used to provide meaningful information on the evolution of the escarpment. Furthermore, we define specific sampling strategies to optimize the information that can be extracted from thermochronological datasets on the rate of escarpment migration, the nature of its retreat as well as the value of poorly constrained parameters such as the local geothermal gradient and the flexural thickness of the lithosphere. In this context, we re-analyze published datasets on the Great Escarpment of Southeastern Australia and demonstrate that they contain incomplete information on the evolution of the escarpment. We define new potential targets that might provide more constraining information.

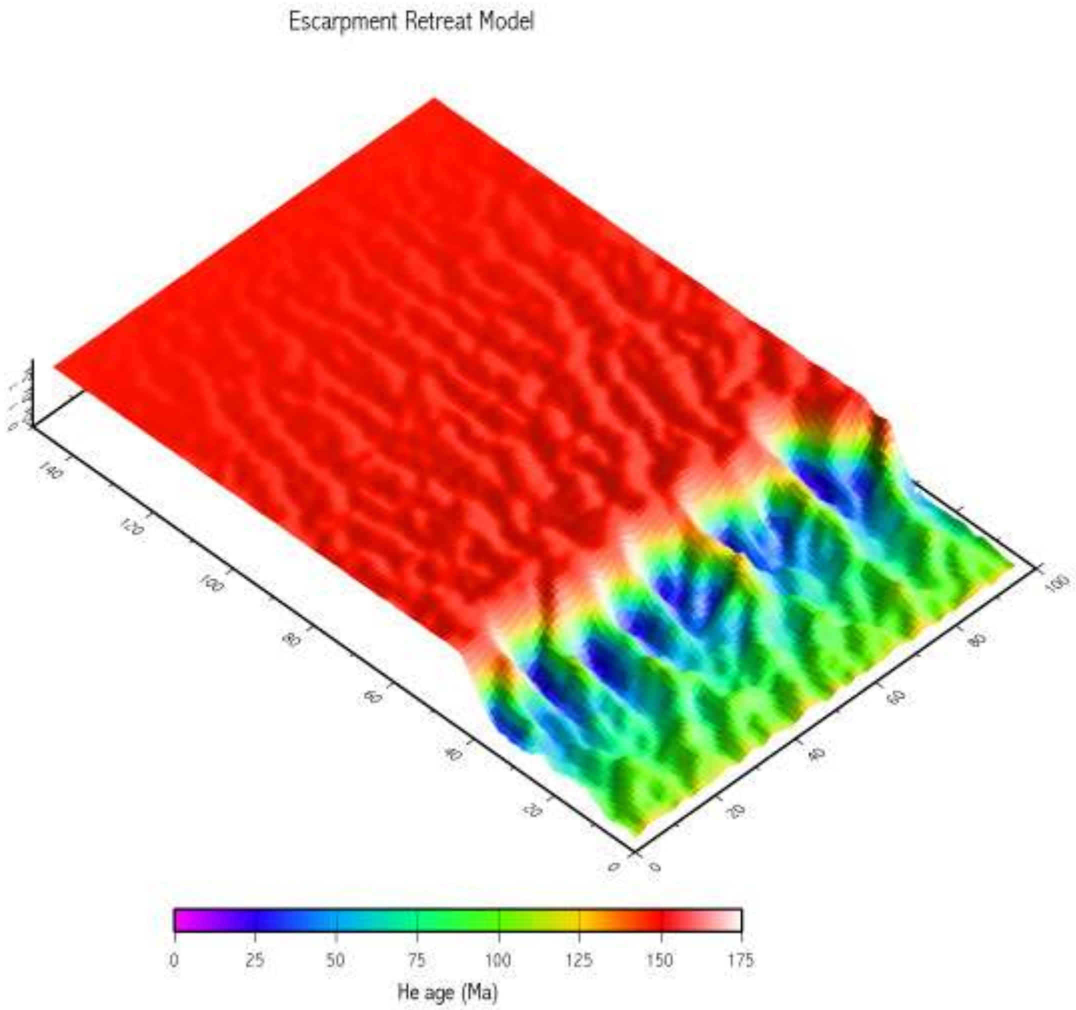


Figure 1. Predicted age distribution along the coastal plain of a passive margin escarpment obtained by assuming a linear retreat of the escarpment through time.

The effect of topography-driven fluid flow on the thermal structure of the crust and its influence on low-temperature age-elevation datasets

Jean Braun

Low temperature thermochronological datasets are commonly used to determine the rate of rock exhumation in active mountain belts. Recent work in our group has shown that by analyzing the relationship between age and elevation at a range of length scales, one can extract information on the mean rate of exhumation (usually related to tectonic-scale processes) and the rate of evolution of the surface (usually related to geomorphic processes). We are investigating the potential influence that topographically-driven fluid flow in the crust may have on its thermal structure and, hence, the temperature history of rocks as they are exhumed towards the surface. We demonstrate that for a range of acceptable values for the permeability of fractured crystalline rocks, the effect of the fluid flow is not negligible and must be taken into account when interpreting thermochronological datasets. Interestingly, for each thermochronological system, there appears to be a critical value of the rock permeability for which the isotherm corresponding to the closure temperature of the system is flattened, i.e. the deflection of the isotherm caused by conduction beneath the finite amplitude surface topography is perfectly compensated by the effect of the topographically-driven fluid flow. This clearly demonstrated that there is no practical way to extract independent evidence from age-elevation datasets on the tectono-morphic evolution of an active mountain belt and the strength of fluid flow, as both processes have a similar effect on the temperature structure of the crust. Additional constraints, such as geochemical information, are needed to estimate the vigour of the topographically-driven fluid flow and its influence on thermochronological data.

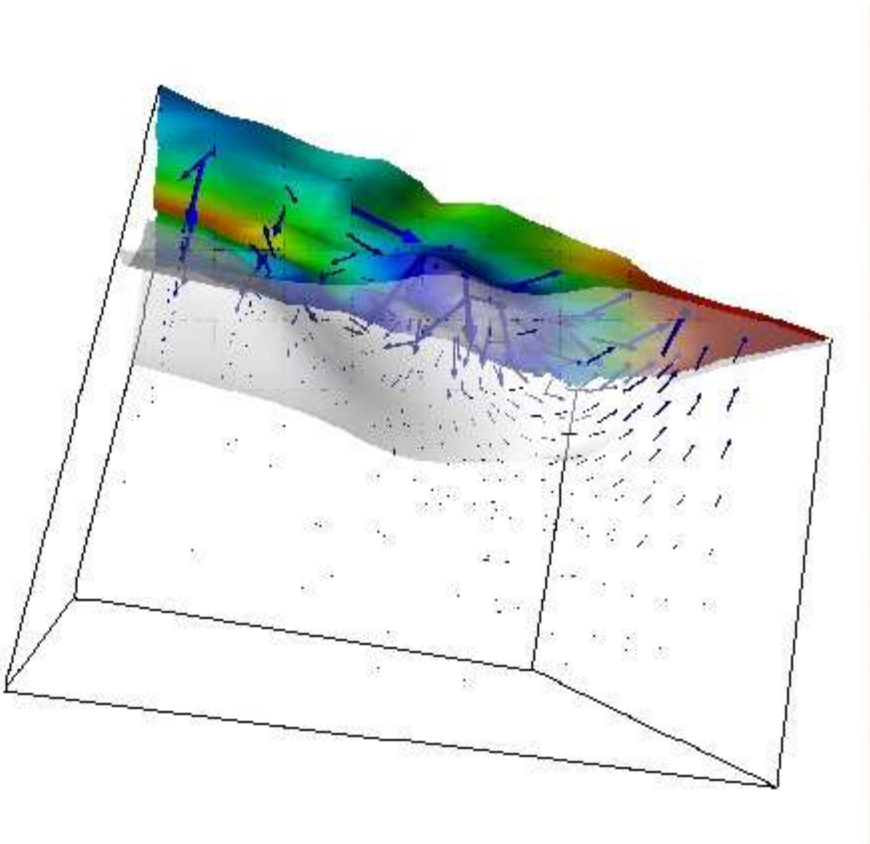


Figure 1: Deflection of the 75oC isotherm (transparent grey surface) by topographically-driven fluid flow (solid blue arrows).

Accurate multi-phase traveltimes in complex layered media using a fast marching method with source grid refinement

Nick Rawlinson and Malcolm Sambridge

The accurate prediction of seismic travel times in layered media is required in many areas of seismology. In addition to simple refractions and reflections, complex phases comprising numerous transmission and reflection branches may exist; for instance, the so-called "multiples" frequently identified in marine reflection seismology. In the 2002 annual report, we presented a fast and robust method for tracking phases comprising any number of reflection and transmission branches in 2-D layered media. A multi-stage Fast Marching Method (FMM) was used to track the propagation path of the wavefront from interface to interface. FMM is a fast and unconditionally stable finite difference scheme which calculates the first-arrival traveltime to all points within a computational domain by solving the eikonal equation along a computational front (narrow band) that approximates the first arrival wavefront.

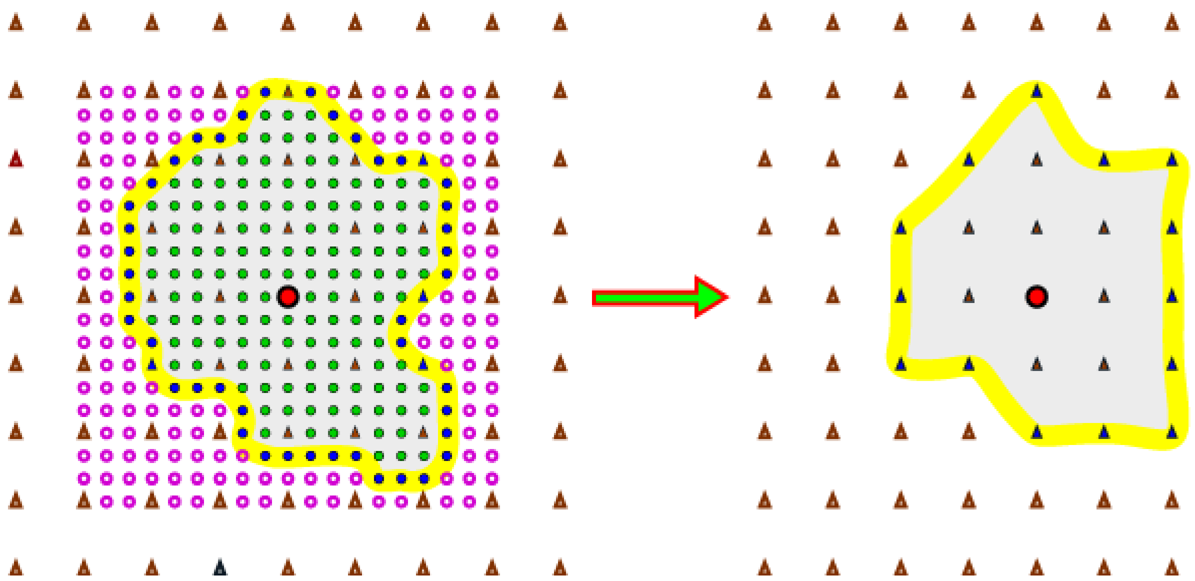


Figure 1: Implementation of source grid refinement. When the narrow band (yellow line) reaches the boundary of the refined grid, it is mapped onto the course grid (denoted by triangles) before continuing to evolve.

Although FMM was initially introduced as a first-order scheme, higher order operators can be used. A mixed-order scheme that preferentially uses second-order operators, but reverts to first-order operators when the required upwind traveltimes are unavailable, is one possibility. However, despite improved accuracy, this scheme still suffers from first-order convergence due to high wavefront curvature and first-order accuracy in the vicinity of the source. To overcome this problem, we implement local grid refinement in the source neighbourhood. In order to retain stability, the edge of the refined grid conforms to the shape of the wavefront, so that information only flows out of the refined grid and never back into it. Figure 1 demonstrates the principle of the approach.

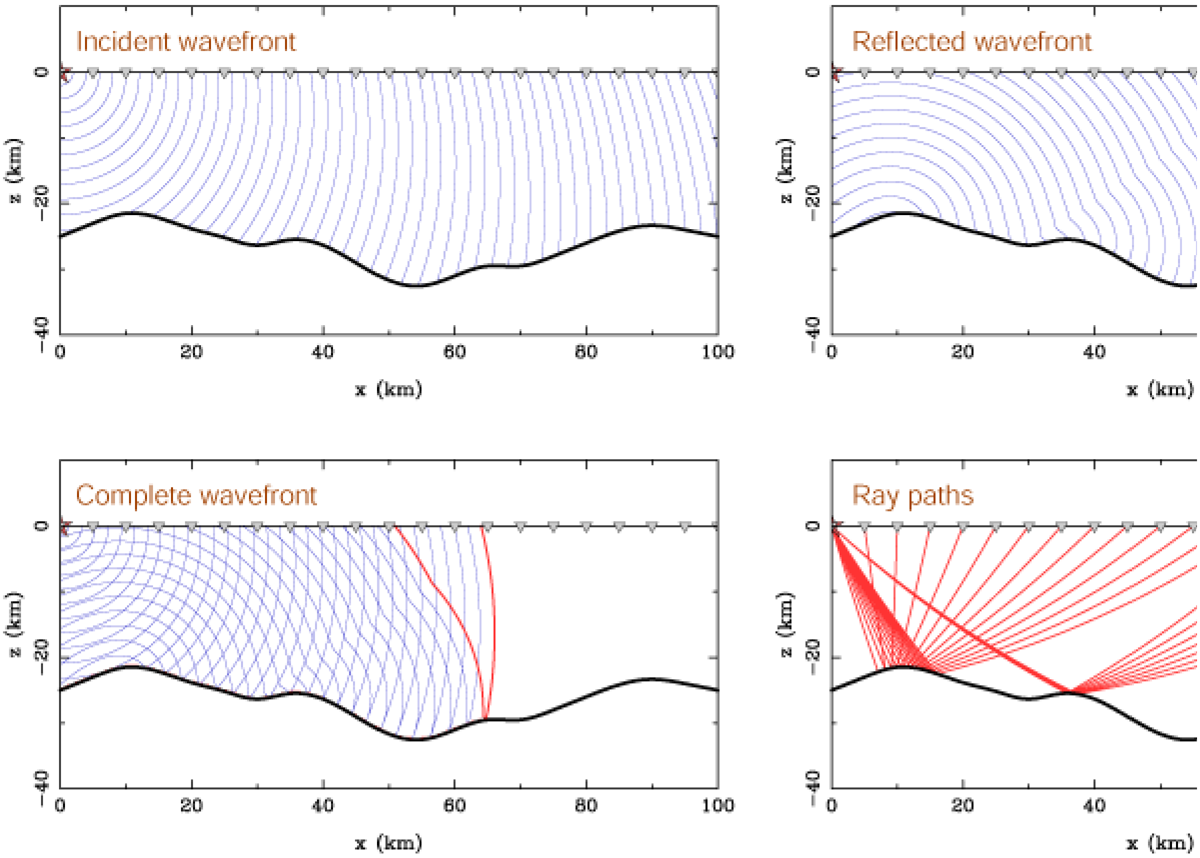


Figure 2: Tracking a simple reflection through a medium in which velocity varies linearly with depth. Traveltimes to all 21 receivers located on the surface form the basis of the analysis shown in Figure 3.

To examine the improvements offered by local grid refinement about the source, we compare FMM solutions with those obtained by an accurate ray tracing scheme. Since ray tracing becomes less robust as the complexity of the medium increases, we choose a relatively simple structure comprising a single interface within a velocity field that varies linearly with depth, and track a phase consisting of a single reflection (see Figure 2). In such a medium, the ray tracing solutions can be considered exact for our purposes. Figure 3 shows a comparison of four different schemes with and without grid refinement using five different grid sizes. RMS error is defined as the RMS difference between the 21 source-receiver traveltimes predicted by FMM and ray tracing. CPU time is for a SunBlade 150. The most notable feature of Figure 3 is that the second order scheme with grid refinement is only marginally slower than the same scheme without grid refinement, yet is approximately an order of magnitude more accurate and has near second-order convergence. Similar improvements can be expected in more complex media.

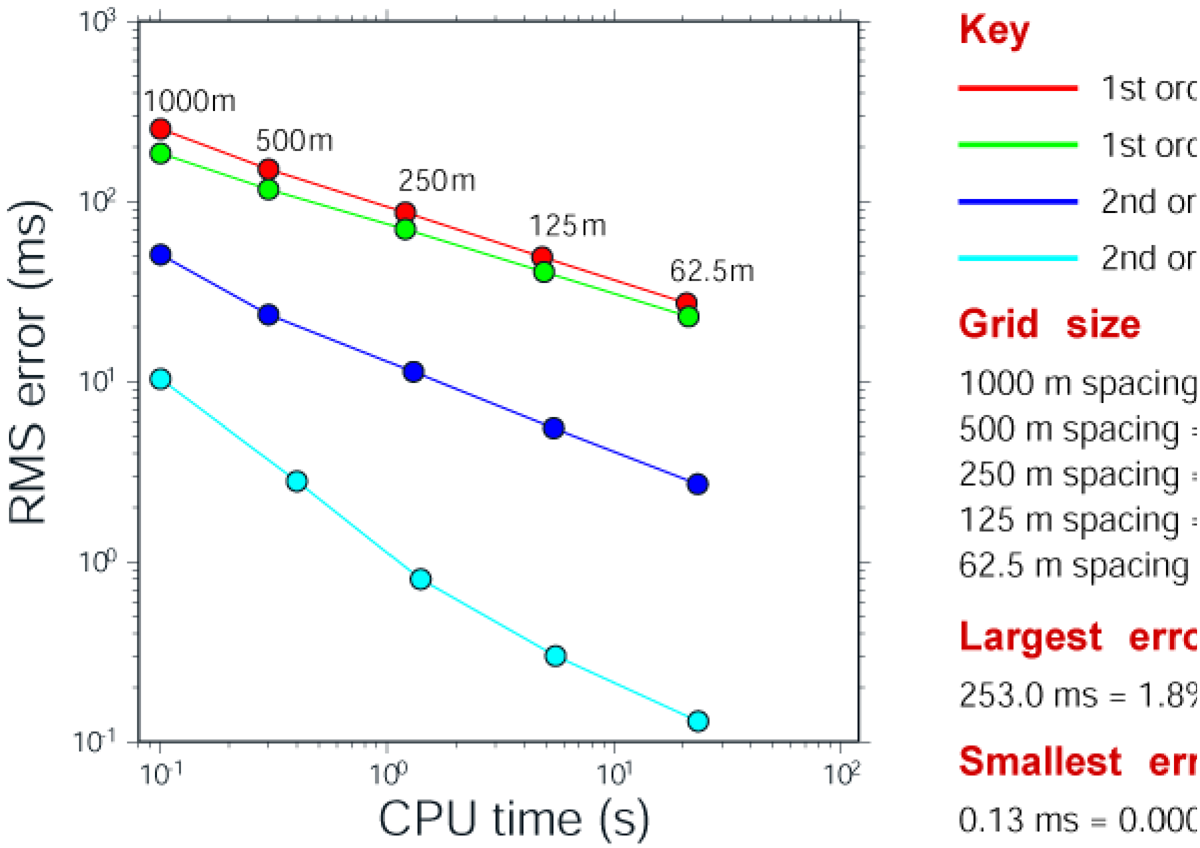


Figure 3: RMS error vs. CPU time for four different FMM schemes using five different grid sizes. A ray tracing scheme is used to calculate reference traveltimes.

Recently, we have extended our FMM code to work in 3-D spherical coordinates (without interfaces at this stage). Several anticipated applications of this scheme include non-linear earthquake relocation (FMM will rapidly solve the forward step, which is crucial to non-linear optimization methods) and local and regional seismic tomography. Figure 4 shows several depth slices through a synthetic model which illustrates the propagation of first-arrival wavefronts from a point source calculated using the 3-D FMM scheme.

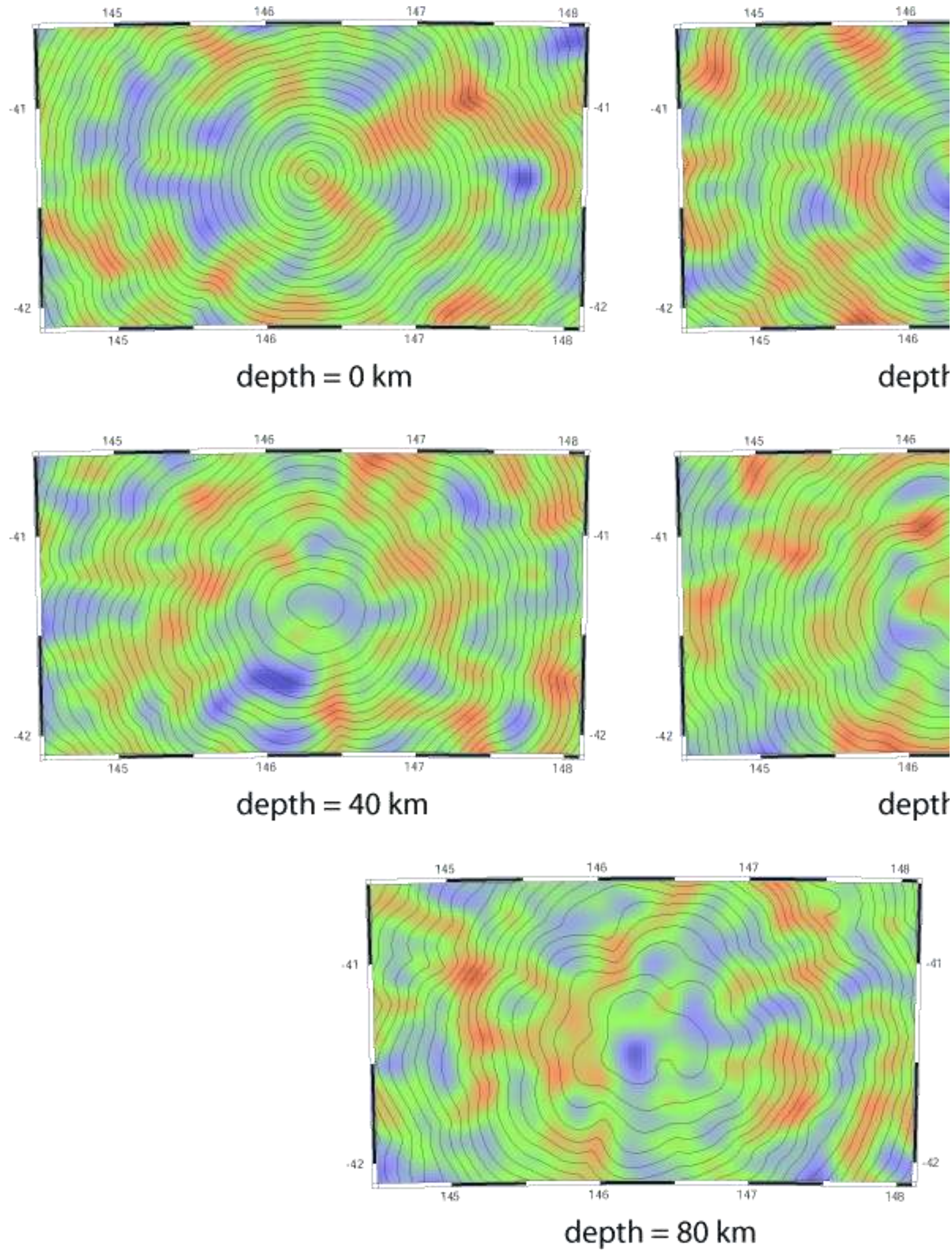


Figure 4: Depth slices through a synthetic velocity structure (blue is fast, red is slow) defined in spherical coordinates. First-arrival wavefronts from a point source on the surface (depth = 0 km) are plotted at 1 s intervals.

Adaptive inversion

M. Sambridge, E. Debayle [EOST Strasbourg], A. Gorbatov [Jamstec], B.L.N. Kennett, and N. Rawlinson

The second year of the adaptive inversion project (supported by an Australian Research Council Discovery grant) has seen progress on a number of fronts. The aim of the project to develop a series of strategies for seismic inverse problems which allow the definition of the physical model to be constrained by the character of data, rather than pre-determined (the current norm). In this way we hope to extract robust information from data sets with variable resolving power, like seismic travel times and surface waveforms.

This year work has been performed in the area of signal parameter estimation using sparse arrays, global travel time inversion with self adaptive meshes, and self adaptive interface parameterization in reflection seismology. A new application has been to the inversion of very large global surface wave data sets with variable resolving power. Here the computational tools previously developed to automatically refine 3-D meshes can be used to produce resolution estimates for highly heterogeneous surface wave datasets. Figure 1a shows an example of using nearest neigbour Voronoi cells to estimate the resolvability of the highly heterogeneous data sets in Figure 1b.

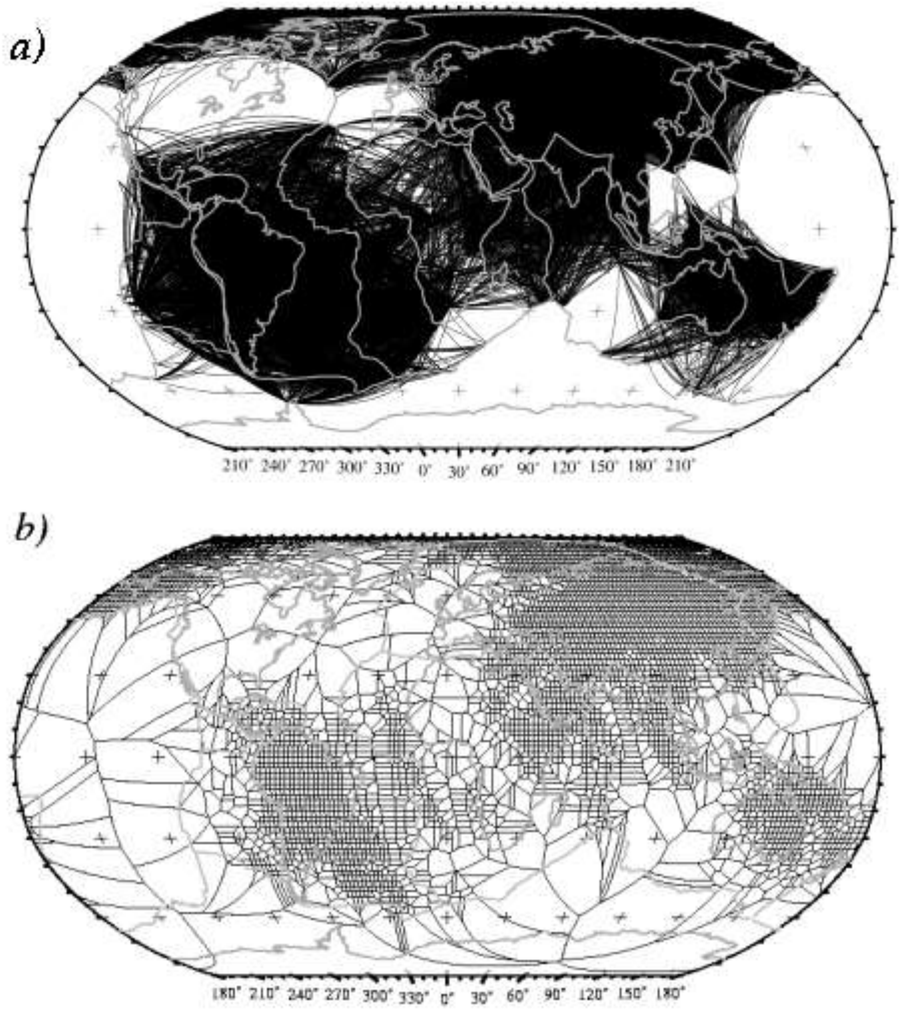


Figure 1. a) Ray path coverage of global and regional surface wave datasets. b) Voronoi diagram showing relative resolvability of Earth structure as measured by both ray path density and azimuthal coverage. Large cells indicate poor resolution, small cells corresponds to high resolution.

The Voronoi cells are designed using a `quality criterion' which reflects both ray path density and azimuthal distribution. Where Voronoi cells are small, structure can be resolved over shorter distance scales, but this occurs only where both path density and azimuthal coverage are sufficient, and not path density alone. Note how regions in the southern Atlantic and Indian Ocean have high raypath density but nevertheless poor resolution due to a lack of azimuthal coverage. This fact is picked up by the Voronoi diagram which shows large cells in these regions even though the path density plot alone indcates apparently high resolution.

A second application of the geometrical tools here is in improving the computational efficiency of the matrix calculations. By incorporating the new algorithms into existing surface wave inversion schemes it has been possible to drammatically improve efficiency and allow many more raypaths to be included 25000 paths are included in Figure 1, but the algorithms are expected to allow 50,000-100,000 paths in the near future. The ability to simultaneously invert large numbers of surface waveforms will allow regional and global datasets to be combined into a single inversion, thereby improving constraints on Earth structure.

During the year the interactive software package for manipulation and visualization of 3-D tomographic data-sets known as *Tomoeye* has been further developed. *Tomoeye* uses the MATLAB programming language which makes it highly versatile and platform independent. The package is designed to allow easy interrogation of tomographic models in 3-D, by producing 2-D slices and 3-D iso-surfaces in either Cartesian or Spherical co-ordinate systems. It produces publication quality output in the form of postscript images, as well as virtual reality modelling language (VRML) files for real time 3-D visualization, and web-based publication. Figure 2 shows an example of VRML output produced with *Tomoeye* of seismicity and an constant perturbation surface in seismic wavespeed beneath the Krakatoa region, taken from a recent tomographic image. The *Tomoeye* package will be made available to the scientific community during 2004. Distribution will be via the adapative inversion web page *http://rses.anu.edu.au/seismology/projects/tireg*)

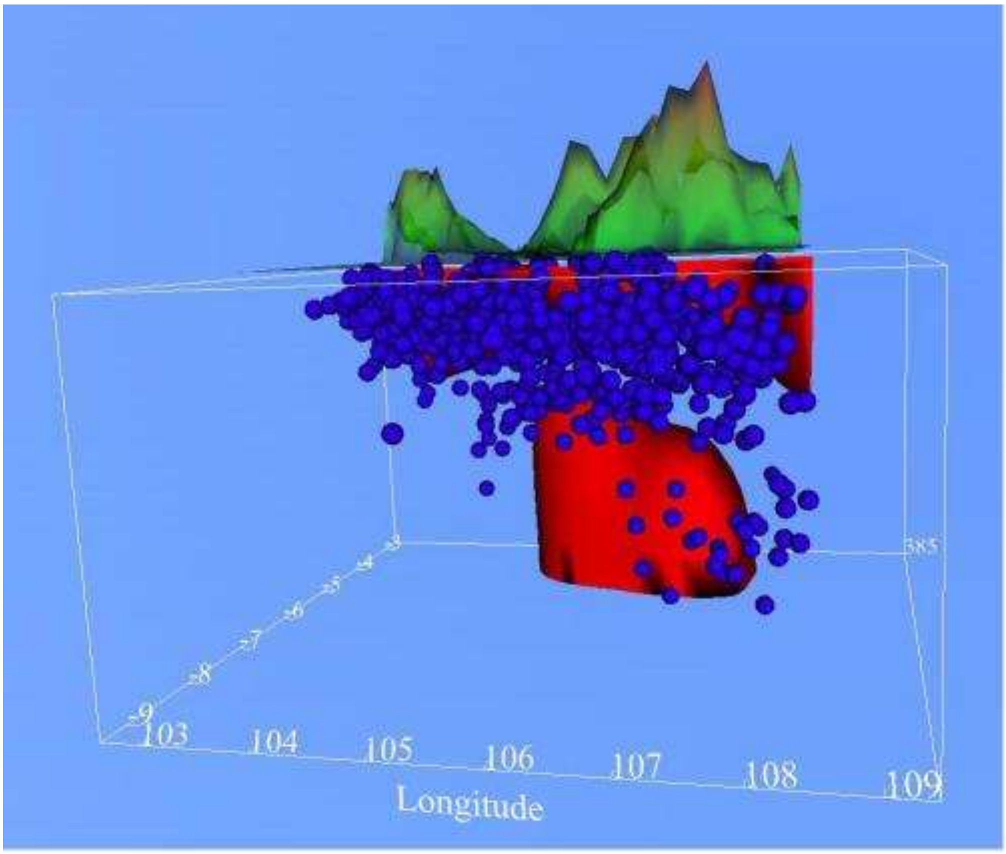


Figure 2. A VRML model produced with *Tomoeye*. An Iso-surface in seismic wavespeed beneath the Krakatoa region is shown in red, while surface topography is in green and seismicity is represented as blue spheres. This type of model can be interactively rotated and `flown through' using standard VRML viewers `plugged in' to web browsers.

Ensemble Inversion and Tomography

M. Sambridge, B.L.N. Kennett, A. Gorbatov [Jamstec]

Two different styles of ensemble techniques have been investigated this year.

In the first we have considered a range of aspects of global seismic tomography with experiments involving variations in data input and modifications to the background mdoel being used in the tomographic inversion. The power of the Terrawulf cluster was used to set up 120 simultaneous tomographic inversions for a full global data set with a separate inversion on each processor. The inversions for P wavespeed structure use full 3-D ray tracing and a common style of LSQR inversion.

Experiments with modified data, including an additional random component, lead to a mean with little difference from the results from the unperturbed data set. Variance is concentrated in the regions of most sampling, but there is little skew or excess in the distribution. In contrast, changes to the background model used for the 3-D ray tracing had a much stronger influence on the higher moments as can be seen in figure 1. Under-sampled regions tend to have positive skew but there can be rapid changes even within areas with good coverage.

Strong negative excess is concenrated in regions with limited sampling. Future experiments will enlarge the size of the ensembles and examine different aspects of the influence of variations in large and medium scale structure on the global inversions.

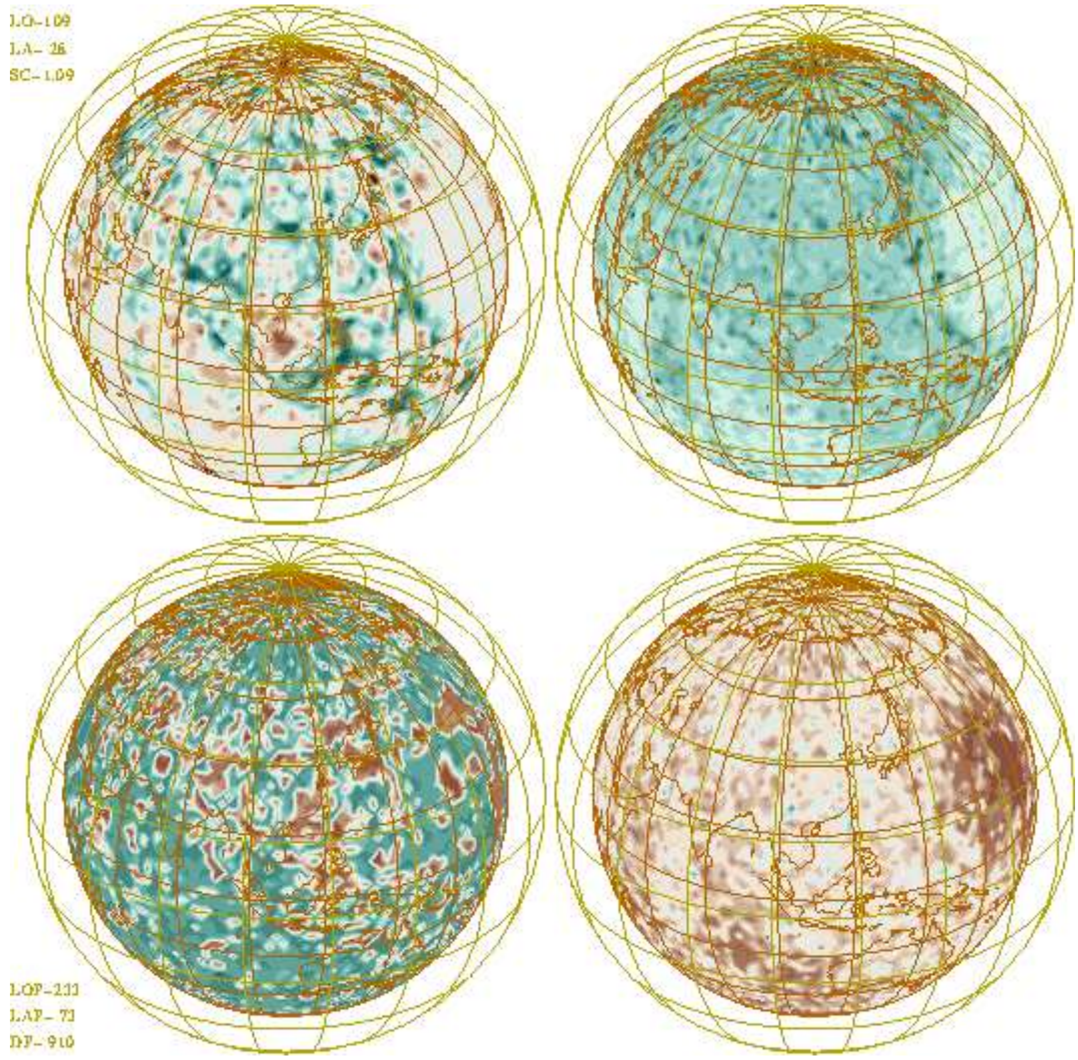


Figure 1: View of the ensemble tomography results for a shell at 910 km deep as moments of the wavespeed distribution. Postive perturbations are shown by stronger levels of cyan and negative as brown. The upper left panel shows the mean model derived from 120 different base models with small scale heterogeneity introduced, the upper right panel is the standard deviation of the results, the lower left panel shows the local skew in the distribution and the lower right panel shows the excess (kurtotis-3) for the distribution.

The second aspect of ensemble inversion is associated with the assessment of the error in nonlinear inversion schemes. Such techniques, e.g. the NA algorithm, can provide very effective exploration of parameter space leading to the mimimisation of some composite measure including both data misfit and regularisation. Hwoever, the assessment of the quality of the estimated model in not straightforward, particularly if different meaures of data misfit are to be compared. A way around this problem is to use an auxiliary weighting function for ensemble properties that can be used with suitablethresholds to define consistency regions of suitable models. This approach does not require detailed knowledge of the misfit distribution nor an underlying probabilistic model. The use of a polyhedral representation of such consistency regions is illustrated in figure 2 with an example from nonlinear seismic event location.

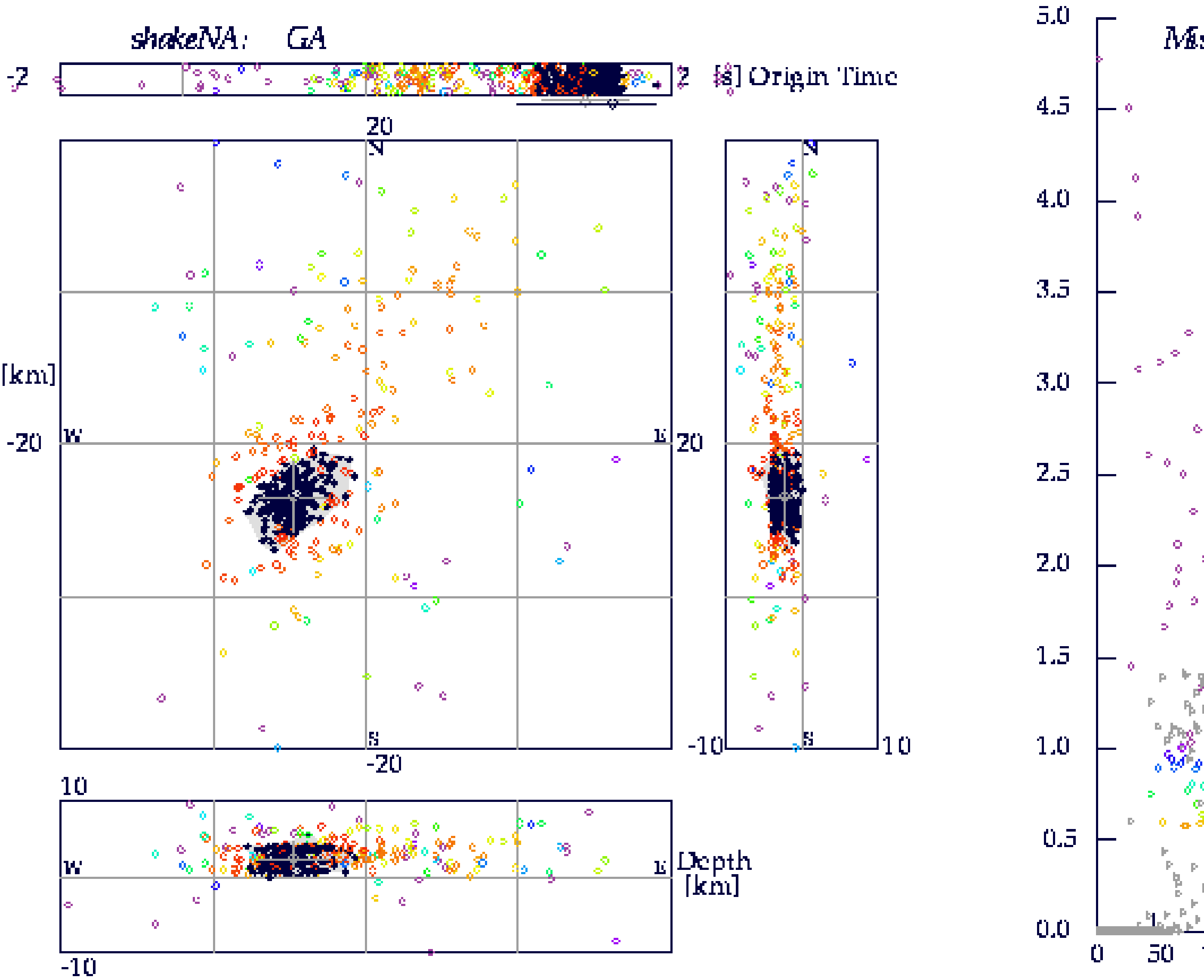


Figure 2: Representation of the progress of the NA technique towards convergence on a location estimate for an event in the Kara Sea with definition of the consistency region of data fit from the properties of the weighting function. The inversion was carried out used a regional model and only a small portion of the model space about the reference point [72.4 N, 57.9 E, 30 km depth] is shown. The open symbols progress through the rainbow colours to red as data fit improves. Models within the consistency region are indicated in black; a polyhedral representation of the region is indicated in grey tone. The misfit distribution and weighting are indicated to the right.

The auxiliary weight function can be used directly with the composite misfit measure used to drive the exploration of model space in the nonlinear inversion. However, considerable benefit can be obtained by storing the data misfit and associated model characteristics for each investigated model, as well as the composite measure. The properties of the model ensemble can then be used retrospectively to define preferred models by the intersection of a consistency region in data misfit with zones constrained by desirable model properties.

Calibration and Inversion of Airborne Geophysical Data

R. Brodie and M. Sambridge

Recent advances in airborne electromagnetic data acquisition systems have motivated a move in the use of their data from qualitative "bump finding" to rigorous quantitative applications. While this has been a major development, ensuing investigations into the accuracy of the predicted earth models, through ground validation, have revealed that they contain significant errors. Aside from the fundamental ambiguity of the data, part of the error in the predicted earth models is attributable to systemic calibration error in the data, like that shown in Figure 1, and the inadequacy in the way it is treated during data processing.

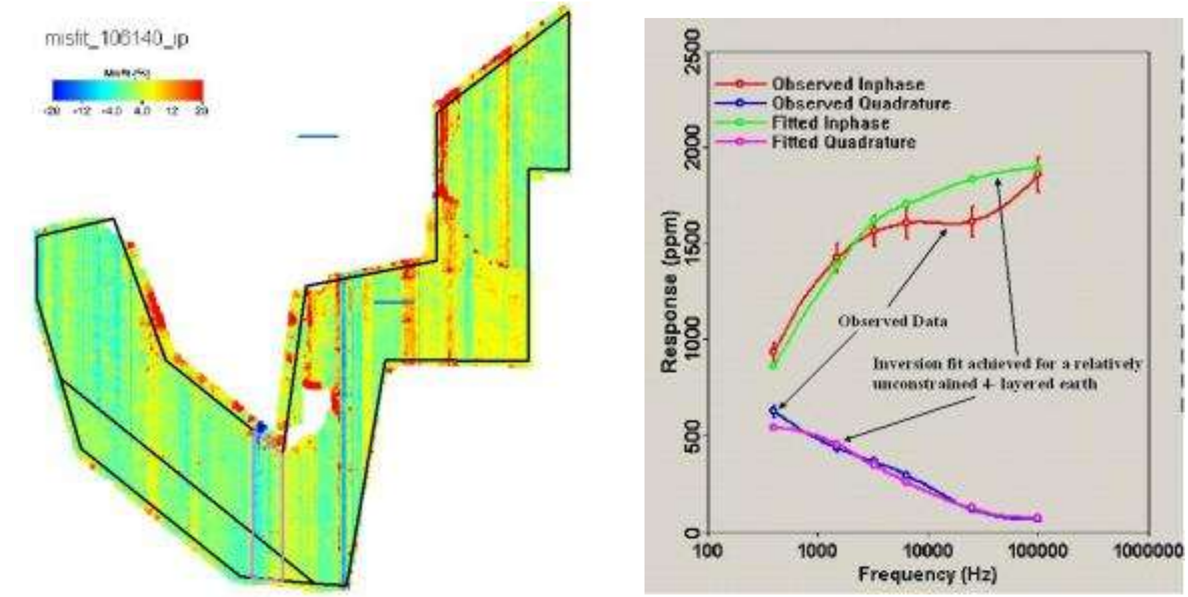


Figure 1: The elongate north-south (parallel with the flight lines) striations in the left hand image depicting percentage data misfit from a multi-layered earth inversion provides evidence of systemic calibration error. The non-monotonically increasing shape of the observed in-phase data (red curve) on the right hand image also indicates calibration error.

The technology of these acquisition systems and the considerable expense of airborne surveys, quality control and ground validation typically far outweigh the sophistication and expense of the data processing and interpretation applied to the data. Traditionally data acquisition, processing and interpretation have been treated as separate entities. Data processing involves time consuming "trial and error" manipulation of the data to remove or reduce error not removed during calibration at the time of data acquisition.

Now is an opportune time to capitalise on the improved calibration and monitoring of acquisition systems and the recent efforts in ground validation along with independent advances in computation power and inversion techniques. Advantage can be taken of a holistic inverse approach which draws upon all available forms of information to infer earth models as well as take care of calibration error. Treatment of calibration error as systemic predictable (nevertheless unwanted) signal rather than unpredictable random noise and dealing simultaneously with acquisition, processing and interpretation issues form the core theme to the approach. The project began in August 2003 and to date only frequency domain airborne electromagnetic data have specifically been considered. In this case a large non-linear inverse problem has been posed that incorporates information from ground and airborne calibrations, survey repeat lines, tie line crossovers, ground truth, model regularisation and a-priori geological and petrophysical knowledge. The procedure thus assimilates into one simultaneous inversion aspects of data acquisition, processing and interpretation which are traditionally treated totally separately.

This formulation requires significant computational power. Efforts so far have concentrated on the efficient numerical integration of the required Hankel transforms sufficiently accurate for use in modelling airborne electromagnetic data (Figure 2). Code has also been developed which utilises matrix propagation methods to evaluate the required earth kernels. Fortunately this can also be used for efficient calculation of analytic derivatives rather than by finite difference. For 10 parameter Earth model inversions we have been able to achieve a 12 fold increase in computational speed in the forward problem, and a further factor of 10 in the calculation of the necessary Jacobian matrix.

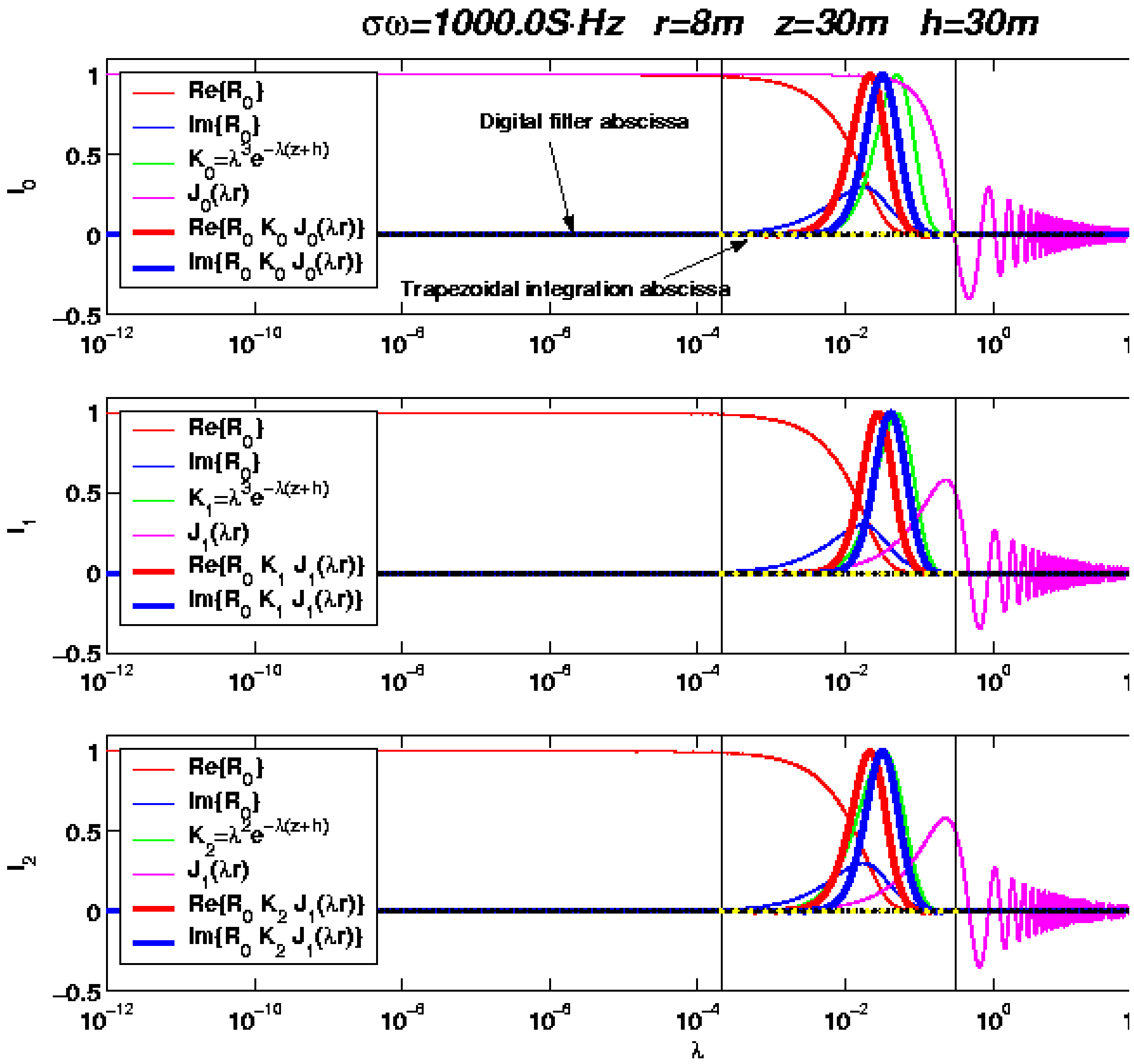


Figure 2: For an airborne system, all three complex Hankel transforms can be simultaneously evaluated to sufficient accuracy with simple trapezoidal integration requiring 15 times fewer abscissas at which the expensive earth kernel need to be evaluated than highly accurate digital filters.

Questions about this topic to Malcolm Sambridge:
Malcolm.Sambridge@anu.edu.au

PRISE

This report is no longer available

RESEARCH SUPPORT

Electronics Group

Demand for Electronics support remained strong during the year. Maintenance activities accounted for 13.8% of human resources,
administration and group support / renovations planning and disruption 35.8%, with the remaining 50.4% devoted to development activity.
The group's accommodation was extensively renovated and expanded during 2003, using funds from the University's Capital Management Plan,
Facilities and Services, RSES, and the Earth Physics and Earth Chemistry groups.

Notable developments undertaken included:

Assembly and bench testing of the prototype 'INSB' assembly to facilitate precision 'Charge Mode' data acquisition utilising Finnigan
electrometer amplifiers. (Mr D Corrigan, Mr N Schram).

Manufacture and testing of 3 'DSCC' (embedded computer assemblies) and Solar
Cell regulators for deployment in Antarctica by the Geodynamics subgroup (Mr A. Welsh, Mr D. Cummins, Mr D. Cassar).

Design and fabrication of a precision data acquisition and high resolution (22-bit) magnet control and housekeeping system for the 61cm
Mass Spectrometer (Mr A. Latimore).

Installation and commissioning of refurbished safety interlocking and furnace control for the 'Rig 3' high pressure apparatus within the Petrophysics group. (Mr A. Forster).

Design, development and commissioning of a Programmable Sample Crusher Controller
for the VG5400 Mass Spectrometer (Mr D. Cassar, Mr D. Cummins, Mr A. Latimore).

Implementation and commissioning of updated control electronics for early SHRIMP II instruments (Mr A. Welsh).

Fabrication of 9 'Tesla Tamer' precision magnetic field probes for ASI and the SHRIMP group (Mr J. Arnold).

Completion of construction and bench testing of two fibre-optically controlled High Voltage systems and test software for the renovated
61 and NG61 Mass Spectrometers (Mr N. Schram, Mr J. Arnold, Mr A. Latimore, Mr D. Cummins, Mr D. Cassar).

Design, manufacture and commissioning of a motorised Cryogenic Head Controller and a specialised microcomputer-firmware-based
GPIB interface for an existing electrometer, both on the VG5400 Mass Spectrometer (Mr D. Cassar, Mr D. Cummins).

Expansion and commissioning of industrial I/O capabilities on the VG5400 Mass Spectrometer (Mr J. Arnold).

Design and modelling of the feasibility of fitting 2 extra Ion Multipliers to the collector of the Neptune ICPMS (Mr D. Corrigan).

Completion and bench testing of an automated filament degasser controller to suit hardware under development for Triton Mass Spectrometer (Mr N. Schram).

Design of source pumping hardware and associated source adjustment and structural support for the existing 61cm Mass Spectrometer (Mr D. Corrigan).

Design, implementation and commissioning of a remote control facility for an industrial RF heater for the Potassium Argon sub group (Mr A. Forster).

Design and partial implementation of electronic and industrial hardware to facilitate automated operation of the Multi Anvil press for Earth Materials
(Mr A. Forster, Mr D. Cummins, Mr D. Cassar).

Staffing

The group comprises an Electronics Engineer and five Technical Officers supplemented by two Trainee Technical Officers, who commenced
duty in February 2003. D Corrigan continues to specialise in engineering design, working closely with both Engineering and Electronics staff.
His primary focus for 2003 was the upgrade of the existing 61cm Mass Spectrometer.

Outlook

2004 promises to be another interesting year, as we turn our attention to the proposed SHRIMP SI, commissioning of the updated 61cm
Mass Spectrometer, and several high-pressure-press automation projects. The group will assume responsibility for implementing the ‘In Service
Testing of Electrical Appliances’ component of the University’s Electrical Safety Policy, and this is expected to absorb significant resources
during the first quarter of 2004. There is anecdotal evidence that the ‘internal recharge’ system of cost recovery is affecting the flow of
spontaneous and low cost projects, however it does not appear to be affecting the flow of major projects. Group finances have been
restructured for 2004 to further encourage accountability and autonomy, whilst offering a financial strategic plan to ensure continuity
and update of resources. Group members and clients appreciate the renovated accommodation and this, together with an age-balanced
and enthusiastic staff profile and a culture of professionalism and client focus, positions the group well for the foreseeable future.

Engineering Group

2003 was a year of change for the engineering workshop. Work commenced on the mezzanine floor extension in May. As expected this construction disrupted workflow until late in the year. Workshop staff took the opportunity to have a general clean up and re-arranged the workshop, steel storage and welding bay resulting in cleaner, more efficient work areas.

Administration, Training, workshop maintenance and extra work relating to the mezzanine extension accounted for 39% of human resources, external work 3%, with the remaining 58% committed to jobs for the school.

Prominent work in 2003 included:

Completion of quadrupole lenses for Stanford SHRIMP (Mr D. Hall, Mr V. Baek-Hansen, Mr A. Wilson).

Completion of prototype electrometers for NG61 mass spectrometer (Mr D. Hall, Mr V. Baek-Hansen, Mr A. Wilson, Mr D. Thomson, Mr G. Woodward).

Continued work on the filament degasser for 61cm mass spectrometer (All staff)
Manufacture of high-pressure six kilobar hydrothermal bombs (Mr D. Thomson).

Manufacture of revised Faraday cups for SHRIMP multi-collector (Mr D. Thomson, Mr G. Woodward, Mr A. Wilson).

Refurbishment of high-pressure vessels (Mr G. Woodward).

Started on a new order of Tantalum crucible. (Mr B. Taylor, Mr A. Wilson, Mr. D Thomson, Mr C Were).

Manufacture of Tantalum heater elements (Mr R. Willison).

Overhaul of several core-drilling systems (All staff).

Additions and modifications to Helium line and Noble gas line including rock crusher (Mr G. Woodward, Mr B. Taylor, Mr D. Thomson, Mr A. Wilson).

Manufacture of a revised mirror support for SHRIMP II (Mr G. Woodward).

Began work on new sample holders designed to extend the capabilities of the HelEx laser ablation ICPMS (Mr D. Thomson, Mr G. Woodward, Mr A. Wilson, Mr C. Were, Mr V. Baek-Hansen).

Staffing

Mr A. Wilson was appointed to the position of workshop head following the retirement of Mr B. Waterford. Mr R. Willison retired during the year. We were pleased to have Mr D. Hall on contract until August when Mr C. Were commenced his appointment as a full-time technical officer.

The group is comprised of four full time technical officers, (Mr A. Wilson, Mr D. Thomson, Mr G. Woodward and Mr C. Were), 1 part time technical officer, (Mr V. Baek-Hansen) and second year apprentice Mr B. Taylor.

Outlook

2004 will be an eventful year for the Engineering workshop with several projects, including the 61cm mass spectrometer systems, ICPMS sample holders and Optically Stimulated Luminescence systems requiring further work. The proposed SHRIMP SI and other smaller proposals will offer some fascinating engineering opportunities. Training will be an important issue for us in 2004. It is hoped that all staff will be fully trained on the operation of the CNC machines to improve flexibility and efficiency. The groups' new financial arrangement will enable tooling and machinery upgrades to be better planned.

Publications by Group

Note: list of 2003 publications contains additional 2002 publications not included in the 2002 Annual Report.

Earth Chemistry Publications

Ashley, P.M., Dawson, M.W., Sivell, W.J., Wilson, J.S. and Dunlap, W.J. New data on the geology and geochronology of the area south of Tooraweenah, New South Wales. Quarterley Notes of the Department of Mineral Resources, Geological Survey of New South Wales, 115, 13-32.

Barnes, M.A., Anthony, E.Y., Williams, I.S. and Asquith, G.B. (2002) Architecture of a 1.38-1.34 Ga granite-rhyolite complex as revealed by geochronology and isotopic and elemental geochemistry of subsurface samples from West Texas, USA. In: Rämö, O.T., Van Schmus, W.R., Bettencourt, J.S. (eds) *Granite Systems and Proterozoic Lithospheric Processes*, *Precambrian Research*, 119(1-4), 9-43

Bastos-Leal, L.R., Cunha, J.C., Cordani, U.G., Teixeira, W, Nutman, A.P., Menezes, A.B., and Macambira, M.J.B. (2003) SHRIMP U-Pb, $^{207}Pb/^{206}Pb$ zircon dating and Nd isotopic signature of the Umbaranas greenstone belt, Northern Sao Fransisco Craton, Brazil. *Journal of the Society of American Earth Science*, 15, 775-785.

Bennett, V.C. (2003) Compositional evolution of the mantle. In: The Mantle and Core, (ed. R.W. Carlson), volume 2 of the *Treatise of Geochemistry*, Published 3 Dec 2003.

Bennett, V.C., Horan, M., Brandon A. B., and Neal C. (2003) Highly siderophile elements in the Earth and Meteorites, Introduction to the John Morgan volume. *Chemical Geology,* 196*,* 1- 3.

Black, L.P., Kamo, S.L., Williams, I.S., Mundil, R., Davis, D.W., Korsch, R.J., and Foudoulis, C. (2003) The application of SHRIMP to Phanerozoic geochronology; a critical appraisal of four zircon standards. *Chemical Geology,* 200(2), 171-188.

Bryant, C.J., Arculus, R.J., and Eggins, S.M. (2003) The geochemical evolution of the Izu-Bonin arc system: a perspective from tephras recovered by deep-sea drilling. *Geochemistry, Geophysics and Geosystems,* 4, Art. No. 1094 Nov. 11.

Bryant, C.J., McCulloch, M.T., and Bennett, V.C. (2003) Impact of Matrix Effects on the Accurate Measurement of Li isotope ratios by Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS) under "cold" plasma conditions. *Journal of Atomic and Analytical Spectrometry,* 18 (7), 734-737.

Buick, I.S., Williams, I.S., Gibson, R.L., Cartwright, I., and Miller, J.A. (2003) Carbon and U-Pb evidence for a Palaeoproterozoic crustal component in the Central zone of the Limpopo Belt, South Africa. *Journal of the Geological Society, London,* 160(4), 601-612.

Campbell, I.H. (2003) Evidence of early continental crust extraction from 3.5 Ga Barberton mantle from Nb/U and Nb/Th ratios in basalts. *Amercian Journal of Science*, 303, 319-351.

Chen, X., Yin, A., Gehrels, G.E., Cowgill, E.S., Grove, M., Harrison, T.M., and Wang, X.F. (2003) Two phases of Mesozoic north-south extension in the eastern Altyn Tagh range, northern Tibetan Plateau. *Tectonics,* 22, 1053.

Cowgill, E.S., Yin, A., Harrison, T.M., and Wang, X.F. (2003) Reconstruction of the Altyn Tagh fault based on U-Pb geochronology: the role of backthrusts, mantle sutures, and heterogeneous crustal strength in forming the Tibetan Plateau. *Journal of Geophysical Research* 108, 2346.

Davis, D.W., Williams, I.S., and Krogh, T.E. (2003) Historical development of zircon geochronology. In: Hanchar, J.M & Hoskin, P.W.O. (eds) *Zircon. Reviews in Mineralogy and Geochemistry*, Volume 53, Mineralogical Society of America, Washington, 145-181.

Dawson, M.W. and Dunlap, W.J. New geochronology from the Coolah-Mendooran area: Evidence for Middle Jurassic erosion in the southern Surat Basin. Quarterley Notes of the Department of Mineral Resources, Geological Survey of New South Wales, 115, 1-12.

Dunlap, W.J. Crystallization versus cooling agees of white micas: Dramatic effect of K-poor inclusions on 40Ar/39Ar age spectra. Journal of the Virtual Explorer, http://virtualexplorer.com.au/2003/forsterwijbrans/dunlap/

Eriksson, K.A., Campbell, I.H., Palin, J.M., and Allen, C.M. (2003) Predominance of Grenvillian magmatism recorded in detrital zircons from the modern Appalachin rivers. *Journal of Geology***,** 111, 707-717.

Giles, D., and Nutman, A.P. (2003) SHRIMP U-Pb zircon dating of the host rocks of the Cannington Ag-Pb-Zn deposit, southeastern Mount Isa Block, Australia. *Australian Journal of Earth Sciences*, 50, 295-309.

Gilley, L.D., Harrison, T.M., Leloup, P.H., Ryerson, F.J., Lovera, O.M., and Wang J.H. (2003) Direct dating of left-lateral deformation along the Red River shear zone, China and Vietnam. *Journal of Geophysical Research,* 108, 2127.

Groves, I.M., Carman, C.E. and Dunlap, W.J. Geology of the Beltana Willemite Deposit, Flinders Ranges, South Australia. Economic Geology and the Bulletin of the Society of Economic Geologists, 98, 797-818.

Harris, A.C., Allen, C. M., Bryan, S. E., Campbell, I.H., Holcombe, R.J., and Palin, J.M. (2003) ELA-ICP-MS U-Pb zircon geochronology of regional volcanism hosting the Bajo de la Alumbrera Cu-Au deposit: implications for porphyry-related mineralization. *Mineralium Deposita*, Published on line, DOI: 10.1007/S00126-033-0381-0.

Hollis, J., Clarke, G., Klepeis, K., Daczko, N., and Ireland, T.R. (2003) Geochronology and geochemistry of high-pressure granulites of the Arthur River Complex, Fiordland, New Zealand: Cretaceous magmatism and metamorphism on the paleoplate margin *Journal of Metamorphic Geology,* 21, 299-313.

Honda, M., Nutman, A.P., and Bennett V.C. (2003) Xenon compositions of magmatic zircons in 3.64 and 3.81 Ga meta-granitoids from Greenland - a search for extinct ^{244}Pu in ancient terrestrial rocks. *Earth and Planetary Science Letters,* 207, 69-82.

Huang, M., Maas, R., Buick, I.S., and Williams, I.S. (2003) Crustal response to continental collisions between the Tibet, Indian, South China and North China Blocks: geochronological constraints from the Songpan-Garz Orogenic Belt, western China. *Journal of Metamorphic Geology, 21(3)*, 223-240.

Ireland, T.R., and Bukovanska, M. (2003) The initial 182Hf/180Hf of the solar system determined from meteoritic zircons. *Geochimica et Cosmochimica Acta,* 67, 4849-4856.

Ireland, T.R., and Williams, I.S. (2003) Considerations in zircon geochronology by SIMS. In: Hanchar, J.M and Hoskin, P.W.O. (eds) *Zircon. Reviews in Mineralogy and Geochemistry*, Volume 53, Mineralogical Society of America, Washington, 215-241.

Kapp, P.A., Yin, A., Manning, C.M., Harrison, T.M., Taylor, M.H., and Lin Ding (2003) Tectonic evolution of the early Mesozoic blueschist-bearing Qiangtang metamorphic belt, central Tibet. *Tectonics,* 22, 1043.

Kapp, P.A., Murphy, M.A., Yin, A., Harrison, T.M., Ding, L., and Guo J. (2003) Mesozoic and Cenozoic tectonic evolution of the Shiquanhe area of western Tibet. *Tectonics* 22, 1029.

Leslie, A.G., and Nutman, A.P. (2003) Evidence of Neoproterozoic orogenesis and early collision- related high temperature Scandian events in the southern East Greenland Caledonides. *Geological Magazine*, 140, 309-333.

McDougall, I., and Feibel, C.S. (2003) Numerical age control for the Miocene-Pliocene succession at Lothagam, a hominoid-bearing sequence in the northern Kenya Rift. In *Lothagam: The Dawn of Humanity in Eastern Africa*, M. G. Leakey and J. M Harris, Eds, Columbia University Press, New York, pp 43-64.

McLaren, S., Sandiford, M., Hand, M., Neumann, N., Wyborn, L., and Bastrakova, I. (2003) The hot southern continent: heat flow and heat production in Australian Proterozoic terranes. In: Hillis, R.R. & Muller, R.D. eds. *Evolution and Dynamics of the Australian Plate*, 383-404. Geological Society of Australia Special Publication 22 and Geological Society of America Special Paper 372.

Mojzsis, S.J., Coath, C.D., Greenwood, J.P., McKeegan, K.D., and Harrison, T.M. (2003) Mass- independent isotope effects in Archean (2.5-3.8 Ga) sedimentary sulfides determined by ion microprobe analysis. *Geochimica et Cosmochimica Acta,* 67, 1635-1658.

Myrow, P.M., Hughes, N.C., Paulsen, T.S., Williams, I.S., Parcha, S.K., Thompson, K.R., Bowring, S.A., Peng, S-C. and Ahluwalia, A.D. (2003) Integrated tectonostratigraphic analysis of the Himalaya and implications for its tectonic reconstruction. *Earth and Planetary Science Letters,* 212(4), 433-441.

Nutman, A.P., Green, D.H., and Cook, A.C. Reply on SHRIMP U-Pb zircon dating of the exhumation of the Lizard Peridotite and its emplacement over crustal rocks: constraints for tectonic models. *Journal of the Geological Society London*, 160, 331-335.

Rahl, J.M., Reiners, P.W., Campbell, I.H., Nicolescu, S., and Allen, C.M. (2003) Combined U-Th/He and U-Pb dating of detrital zircon from Jurassic sandstones of western North America. *Geology,* 31, 761-764.

Ratschbacher, L., Hacker, B.R., Calvert, A., Webb, L.E., Grimmer, J.C., McWilliams, M., Ireland, T.R., Dong, S., and Hu, J. (2003) Tectonics of the Qinling (central China): Tectonostratigraphy, geochronology, and deformation history. *Tectonophysics,* 366, 1-53.

Robinson, D.M., DeCelles, P.G., Garzione, C.N., Pearson, O.N., Harrison, T.M., and Catlos, E.J. (2003) Kinematic model for the Main Central thrust in Nepal. *Geology,* 31, 359-362.

Schmitt, A.K., Grove, M., Harrison, T.M., Lovera, O.M., Hulen, J., and Waters, M. (2003) The Cobb Mountain-Geyser's magma system, California (Part 1): U-Pb zircon ages, conditions of crystallization, and magma residence times. *Geochimica et Cosmochimica Acta,* 67, 3423- 3442.

Schmitt, A.K., Grove, M., Harrison, T.M., Lovera, O.M., Hulen, J., and Waters, M. (2003) The Cobb Mountain-Geyser's magma system, California (Part 2): Timescales of pluton emplacement and implications for the evolution of a thermally active aureole. *Geochimica et Cosmochimica Acta,* 67, 3343-3358.

Schmitz, M.D., Bowring, S.A., and Ireland T.R (2003) Evaluation of Duluth Complex anorthositic series (AS3) zircon as a U-Pb geochronological standard: new high-precision isotope dilution thermal ionization mass spectrometry results. *Geochimica et Cosmochimica Acta,* 67, 3665- 3672.

Spell, T.L., and McDougall, I. (2003) Characterization and calibration of $^{40}Ar/^{39}Ar$ dating standards. *Chemical Geology*, 198, 189-211, 2003.

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

Sun, W., Bennett, V.C., Eggins, S.M. Arculus, R.J., and Perfit, M.R. (2003) Rhenium systematics in submarine MORB and Back-arc basin glasses: Laser ablation ICP-MS results. *Chemical Geology,* 196, 259-281.

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

Vanderhaeghe, O., Teyssier, C., McDougall, I., and Dunlap, W. J. (2003) Cooling and exhumation of the Shuswap Metamorphic Core Complex constrained by $^{40}Ar/^{39}Ar$ geochronology. *Bulletin Geological Society of America,* 115, 200-216, 2003.

Wing, B.A., Ferry, J.M., and Harrison, T.M. (2003) Prograde destruction and formation of monazite and allanite during contact and regional metamorphism of pelites: Petrology and geochronology. *Contributions to Mineralogy and Petrol*ogy, 145, 228-250.

Zeh, A., Williams, I.S., Brþtz, H., and Millar, I.L. (2003) Different age response of zircon and monazite during tectono-metamorphic evolution of a high grade paragneiss from the Ruhla Crystalline Complex, central Germany. *Contributions to Mineralogy and Petrology,* 145(6), 691-706.

top of page

Earth Environment Publications

Abram N.J., Gagan M.K., McCulloch M.T., Chappell J., and Hantoro W.S. (2003) Coral reef death during the 1997 Indian Ocean Dipole linked to Indonesian wildfires. *Science* 301, 952-955.

Alibert, C., Kinsley, L., Fallon, S., McCulloch, M.T. Berkelmans, R., and McAllister, F., (2003) Source of trace element variability in Great Barrier Reef corals affected by the Burdekin flood plumes. *Geochimica et Cosmochimica Acta*, 67(2), 231-246.

Bryant, C.J., Arculus, R.J., and Eggins, S.M. (2003) The geochemical evolution of the Izu -Bonin arc system: A perspective from tephras recovered by deep-sea drilling. *Geochemistry, Geophysics, Geosystems*, 4(11), 1094, doi:10.1029/2002GC000427.

Calvo, E., Pelejero, C., and Logan, G. (2003) Pressurized liquid extraction of selected molecular biomarkers in deep sea sediments used as proxies in paleoceanography. *Journal of Chromatography, A* 989, 197-205.

Chappell J. (2003) Living with climate change: can we take lessons from history? In Living with Climate Change: National Academies Forum, Dec 2002, pp 67-76. Canberra: Australian Academy of Science

Curnoe, D., Grün, R., and Thackeray, J.F. (2002) Electron spin resonance dating of tooth enamel from Kromdraai B, South Africa. *South African Journal of Science*, 98: 540.

Danyushevsky, L.D., Perfit, M.R., Eggins, S.M., and Falloon, T.J. (2003) Crustal origin for coupled Ôultra-depletedÕ and ÔplagioclaseÕ signatures in MORB olivine-hosted melt inclusions: evidence from the Siquerios Transform Fault, East Pacific Rise. *Contributions to Mineralogy and Petrology*, 144, 619-637.

Eggins, S., Grün, R., Pike, A.W.G., Shelley, M., and Taylor, L. (2003) ^{238}U and ^{232}Th profiling and U-series isotope analysis of fossil teeth by laser ablation-ICPMS. *Quaternary Science Reviews*, 22, 1373-1382.

Eggins, S., De Deckker, P., and Marshall, J. (2003) Mg/Ca variation in planktonic foraminifera tests: implications for reconstructing palaeo-seawater temperature and habitat migration. *Earth and Planetary Science Letters*, 212, 291-306.

Eggins, S.M. (2003) Laser ablation ICP-MS analysis of geological materials as lithium-borate glasses. *Geostandards Newsletter: the Journal of Geostandards and Geoanalysis*, 27, 147-162.

Fallon, S., McCulloch, T. M., and Alibert, C. (2003) Examining water temperature proxies in Porites corals from the Great Barrier Reef: a cross-shelf comparison. *Coral Reefs*, 22, 389-404.

Grün, R. (2003) Introduction to Quaternary geochronology. *Advances in ESR Applications,* 20, 20-33.

Grün, R., Beaumont, P., Tobias, P.V. and Eggins, S. (2003) On the age of Border Cave 5 human mandible. *Journal of human Evolution*, 45, 155-167.

Hendy, E.J., Gagan, M.K., and Lough, J.M., (2003) Chronological control of coral records using luminescent lines and evidence for non-stationary ENSO teleconnections in northeast Australia. *The Holocene,* 13(2), 187-199.

Hendy, E. J., Lough, J.M. and Gagan, M.K., (2003) Historical mortality in massive Porites from the central Great Barrier Reef, Australia: evidence for past environmental stress? *Coral Reefs,* 22(3), 207-215.

Ihlenfeld, C., Norman, M.D., Gagan, M.K., Drysdale, R.N., Maas, R., and Webb, J., (2003) Climatic significance of seasonal trace element and stable isotope variations in a modern freshwater tufa. *Geochimica et Cosmochimica Acta,* 67(13), 2341-2357.

Ito, E., De Deckker, P., and Eggins, S.M., (2003) Ostracodes and their shell chemistry: implications for paleohydrologic and paleoclimatoligic applications. In: Bridging the Gap -
Trends in the Ostracode Biological and Geological Sciences. Ed. R. D. White. *The Paleotological Society Special Publications*, Vol 9, November 2003, pp119-151. Yale University, New Haven CT.

Jacobi, R., and Grün, R., (2003) ESR dates from Robin Hood Cave, Crewell Crags, Derbyshire, UK, and the age of its Neanderthal occupation. *Quaternary Newsletter,* 100, 1-12.

Jia, Y., Kerrich, R., Gupta, A.K., and Fyfe, W.S. (2003) ^{15}N enriched Gondwana potassic rocks, eastern India: crustal N in the mantle source. *Earth and Planetary Science Letters*, 215, 43-56.

Jia, Y., Kerrich, R., and Goldfarb, R.J. (2003) Metamorphic Origin of Ore-Forming fluids for Orogenic Gold Quartz Vein Systems in the North American Cordillera: Constraints from a
Reconnaissance study of $\delta^{15}N$, δD, and $\delta^{18}O$. *Economic Geology*, 98, 109-123.

Kienast, M., Hanebuth T. J. J., Pelejero, C., and Steinke, S. (2003) Synchroneity of meltwater pulse 1a and the Bolling warming: New evidence from the South China Sea. *Geology,* 31, 67-70.

Kutschera, W., and MŸller, W. (2003) "Isotope Language" of the Alpine Iceman investigated with AMS and MS. *Nuclear Instruments and Methods in Physics Research*, *Vol B* 204, 705-719.

Lisker, F. Brown, R., and Fabel, D. (2003) Denudational and thermal history along a transect across the Lambert Graben, northern Prince Charles Mountains, Antarctica, derived from apatite fission track thermochronology. *Tectonics*, 22(5), 1055-1069.

Lomax, J., Hilgers, A., Wopfner, H., Grün, R., Twidale, C.R., and Radtke, U. (2003) The onset of dune formation in the Strzelecki Desert, South Australia. *Quaternary Science Reviews*, 22, 1067-1076.

McCulloch, M., Pailles, C., Moody, P., and Martin, C.E., (2003) Tracing the source of sediment and phosphorus into the Great Barrier Reef lagoon, *Earth and Planetary Science Letters*, 210, 249-258

McCulloch, M., Fallon, S.R., Wyndham, T., Hendy, E., Lough, J., and Barnes, D. (2003) Coral Record of increased sediment flux to the inner Great Barrier Reef since European settlement, *Nature*, 421, 727-730.

McGregor, H.V., and Gagan, M.K. (2003) Diagenesis and geochemistry of Porites corals from Papua New Guinea: implications for paleoclimate reconstruction. *Geochimica et Cosmochimica Acta*, 67 (12), 2147-2156.

Müller, W., Fricke, H., Halliday, A.N., McCulloch, M.T., and Wartho, J.-A. (2003) Origin and Migration of the Alpine Iceman. *Science* 302, 862-866. [see also related commentary in Science's Focus by Constance Holden (2003) Isotopic Data Pinpoint Iceman's Origins. *Science*, 302, 759-761.]

Müller, W., Fricke, H., Halliday, A.N., and McCulloch, M.T. (2003) Origin of the Alpine Iceman -
constraints from isotope geochemistry. In: Fleckinger, A. (ed.): Die Gletschermumie aus der Kupferzeit
2 / La mummia dell' eta del rame 2 (Proceedings of scientific congress to celebrate the 10th anniversary
of the discovery of the Iceman; Bolzano, Italy), Schriften des Südtiroler Archþologiemuseums /
Collana del Museo Archeologico dell' Alto Adige, Vol 3, pp 75-90.

Müller, W., (2003) Strengthening the link between geochronology, textures and petrology. *Earth and Planetary Science Letters*, 206, 237-251.

Nathan, R.P., Thomas, P.J., Jain, M., Murray, A.S., and Rhodes, E.J., (2003) Environmental dose rate heterogeneity
of beta radiation and its implications for luminescence dating: Monte Carlo modelling and experimental validation.
Radiation Measurements, 37, 305-313.

O'Connor S., and Chappell J., (2003) Colonisation and coastal subsistence in Australia and Papua New Guinea:
different timing, different modes. In C. Sand (ed.), Pacific Archaeology: assessments and prospects. Proceedings
of the International Conference for the 50th anniversary of the first Lapita excavation (July 1952),
Koné-Nouméa 2002, pp. 15-32, Nouméa: Le Cahiers de l¹Archéologie en Nouvelle-Calédonie 15.

Parkinson, I.J., Arculus, R.J., and Eggins, S.M. (2003) Peridotite xenoliths from Grenada, Lesser Antilles Island Arc, *Contributions to Mineralogy and Petrology*, 146(2), 241-262.

Pelejero, C., Calvo, E., Logan, G.A., and De Deckker, P. (2003) Marine Isotopic Stage 5e in the Southwest Pacific:
Similarities with Antarctica and ENSO inferences. *Geophysical Research Letters*, 30 (23) 2185, doi:10.1029/2003GL018191, 2003.

Pelejero C. (2003) Terrigenous n-alkane input in the South China Sea: high-resolution records and surface sediments.
Chemical Geology, 200, 89-103.

Pelejero, C., and Calvo E. (2003) The upper end of the $U^{K'}_{37}$ temperature calibration revisited. *Geochemistry, Geophysics, Geosystems*, 4, 1014, doi:10.1029/ 2002GC000431.

Pillans, B. (2003) Subdividing the Pleistocene using the Matuyama-Brunhes boundary (MBB): an Australasian perspective. *Quaternary Science Reviews* ,22, 1569-1577.

Ree, J.H., Lee, Y. J., Rhodes, E.J., Park, Y., Kwon, S.T., Chwae, U., Jeon, J.S., and Lee, B., (2003) Quaternary reactivation of Tertiary faults in southeastern Korean peninsula: Age constraint by optically stimulated luminescence dating. *Island Arc*, 12, 1-12.

Rhodes, E.J., Bronk-Ramsey, C., Outram, Z., Batt, C., Willis, L., Dockrill, S., and Bond, J., (2003) Bayesian methods applied to the interpretation of multiple OSL dates: high precision sediment age estimates from Old Scatness Broch excavations, Shetland Isles. *Quaternary Science Reviews*, 22, 1231-1244.

Rhodes, E.J., Chappell, J., and Spooner, N.A., (2003) Age and mobility of arid regolith: assessment by luminescence dating methods. In: Roach I.C. ed. Advances in Regolith, CRC LEME, pp 342-344.

Sancho, C., Pe–a, J.L., Lewis, C., McDonald, E., and Rhodes, E. (2003) Preliminary dating of glacial and fluvial deposits in the Cinca River Valley (NE Spain): chronological evidence for the Glacial Maximum in the Pyrenees?. In: Ruiz, M.B., Dorado, M., Valdeolmillos, A., Gil, M.J., Bardaji, T., Bustamante, I. & Martinez, I. (eds.). Quaternary climatic changes and environmental crises in the Mediterranean region, Universidad de Alcal‡-Ministerio de Ciencia y Tecnolog’a-INQUA, pp 169-173.

Sinton, J.M., Ford, L.L., Chappell, B., and McCulloch, M.T. (2003) Magma genesis and mantle heterogeneity in the Manus Back-Arc Basin, Papua New Guinea, *Journal of Petrology*, 44(1), 159-195.

Smith, M. L., Eggins, S., and Pillans, B. (2003) U-Pb dating of anatase in silcrete. In: Roach, I.C., ed., *Advances In Regolith,* pp. 388 - 390.

Spandler, C.J., Arculus, R.J., Eggins, S.M., Mavrogenes, J.A., Price, R.C., and Reay, A.J. (2003) Petrogenesis of the Greenhills Complex, Southland, New Zealand: magmatic differentiation and cumulate formation at the roots of a Permian island-arc volcano. *Contributions to Mineralogy and Petrology*, 144, 703-721.

Sun, W., Bennett, V.C., Eggins, S.M., Kamenetsky, V.S., and Arculus, R.J. (2003) Evidence for enhanced mantle to crust rhenium transfer from undegassed arc magmas. *Nature,* 422, 294-297.

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

Sun, W., Bennett, V.C., Eggins, S.M., and Arculus, R.J. (2003) Rhenium systematics in submarine MORB and back-arc basin glasses: laser ablation ICP-MS results. *Chemical Geology*, 196(1-4), 259-281.

Suzuki, A., Gagan, M.K., Fabricius, K., Isdale, P.J., Yukino, I., and Kawahata, H. (2003) Skeletal isotope microprofiles of growth perturbations in Porites corals during the 1997-1998 mas 8 June, 2005 357-369, doi: 10.1007/s00338-003-0323-4.

Treble P., Shelley J.M.G., and Chappell J. (2003) Comparison of high resolution sub-annual records of trace elements in a modern (1911-1992) speleothem with instrumental climate data from southwest Australia, *Earth and Planetary Science Letters*, 216, 141-153.

Vance, D., MŸller, W., and Villa, I.M. (eds.) (2003) Geochronology: Linking the Isotopic Record with Petrology and Textures. *Geological Society of London*, *Special Publications,* 220, pp 266.

Vance, D., MŸller, W., and Villa, I.M. (2003) Geochronology: linking the isotopic record with petrology and textures - an introduction. In: Vance, D., MŸller, W., Villa, I.M.. (eds.) (2003): Geochronology: Linking the Isotopic Record with Petrology and Textures. *Geological Society of London, Special Publications*, 220, 1-24.

Watanabe, T., Gagan, M.K., Correge, T., Scott-Gagan, H., Cowley, J., and Hantoro, W.S. (2003) Oxygen isotope systematics in Diploastrea heliopora: new coral archive of tropical paleoclimate. *Geochimica et Cosmochimica Acta,* 67(7), 1349-1358.

Witt-Eickschen, G., Seck, H.A., Mezger, K., Eggins, S.M., and Altherr, R. (2003) Lithospheric mantle evolution beneath the Eifel (Germany): constraints from Sr-Nd-Pb isotopes and trace element abundances in spinel peridotite and pyroxenite xenoliths. *Journal of Petrology*, 44(6), 1077-1095.

Woodroffe, C.D., Beech, M., and Gagan, M.K. (2003) Mid-late Holocene El Ni–o variability in the equatorial Pacific from coral microatolls. *Geophysical Research Letters*, 30(7), 1358, doi:10.1029/2002GL015868.

Wynn, J.G. (2003) Miocene Paleosols of Lothagam, in Harris, J. M. & Leakey, M. G. (eds.) Lothagam: *The Dawn of Humanity in Eastern Africa*, Columbia University Press, pp. 31-42.

Wynn, J.G., (2003) Towards a physical model of CO_2-induced stomatal frequency response. *New Phytologist*, 157, 394-398.

Zhao, J.-x., Wang, Y.-j., Collerson, K.D., and Gagan, M.K., (2003) Speleothem U-series dating of semi-synchronous climate oscillations during the last deglaciation. *Earth and Planetary Science Letters,* 216(1-2), 155-161.

Top of page

Earth Materials Publications

Ashbrook, S.E., Berry, A.J., Hibberson, W.O., Steuernagel, S., and Wimperis, S. (2003) High-resolution ^{17}O NMR spectroscopy of wadsleyite (ß-Mg_2SiO_4). *Journal of the American Chemical Societ,* 125, 11824-11825, 2003

Berry, A.J., O'Neill, H.S.C., Jayasuriya, K.D., Campbell, S.J., and Foran, G.J. (2003) XANES calibrations for the oxidation state of iron in a silicate glass. *American Mineralogist*, 88, 967-977.

Berry, A.J., Shelley, J.M.G., Foran, G.J., O'Neill, H.S.C., and Scott, D.R. (2003) A furnace design for XANES spectroscopy of silicate melts under controlled oxygen fugacities and temperatures to 1773K. *Journal of Synchrotron Radiation*, 10, 332-336.

Betts, P.G., Giles, D., and Lister, G.S. (2003) Tectonic environment of shale-hosted massive sulphide Pb-Zn-Ag deposits of Proterozoic northeastern Australia. *Economic Geology,* 98, 557-576.

Braun, J., Munroe, S., and Cox, S.F. (2003) Transient fluid flow in and around a fault. *Geofluids,* 3, 81-87.

Cesare, B., Marchesi, C., Hermann, J. and G—mez-Pugnaire, M.T. (2003) Primary melt inclusions in andalusite from anatectic graphitic metapelites: Implications for the position of the Al_2SiO_5 triple point.
Geology, 31, 573-576

Chen, Y., Conway, M., and Fitz Gerald, J.D. (2003) Carbon nanotubes formed in graphite after mechanical grinding and thermal annealing. *Applied Physics, A* 76, 633-636.

Fitz Gerald, J.D., Chen, Y., and Conway, M.J. (2003) Nanotube growth during annealling of mechanically milled Boron. *Applied Physics, A 76,* 107-110.

Forster, M.A., and Lister, G.S. (2003) Cretaceous metamorphic core complexes in the Otago Schist, New Zealand. *Australian Journal of Earth Sciences*, 50, 181-198

Glikson, A. (2003) Early Archean spherule beds: Chromium isotopes confirm origin through multiple impacts of projectiles of carbonaceous chondrite type: Comment and Reply. *Geology Online Forum*, doi 10.1130/0091-7613(2003)31, e36.

Glikson, A.Y. (2003) Comment on "Extraterrestrial influences on mantle plume activity" by D.H.Abbott and A.E. Isley [*Earth and Planetary Science Letters* 205 (2002) 53-62]. *Earth and Planetary Science Letters*, 215, 425-427.

Glikson, A.Y. (2003) A comment on Hamilton, W.B., 2003, An alternative Earth. *GSA Today,* 13, 4-12.

Glikson, A.Y. (2003) Comment on "Impacts do not initiate volcanic eruptions: eruptions close to the crater"
by B.A. Ivanov and H.J. Melosh. *Geology*, 31.

Hermann, J. (2003) Carbon recycled into deep Earth: Evidence from dolomitic dissociation in subduction-zone rocks: Comment and reply. *Geology Forum*, Published Online: May 2003, doi:10.1130/0091-7613(2003)031, e4-45, 2003a.

Hermann, J. (2003) Experimental evidence for diamond-facies metamorphism in the Dora-Maira massif. *Lithos,* 70, 163-182.

Hermann, J., and Rubatto, D. (2003) Relating zircon and monazite domains to garnet growth zones: age and duration of granulite facies metamorphism in the Val Malenco lower crust. *Journal of Metamorphic Geology,* 21, 833-852.

Hills, Q., Betts, P.G., and Lister, G.S. (2003) Geophysical interpretation and modelling of the Oleary domain under cover: a hidden inverted rift system. *Australian Journal of Earth Sciences*, 50, 633-644.

Jackson, I., FitzGerald, J.D., Faul, U.H., and Tan, B. (2003) Grain-sized-sensitive seismic wave attenuation in polycrystalline olivine, *Journal of Geophysical Research* 2360, doi: 10.1029/2001JB001225

Liu, Y., Withers, R.L., and Fitz Gerald, J.D. (2003) A TEM, XRD, and crystal chemical investigation of oxygen/vacancy ordering in $(Ba_{1-x}La_x)\ {}_2In_2O_{5+x}$, 0²x²0.6, *Journal of Solid State Chemistry,* 170, 247-254.

Mack, S.J., and Paterson, M.S. (2002) New developments in deformation studies: high strain deformation, In: Plastic deformation of minerals and Rocks, Ed. S-I. Karato and H-R. Wenk, *Reviews in Mineralogy and Geochemistry*, Mineralogical Society of America, Washington DC, 51, 1-19.

Miller, M.S., Kennett, B.L.N., and Lister, G.S. (2003) Three-dimensional slab structure of the Izu- Bonin-Mariana arc system. *EOS Transactions*, 84, 46

Morishita, T., and Arai, S. (2003) Evolution of spinel-pyroxene symplectite in spinel-lherzolites from the Horoman Complex, Japan. *Contributions to Mineralogy and Petrology,* 144, 509-522.

Morishita, T., Arai, S., Gervilla, F., and Green, D.H. (2003) Closed-system geochemical recycling of crustal materials in alpine-type peridotite. *Geochimica et Cosmochimica Acta*, 67, 303- 310.

Morishita, T., Arai, S., and Green, D.H. (2003) Evolution of low-Al orthopyroxene in the Horoman peridotite,
Japan: an unusual indicator of metasomatising fluids. *Journal of Petrology,* 44, 1237- 1246.

Morishita, T., Arai, S., and Tamura, A. (2003) Petrology of an apatite-rich layer in the Finero phlogopiteÐperidotite, Italian Western Alps; implications for evolution of a metasomatising agent. *Lithos*, 69, 37-49.

O'Neill, H.S.C. (2003) The influence of next nearest neighbours on cation radii in spinels: the example of the Co_3O_4 - $CoCr_2O_4$ solid solution. *Mineralogical Magazine,* 67, 547-554.

O'Neill, H.S.C., Pownceby, M.I., and McCammon, C.A. (2003) The magnesiowüstite: iron equilibrium and its implications for the activity-composition relations of $(Mg,Fe)_2SiO_4$ olivine solid solutions. *Contributions to Mineralogy and Petrology*, 146, 308-325.

O'Neill, H.S.C., Redfern, S.A.T., Kesson, S.E., and Short, S. (2003) An in situ neutron diffraction study of cation disordering in synthetic qandilite Mg_2TiO_4 at high temperatures. *American Mineralogist,* 88, 860-865.

Pirajno, F., Hawke, P., Glikson, A.Y., Haines, P.W., and Uysal, T. (2003) Shoemaker impact structure, Western Australia. *Australian Journal of Earth Science*, 50(5), 775-796.

Rolland, Y., Cox, S.F., Boullier, A.-M., Pennacchioni, G., and Mancktelow, N. (2003) Rare Earth and trace element mobility in mid-crustal shear zones: insights from the Mont Blanc Massif (Western Alps). *Earth and Planetary Science Letters*, 214, 203-219.

Rubatto, D., and Hermann, J. (2003) Zircon formation during fluid circulation in eclogites (Monviso, Western Alps): Implications for Zr and Hf budget in subduction zones. *Geochimica et Cosmochimica Acta*, 67, 2173-2187.

Rybacki, E., Paterson, M.S., Wirth, R., and Dresen, G. (2003) Rheology of calcite-quarts aggregates deformed to large strain in torsion, *Journal of Geophysical Research,* 108, 2089, doi:10.1029/2002JB001833.

Schellart, W.P., Jessell, M.W., and Lister, G.S. (2003) Asymmetric deformation in the back-arc region of the Kuril Arc, Northwest Pacific: some insights from analogue modelling. *Tectonics*, 22, 1047-1065.

Spandler, C., Hermann, J., Arculus, R., and Mavrogenes, J. (2003) Redistribution of trace elements during prograde metamorphism from lawsonite blueschist to eclogite facies; implications for deep subduction-zone processes. *Contributions to Mineralogy and Petrology,* 146, 205-222.

Spandler, C.J., Arculus, R.J., Eggins, S.M., Mavrogenes, J.A., Price, R.C., and Reay, A.J. (2003) Petrogenesis of the Greenhills Complex, Southland, New Zealand: magmatic differentiation and cumulate formation at the roots of a Permian island-arc volcano. *Contributions to Mineralogy and Petrology,* 144, 703-721.

Stünitz, H., Fitz Gerald, J.D., and Tullis, J. (2003) Dislocation generation, slip systems, and dynamic recrystallization in experimentally deformed plagioclase single crystals. *Tectonophysics*, 372**,** 215-233.

Tenthorey, E., and Cox, S.F., (2003) Reaction-enhanced permeability during serpentinite dehydration. *Geology,* 31, 921-924.

Tenthorey, E., Cox, S., and Todd, H. (2003) Evolution of strength recovery and permeability during fluid-rock reaction in experimental fault zones. *Earth and Planetary Science Letters,* 206, 161-172

Tomkins, A.G., and Mavrogenes, J.A. (2003) Generation of metal-rich felsic magmas during crustal anatexis. *Geology*, 31, 765-768.

Treble, P., Shelley, J.M.G., and Chappell, J. (2003) Comparison of high resolution sub-annual records of trace elements in a modern (1911-1992) speleothem with instrumental climate data from southwest Australia. *Earth and Planetary Science Letters,* 216, 141-153

Webb, S., and Jackson, I. (2003) Anelasticity and microcreep in polycrystalline MgO at high temperature: an exploratory study, *Physics and Chemistry of Minerals,* 30, 157-166.

Wang, Z., Saxena, S.K., Lazor, P., and O'Neill, H.S.C. (2003) An in situ Raman spectroscopic study of pressure induced dissociation of spinel $NiCr_2O_4$. *Journal of the Physics and Chemistry of Solids*, 64, 425-431

top of page

Earth Physics Publications

Bannister S., Yu J., Leitner B., and Kennett B.L.N. (2003) Variations in crustal structure across the transition from West to East Antarctica, Southern Victoria Land, *Geophysical Journal International,* 155, 870-884.

Beavan J., Tregoning P., Bevis M., Kato T., and Meertens C. (2003) Motion and rigidity of the Pacific Plate and implications for plate boundary deformation, *Journal of Geophysical Research-Solid Earth,* 107(B11): art. No.-2261 Oct 2003

Braun, J. (2003) Geodynamics: recent advances in quantitative modeling of compressional orogens, in Geology, edited by K. Stuwe and B. Grasemann, in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK, [http://www.eolss.net]

Braun, J., (2003) Pecube: a new finite-element code to solve the 3D heat transport equation including the effects of a time-varying, finite amplitude surface topography. *Computers and Geosciences*, 29, 787-794.

Braun, J., Munroe, S.M., and Cox, S.F. (2003) Transient fluid flow in and around a fault. *Geofluids,* 3, 81-87.

Debayle E., and Kennett B.L.N. (2003) Surface wave studies of the Australian region, 25-40 in *The Evolution and Dynamics of the Australian Plate*, Geological Societies of Australia and America, (Ed. D. MŸller & R. Hillis).

Flemming, N.C., Bailey, G.N., Courtillot, V., King, G., Lambeck, K., Ryerson, F., and Vita-Finzi, C. (2003) *Coastal and marine palaeo-environments and human dispersal points across the Africa-Eurasia boundary*, Maritime Heritage, 2003, p. 61-74. in Brebbia, C.A. and Cambin T. (Eds.) Advances in Architecture, WIT Press, Southampton, 198 pp.

Furumura T., Kennett B.L.N., and Koketsu K. (2003) Visualization of 3-D wave propagation from the 2000 Tottori-Ken Seibu, Japan earthquake: observation and numerical simulation, *Bulletin of the Seismological Society of America,* 93, 870-881.

Gorbatov, A., and Kennett B.L.N. (2003) Joint bulk-sound and shear tomography for Western Pacific subduction zones, *Earth and Planetary Science Letters,* 210, 527-543.

Griffiths, R.W., Kerr, R.C., and Cashman, K.V. (2003) Patterns of solidification on channel flows with surface cooling. *Journal of Fluid Mechanics,* 496, 33-62.

Hansen, V.L. (2002) Artemis: signature of a deep Venusian mantle plume. *Geological Society of America Bulletin*, 114, 839-848.

Hansen, V.L. (2003) Venus diapirs: Thermal or compositional. *Geological Society of America Bulletin,* 115, 1040-1052.

Hong T-K., and Kennett B.L.N. (2002) On a wavelet-based method for the muerical simulation of wave propagation, *Journal of Computational Physics,* 183(2), 577-622.

Hong T-K., and Kennett B.L.N. (2003) Scattering attenuation of 2-D elastic waves: theory and numerical modelling using a wavelet-based method, *Bulletin of the Seismological Society of America,* 93, 922-938.

Hong, T-K., and Kennett, B.L.N. (2003) Modelling of seismic waves in heterogeneous media using a wavelet-based method: application to fault and subduction zones, *Geophysical Journal International*, 154, 483-498.

Kaufmann, G., and Lambeck, K. (2003) Glacial isostatic adjustment and the radial viscosity profile from inverse modelling, *Journal of Geophysical Research-Solid Earth,* 107(B11): art. No.-2280 Nov 2003.

Kennett, B.L.N. (2003) 85.10 Synthetic seismogram calculation using the reflectivity method, 1625-1626 (+ code on CD), *International Handbook of Earthquake and Engineering Seismology, Part B*, eds. W.H.K. Lee, H. Kanamori, P.C. Jennings & C. Kisslinger, Academic Press.

Kennett, B.L.N. (2003) Seismic Structure in the mantle beneath Australia, 7-23, in *The Evolution and Dynamics of the Australian Plate*, Geological Societies of Australia and America. (Ed. D. MŸller & R. Hillis).

Kennett, B.L.N., Brown, D.J., Sambridge, M., and Tarlowski, C. (2003) Signal parameter estimation for sparse arrays, *Bulletin of the Seismological Society of America* 93, 1765 -1772.

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

Kiss, A.E. (2002) Potential vorticity "crises", adverse pressure gradients and western boundary current separation, *Journal of Marine Research,* 60, 779-803.

Kiss, A.E. (2003) A modified quasigeostrophic formulation for weakly nonlinear barotropic flow with large-amplitude depth variations. *Ocean Modelling*, 5, 171-191

Lambeck, K., and Purcell, A. (2003) Glacial Rebound and Crustal Stress in Finland. *Posiva,* 2003-10, 1-84.

Lambeck, K., Purcell, A., Johnston, P., Nakada, M., and Yokoyama, Y. (2003) Water-load definition in the glacio-hydro-isostatic sea-level equation. *Quaternary Science Reviews,* 22, 309-318.

Tregoning, P. (2003) Is the Australian Plate deforming? A space geodetic perspective, *Geological Society of Australia. Special Publication* 22 and *Geological Society of America Special Publication,* 375, 2003.

Potter, E.-K., and Lambeck, K. (2003) Reconciliation of sea-level observations in the Western North Atlantic during the last glacial cycle. *Earth and Planetary Science Letters*, 217, 171-181.

Rawlinson, N., and Sambridge, M. (2003) Irregular interface parameterization in 3-D wide-angle seismic traveltime tomography, *Geophysical Journal International*, 155, 79-92.

Rawlinson, N., and Sambridge, M. (2003) Seismic travel time tomography of the crust and lithosphere, *Advances in Geophysics*, 46, 81-198.

Reading, A., Kennett, B., and Sambridge, M. (2003) Improved inversion for seismic structure using transformed S-wavector receiver functions: removing the effect of the free surface, *Geophysical Research Letters,* 30(19) 1981 doi: 10.1029/2003GL018090

Reading, A.M., and Kennett, B.L.N. (2003) Lithospheric structure of the Pilbara Craton, Capricorn Orogen and northern Yilgarn craton, Western Australia, from teleseismic receiver functions,*Australian Journal of Earth Sciences*, 50, 439-445.

Reading, A.M., Kennett, B.L.N., and Dentith, M.C. (2003) The seismic structure of the YilgarnCraton, Western Australia, *Australian Journal of Earth Sciences*, 50, 427-438.

Reading, A.M., Kennett, B.L.N., Sambridge, M. (2003) *Geophysical Research Letters,* 30, No.19, doi:10.1029/2003GL018090, 4th October 2003.

Subbey, S., Christie, M., and Sambridge, M. (2003) A strategy for Rapid Quantification of Uncertainty in Reservoir Performance Prediction, Society of Petroleum Engineers, SPE Reservoir Simulation symposium held in Houston, Texas, USA, 3-5 February, 2003, pp 1-12.

Sambridge, M. (2003) An ensemble view of Earth's inner core, *Science,* 299, 529-530.

Sambridge, M. (2003) Nonlinear inversion by direct search using the Neighbourhood Algorithm, *IASPEI Centennial International Handbook of Earthquake and Engineering Seismology*, 81B, Ch. 85-15, 1635-1637.

Sambridge, M., and Faletic, R. (2003) Adaptive whole Earth tomography, *Geochemistry, Geophysics, Geosystems*, 40(3) doi:10.10292001GC000213, 5 March 2003.

Sandiford, M., Frederiksen, S., and Braun, J. (2003) The long-term thermal consequences of rifting: implications for basin reactivation. *Basin Research,* 15, 23-43.

Takenaka, H., Tanaka, H., Okamoto, T., and Kennett, B.L.N. (2003) Quasi-cylindrical 2.5D modeling for large-scale seismic surveys, *Geophysical Research Letters,* 30(21), 2086, doi: 10.1029/2003GL018068.

Turner, J.S. (2003) Vertical transports produced by double-diffusive plumes in a confined homogeneous environment. *Journal of Fluid Mechanics,* 493, 131-149.

Wells, M.G., and Griffiths, R.W. (2003) The interaction of salt fingers with intermittent turbulence. *Journal of Geophysical Research,* 108 (C3): Art. No. 3080.

Zhao, C.-P., Kennett, B.L.N., and Furumura, T. (2003) Contrasts in regional wave propagation to station WMQ in central Asia, *Geophysical Journal International*, 155, 44-56.

Top of page

PRISE Publications

Augé, T., Cocherie, A., Genna, A., Armstrong, R., Guerrot, C. Mukherjee, M.M., and Patra, R.N.(2003) Age of the Baula PGE mineralization (Orissa, India) and its implications concerning the Singhbhum Archaean nucleus. *Precambrian Research,* 121, 85-101

Bauer, W., Jacobs, J., Fanning, C.M., and Schmidt, R. (2003) Late Mesoproterozoic arc and back-arc volcanism in the Heimefrontfjella (East Antarctica) and implications for the palaeogeography at the southeastern margin of the Kaapvaal_Grunehogna Craton. *Gondwana Research,* 6, 449-465

Borg, G., Kþrner, Buxton, M., Armstrong, R., and van der Merwe, S.W. (2003) Geology of the Skorpion Supergene Zinc Deposit, Southern Namibia. *Economic Geology,* 98, 749-771

Da Silva, L.C., Armstrong, R.A., Delgado, I.M., Pimentel, M., Arcanjo, J.B., De Melo, R.C., Teixeira, L.R., Jost, H., Filho, J.M.C. and Pereira, L.H.M. (2002) Reavaliação da evolução geológica em terrenos Pré-Cambrianos Brasileiros com base em novos dados U-Pb SHRIMP, Parte I: limite Centro-Oriental do Craton S‹o Francisco na Bahia. *Revista Brasileira de Geociencias,* 32(4), 501-512

Da Silva, L.C., Armstrong, R.A., Noce, C.M., Carneiro, M.A., Pimentel, M., Pedrosa-Soares, A.C., Leite, C.A., Vieira, V.S., Da Silva, M.A., De Castro Paes, V.J., and Filho, J.M.C. (2002) Reavaliação da evolução geológica em terrenos Pré-Cambrianos Brasileiros com base em novos dados U-Pb SHRIMP, Parte II: Or—geno Araçuai, Cinturão Mineiro e Cráton São Francisco Meridional. *Revista Brasileira de Geociencias*, 32(4), 513-528

Da Silva, L.C., Armstrong, R.A., Pimentel, M., Scandolara, J., Ramgrab, G., Wildner, W., Angelim, L.A.D.A., Vasconcelos, A.M., Rizzoto, G., Quadros, M.L.D.E.S., Sander, A. and De Rosa, A.L.Z. (2002) Reavaliação da evolução geológica em terrenos Pré-Cambrianos Brasileiros com base em novos dados U-Pb SHRIMP, Parte II: Orógeno Araçuai, Cinturão Mineiro e Cráton São Francisco Meridional. *Revista Brasileira de Geociencias* 32(4), 513-528

Eglington, B.M., and Armstrong, R.A. (2003) Geochronological and isotopic constraints on the Mesoproterozoic Namaqua-Natal Belt: evidence from deep borehole intersections in South Africa. *Precambrian Research*, 125, 179-189

Eglington, B.M., Thomas, R.J., Armstrong, R.A., and Walraven, F. (2003) Zircon geochronology of the Oribi Gorge Suite, KwaZulu-Natal, South Africa: constraints on the timing of trans-current shearing in the Namaqua-Natal belt. *Precambrian Research*, 123, 29-46

Fagan T.J, Taylor G. J., Keil K., Hicks T.L., Killgore M., Bunch T. E., Wittke J. H., Mittlefehldt D.W, Clayton R. N., Mayeda T. K., Eugster O., Lorenzetti S., and. Norman M. D. (2003) Northwest Africa 773: Lunar origin and iron-enrichment trend. *Meteoritics and Planetary Science*, 38, 529-554

Hervé, F., Fanning, C.M., and Pankhurst, R.J. (2003) Detrital zircon age patterns and provenance of the metamorphic complexes of southern Chile. *Journal of South American Earth Sciences,* 16, 107-123

Hervé, F., and Fanning, C.M. (2003) Early Cretaceous subduction of continental crust at the Diego de Almagro archipelago, southern Chile. *Episodes*, 26, 285-289

Ihlenfeld C., Norman M.D., Gagan M.K., Drysdale R.N., Maas R., and Webb J. (2003) Climatic significance of seasonal trace element and stable isotope variations in a modern freshwater tufa. *Geochimica et Cosmochimica Acta*, 67, 2341-2357

Jacobs, J., Bauer, W., and Fanning, C.M. (2003) New age constraints for Grenville-age metamorphism in western central Dronning Maud Land (East Antarctica), and implications for the palaeogeography of Kalahari in Rodinia. *International Journal of Earth Sciences,* 92, 301-315

Jacobs, J., Bauer, W., and Fanning, C.M. (2003) Late Neoproterozoic/Early Palaeozoic events in central Dronning Maud Land and significance for the southern extension of the East African Orogen into East Antarctica. *Precambrian Research*, 126, 27-53

Jacobs, J., Fanning, C.M., and Bauer, W. (2003) Timing of Grenville-age vs. Pan-African medium- to high grade metamorphism in western Dronning Maud Land (East Antarctica) and significance for correlations in Rodinia and Gondwana. *Precambrian Research,* 125, 1-20

Jacobs, J., Klemd, R., Fanning, C.M., Bauer, W., and Colombo, F. (2003) Extensional collapse of the late Neoproterozoic-Early Palaeozoic East African-Antarctic Orogen in central Dronning Maud Land, East Antarctica. *In*: Yoshida, M., Windley, B.F. and Dasgupta, S. (eds) *Proterozoic East Gondwana: Supercontinent Assembly and Breakup*, Geological Society, London, Special Publications 206, 271-287

Johnson, S.E., Fletcher, J.M., Fanning, C.M., Vernon, R.H., Paterson, S.R., and Tate, M.C. (2003) Structure, emplacement and lateral expansion of the San Jose« tonalite pluton, Peninsular Ranges batholith, Baja California, Mexico. *Journal of Structural Geology*, 25, 1933-1957

Kisters, A.F.M., Stevens, G., Dziggel, A., and Armstrong, R.A. (2003) Extensional detachment faulting and core-complex formation in the southern Barberton granite-greenstone terrain, South Africa: evidence for a 3.2 Ga orogenic collapse. *Precambrian Research* ,127, 355-378

Lee,C-T., Brandon, A.D., and Norman, M. (2003) Vanadium in peridotites as a proxy for paleo- fO2 during partial melting: prospects, limitations, and implications. *Geochimica et Cosmochimica Acta,* 67, 3045-3064

Liati, A., Gebauer, D., and Fanning, C.M. (2003) The youngest basic oceanic magmatism in the Alps (Late Cretaceous Chiavenna unit, Central Alps): geochronological constraints and geodynamic significance. *Contributions toMineralogy & Petrology,* 146, 144-158

Lund, K., Aleinikoff, J.N., Evans, K.V., and Fanning, C.M. (2003) SHRIMP U-Pb geochronology of Neoproterozoic Windermere Supergroup, central Idaho: Implications for rifting of western Laurentia and synchroneity of Sturtian glacial deposits. *Geological Society of America Bulletin,* 115, 349-372

Möller, A., Hensen, B.J.,Armstrong, R.A., Mezger, K., and Ballèvre, M. (2003) U-Pb zircon and monazite age constraints on granulite-facies metamorphism and deformation in the Strangways Metamorphic Complex (central Australia). *Contributions to Mineralogy and Petrology,* 145, 406-423

Norman M., Borg L., Nyquist L., and Bogard D. (2003) Chronology, geochemistry, and petrology of a ferroan noritic anorthosite clast from Descartes breccia 67215: clues to the age, origin, structure, and impact history of the lunar crust. *Meteoritics and Planetary Science*, 38, 645- 661

Norman M., Robinson P., and Clark D. (2003) Major and trace element analysis of sulphide ores by laser ablation ICPMS, solution ICPMS, and XRF. *Canadian Mineralogist,* 41, 293-305

Oberc-Dziedzic, T., Klimas, K., Kryza, R., and Fanning, C.M. (2003) SHRIMP U-Pb zircon geochronology of the Strzelin gneiss, SW Poland:evidence for a Neoproterozoic thermal event in the Fore-Sudetic Block, Central European Variscides. *International Journal of Earth Sciences*, 92, 701-711

Pankhurst, R.J., Rapela, C.W., Loske, W.P., Fanning, C.M., and M‡rquez, M. (2003) Chronological study of the pre-Permian basement rocks of southern Patagonia. *Journal of South American Earth Sciences,* 16, 27-44

Pimentel, M.M., Dantas, E.L., Fuck, R.A., and Armstrong, R.A. (2003) SHRIMP and conventional U-Pb age, Sm-Nd isotopic characteristics and tectonic significance of the K-rich Itapuranga Suite in Goi‡s, Central Brazil. *Anais da Academia Bras. de Ciências,* 75, no.1, 97-108

Pimentel, M.M., Hollanda, M.B.M., and Armstrong, R. (2003) Shrimp U-Pb age and Sr-Nd isotopes of the Morro do Baœ mafic intrusion: implications for the evolution of the Arenópolis volcano-sedimentary sequence, Goiás Magmatic Arc. *Anais da Academia Bras. de Ciências, 75, no.3, 331-339*

Pimentel, M.M., Lindenmayer, Z.G., Laux, J.H., Armstrong, R.A., and de Araœjo, J.C. (2003) Geochronology and Nd isotope geochemistry of the Gameleira Cu-Au deposit, Serra dos Carajás, Brazil: 1.8-1.7 Ga hydrothermal alteration and mineralization. *Journal of South American Earth Science,* 15, 803-813

Piuzana, D., Pimentel, M.M., Fuck, R.A., and Armstrong, R.A. (2003) SHRIMP U-Pb and Sm-Nd data for the Araxá Group and associated magmatic rocks: contsraints for the age of sedimentation and geodynamic context of the southern Bras'lia Belt, central Brazil. *Precambrian Research,* 125, 139-160

Piuzana, D., Pimentel, M.M., Fuck, R.A., and Armstrong, R.A. (2003) Neoproterozoic granulite facies metamorphism and coeval granitic magmatism in the Brasilia Belt, Central Brazil: regional implications of new SHRIMP U-Pb and Sm-Nd data. *Precambrian Research,* 125, 245-273

Puga, E., Fanning, C.M., Nieto, J.M., and D'az de Federico, y A. (2003) Datación U-Pb con SHRIMP de circones de las eclogitas ofiol'tas del Complejo del Mulhacén (Cordillera Bética). *Geogaceta*, 23, 131-134

Rainaud, C., Master, S., Armstrong, R.A., and Robb, L.J. (2003) A cryptic Mesoarchaean terrane in the basement to the Central African Copperbelt. *Journal of the Geological Society of London*, 160, 11-14

Rapela, C.W., Pankhurst, R.J., Fanning, C.M., and Grecco, L.E. (2003) Basement evolution of the Sierra de la Ventana fold belt: new evidence for Cambrian continental rifting along the southern margin of Gondwana. *Journal of the Geological Society of London,* 160, 613-628

Rapp R.P., Shimizu N., and Norman M.D. (2003) Growth of early continental crust by partial melting of eclogite. *Nature,* 425, 605-609

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

Seth, B., Armstrong, R.A., Brandt, S., Villa, I.M., and Kramers, J.D. (2003) Mesoproterozoic U-Pb and Pb-Pb ages of granulites in NW Namibia: reconstructing a complete orogenic cycle, *Precambrian Research,* 126, 147-168

Shiraishi, K., Hokada, T., Fanning, C.M., Misawa, K., and Motoyoshi, Y. (2003) Timing of thermal events in the eastern Dronning Maud Land, East Antarctica. *Polar Gesoscience*, 16, 76-99

Steven, N., and Armstrong, R.A. (2003) A metamorphosed Proterozoic carbonaceous shale-hosted Co-Ni-Cu deposit at Kalumbila, Kabompo Dome: the Copperbelt Ore Shale in northwest Zambia. *Economic Geology*, 98, 893-909

Tosdal, R.M., Cline, J.S., Fanning, C.M., and Wooden, J.L. (2003) Lead in the Getchell-Turquoise Ridge Carlin-type gold deposits from the perspective of potential igneous and sedimentary rock sources in northern Nevada: Implications for fluid and metal sources. *Economic Geology,* 98, 1189-1211

Yu Z., Norman M., and Robinson P. (2003) Major and trace element analysis of silicate rocks by XRF and laser ablation ICPMS using lithium borate fused glasses: matrix effects, instrument response, and results for international reference materials. *Geostandards Newsletter - Journal of Geostandards and Geoanalysis,* 27, 67-89

NEW GRANTS for 2003

Australian Research Council Grants (commenced in 2003)

Discovery Project Grants

Dr R. Armstrong: Precise global time scale for the oxidation of Earth's atmosphere between 2.6 and 2.0 billion years ago,
$60,000 (2003-05).

Dr A. J. Berry and Dr J. Hermann: Water storage in the Earth's mantle – understanding the process of OH incorporation in olivine,
$87,000 (2003-04).

Dr J. Braun: Constraining landform response to tectonic and climate changes in an active orogen: a multi-disciplinary approach,
$385,000 (2003 - 05).

Prof J. Chappell, Dr M. Honda, Dr D. Fabel and Dr L.K. Fifield: Production and transport of soil and sediments,
determined by cosmogenic radionuclides and noble gases, $295,000 (2003-05).

Prof J. Chappell and Dr T. Esat: Millenial scale instability of sea level and climate system: new analysis of coral terraces
in Papua New Guinea, $295,000 (2003-05).

Dr W. Dunlap and Dr S. McLaren: From synchrotron characterisation of single fluid inclusions to archaen geodynamic:
an integrated study of fluid-rock interaction in the primitive crust, $46,200 (2003-05).

Dr M. Gagan: Quantifying the El-Nino-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives,
$300,000 (2003-05).

Dr R.W. Griffiths and Dr R.C. Kerr: The fluid dynamics of lava flows: Silicic domes and basaltic channels. $220,000, (2003-05).

Prof R. Grün and Dr M.K. Gagan: Stable Isotopes in marsupials: reconstruction of environmental change in Australia,
$210,000 (2003-05).

Prof T.M. Harrison, Dr T.R. Ireland and Dr V.C Bennett: A mission to very early Earth: when did conditions suitable
for life emerge on Earth?' $300,000 (2003-05).

Dr M. Honda: Diamonds – a window into the ancient mantle; the origin and Earth's atmosphere and outgassing of the mantle,
$50,000 (2003).

Dr T. Ireland: Lithic astronomy: the age and origin of the elements and their incorporation in the solar nebular, $195,000 (2003-05).

Prof B.L.N. Kennett: Craton edges and sutures in the Australian mantle, $340,000 (2003-05).

Prof K. Lambeck, Dr D. Fabel and Dr P. Tregoning: Looking back to see the future: Change in the Lambert Glacier
and the East Antarctic Ice Sheet, $530,000 (2003-2006).

Prof G.S. Lister and Prof T.M. Harrison:Tectonic reconstruction of the evolution of the Alpine-Himalayan orogenic chain,
$710,000 (2003-07).

Dr A.P. Nutman and Dr V.C. Bennett: Early Archaen Ecology – exploring the evidence and habitats for early
(3.6 – 3.85 billion year old) life, $162,000 (2003-05).

Dr A.P. Nutman: Deep crustal section through a late archaen orogon (Greenland): Archaen crustal sutures, abyssal peridotites
and gold, $170,000 (2003-05).

Dr H.S.C. O'Neill, Dr J. Hermann, Dr J. Mavrogenes and Prof R.J. Arculus: Properties of hydrous fluids and silicate melts
at very high temperatures and pressures, $260,000 (2003-05).

Dr C. Pelejero: Uptake of Atmospheric CO2 in the oceans and implications for global change: new proxy developments, $263,035
(2003-05).

Dr P. Tregoning: Caught in a vice: Modelling crustal deformation in Papua New Guinea, $380,000 (2003-07).

ARC Linkage International Grant

Dr I. Jackson: High temperature elastic wave speeds of mantle minerals and their seismological implications, $20,000 (2003-04).

ARC Linkage Infrastructure, Equipment and Facilities Grant

Dr J. Braun, Dr M Sambridge ARC LIEF: GeoWulf: An Inference Engine for Complex Earth Systems, $376,951 (2003).

Other Grants commenced in 2003

Dr A.J. Berry, grant from the Victorian Dept of Innovation, Industry and Regional Development for the Australian Geological Convention,
$10,795 (2003).

Dr A.J. Berry, ANSTO ASRP grant to undertake work at the Australian National Beamline Facility, Photon Factory, Japan, $4,370 (2003).

Dr A.J. Berry, Dr J. Mavrogenes and Dr H. O'Neill, ANSTO AMRFP grant to visit GSECARS, Advanced Photon Source,
Argonne National Laboratory, USA, $11,050 (2003).

Dr A.J. Berry, Dr H. O'Neill and Mr S. Sommacal, ANSTO AMNRF grant to visit the European Synchrotron Radiation Facility,
Grenoble, France, $11,150 (2003).

Dr A.J. Berry, ANSTO ASRP grant, $6,680 (2003).

Dr E. Tenthorey, Swiss National Science Foundation Research Fellowship for work to be conducted at the ANU, $105,000 (2003).

Dr J.G. Wynn, Australian Institute of Nuclear Science and Engineering: AMS C-14 determinations of particle size fractions
from Australian soil organic carbon (SOC) to test Century model of SOC dynamics, $7357 (2003).

NATIONAL AND INTERNATIONAL LINKS

COLLABORATION WITH AUSTRALIAN UNIVERSITIES

Earth Chemistry

Dr C. Bryant with Prof B.W. Chappell (Macquarie University); Geochemistry, classification and petrogenesis of granites from the New England Batholith, Eastern Australia.

Dr I. H. Campbell and Dr C. Allen with Dr R. Squire and Dr C. Wilson (University of Melbourne); Dating detrital zircons from sandstones collected adjacent to Stawell gold mine in Victoria.

Dr I.H. Campbell and Dr C. Allen with Dr K. Sircombe (Tectonics Special Research Centre, University of Western Australia); Dating detrital zircons from sandstones collected from the Ashburton basin in Western Australia.

Prof T. M. Harrison member, Advisory Committee of the Australian Crustal Research Centre, School of Geosciences, Monash University.

Prof T. M. Harrison member, Science Advisory Council of the Tectonics Special Research Centre, The University of Western Australia.

Dr M. Honda with Dr D. Phillips (University of Melbourne); Noble gas studies in diamonds.

Dr T. R. Ireland with Dr J. Lattanzio (Monash University); Stellar nucleosynthesis.

Dr R. Page with Dr K. Barovich (School of Earth Sciences, University of Adelaide).

Dr I.S. Williams with Prof B.W. Chappell (Macquarie University); The evolution of the Lachlan Fold Belt as recorded in zircon preserved in igneous and sedimentary rocks.

Dr I.S. Williams with Dr I.S. Buick (La Trobe University) and Dr M. Hand (Adelaide University); Metamorphism in central Australia.

Dr I.S. Williams with Prof J. Hergt, Dr J. Woodhead and Mr R. Kemp (all of the University of Melbourne); Hf isotopes in zircon to study magma genesis in south-eastern Australia.

Dr I.S. Williams with Dr P. Lennox (University of New South Wales); Using granites to date deformation in the Wyangla region.

Earth Environment

Dr E. Calvo and Dr C. Pelejero with Dr P. De Deckker (Department of Geology, ANU); Reconstruction of past oceanic and climatic conditions using deep sea sediments.

Dr E. Calvo and Dr C. Pelejero with Dr W. Howard (Cooperative Research Centre for Antarctic and Southern Ocean Studies, University of Tasmania); Comparison of different proxies of past ocean chemistry.

Dr E. Calvo and Dr C. Pelejero with Prof A. Chivas (School of Geosciences, University of Wollongong); Geochemistry of sediments from Gulf of Carpentaria.

Prof J. Chappell with Mr M. Wilkinson and Dr G. Humphries (School of Earth Sciences, Macquarie University); Determination of long-term erosion rates under contrasting vegetation and physiographic conditions in the Blue Mountains, NSW.

Prof J. Chappell with Assoc Prof M. Melville and Mr A. Fisher (both School of Biology, Environment and Earth Science, University of New South Wales); Determination of semi-arid landscape evolution, Barrier Range, western NSW.

Dr S. Eggins with Dr P. De Deckker (Department of Geology, ANU), Chemistry of biogenic calcite precipitated by foraminifera and ostracoda.

Dr S. Eggins with Dr L. Danyushevsky (CODES, University of Tasmania); Accuracy of laser ablation ICPMS analysis of geological standard glasses using 213 nm and 193 nm wavelengths.

Dr S. Eggins and Prof R. Grün with Dr C. Murray-Wallace (School of Geosciences, University of Wollongong); Uranium uptake and open-system U-series dating of molluscs.

Dr D. Fabel with Assoc Prof J. Webb (Department of Earth Sciences, La Trobe University); The neotectonic evolution of the Cape Liptrap region, Victoria.

Dr M. Gagan with Dr P. De Deckker and Dr B. Opdyke (Department of Geology, ANU), Dr I. Goodwin and Dr R. Drysdale (School of Geoscience, University of Newcastle) and Prof R. Henderson (School of Earth Sciences, James Cook University); Continuing development of the ANU Major Equipment Committee funded “Stable-isotope microanalytical facility for palaeoclimate systems and global change research”.

Dr M. Gagan with Ms H. Bostok, Ms M. Spooner, and Ms K. Lilley (Department of Geology, ANU); Use of stable-isotope ratios in foraminifera and corals to reconstruct the palaeoceanography of Austral-Asian marginal seas.

Dr M. Gagan with Dr J. Magee (Department of Geology, ANU); Reconstruction of Australian palaeoclimates using isotopic signatures in emu and 'Genyornis' eggshell.

Dr M. Gagan with Dr J. Stevenson (Research School of Pacific and Asian Studies, ANU); Carbon-isotope ratios in
lacustrine sequences in the Philippines and New Caledonia.

Dr M. Gagan with Dr W. Howard and Mr A. Moy (University of Tasmania); Reconstruction of Southern Ocean
palaeoceanography from deep-sea sediment cores.

Prof R. Grün and Dr M. Gagan with Dr R. Wells (Flinders University) and Dr D. Bowman (Northern Territory University);
Stable isotopes in marsupials: reconstruction of environmental change in Australia (ARC Discovery Project grant).

Prof R. Grün with Prof A. Gleadow (Department of Earth Sciences, University of Melbourne); The thermal stability of
paramagnetic centres from cores of the Otway basin.

Prof R. Grün with Dr P. White and Dr J. Field, (University of Sydney); Dating of the Cuddie Springs site.

Prof R. Grün with Dr R. Wells (Flinders University), Dating South Australian sites with faunal remains, including
Naracoorte Cave and the Rocky River Site on Kangaroo Island.

Prof R. Grün with Prof R. Twidale (University of Adelaide); Onset of dune formation in the Stretzlecki Desert.

Dr W. Müller with Dr S. Blau (Flinders University); Reconstruction of prehistoric ways of life (sedentary vs. nomadic)
using isotopic techniques, especially using LA-MC-ICPMS for high-time resolved Sr isotopic data in tooth enamel.

Dr W. Müller with Dr J. Wartho (Curtin University); Single-grain IR laser 40Ar/39Ar dating of individual white micas
from the Iceman's intestine.

Dr W. Müller with Dr D. Durney (Macquarie University); Rb-Sr microsampling dating of fibrous minerals in strain shadows
around pyrite.

Dr B. Pillans with Prof A. Chivas (University of Wollongong) and Prof R. Bourman (University of South Australia); Regolith dating.

Dr E. Rhodes with Dr T. Fanning (Macquarie University); Fieldwork at Fowlers Gap, NSW, as part of continuing
collaborative research into the age, preservation and geomorphology of archaeological material in arid Australian environments.

Dr E. Rhodes, Prof R. Grün, Prof M. McCulloch and Prof J. Chappell with Dr P. Hearty (James Cook University) and
Dr C. Dortch (Perth); OSL dating of samples from Rottnest Island.
Dr E. Rhodes with Prof R. Twidale (Adelaide University); Dating of dunes from Victoria.

Dr E. Rhodes with Dr Karl-Heinz Wyrwoll (University of Western Australia); Dating of dune and lake shoreline samples from WA.

Dr E. Rhodes with Prof E. Colhoun (University of Newcastle); The chronology of glaciation in Ireland continued.

Earth Materials

Prof S.F. Cox, with Dr R. Offler and Mr K. Ruming (University of Newcastle); Dating of fault rocks in the Sydney Basin.

Dr A.J. Berry with Dr S.J. Campbell (Australian Defence Force Academy, University of New South Wales); Determining
Fe oxidation states in silicate glasses by Mössbauer spectroscopy.

Dr A. Glikson with Dr S. Golding and Dr T. Uysal (Department of Earth Science, University of Queensland);
Environmental effects of the late Devonian Woodleigh impact event.

Dr A. Glikson with Dr M.V. Glikson (Department of Earth Science, University of Queensland);
The palaeobiology and geochemistry of early Proterozoic black shales, Hamersley Basin, Western Australia.

Prof D.H. Green with Dr T.J. Falloon and Prof A.J. Crawford (Department of Earth Sciences, University of Tasmania);
Collaborative research while a Visiting Fellow in the School of Earth Sciences, University of Tasmania.

Dr J. Hermann with Dr D. Rubatto (Department of Geology, ANU);
Experimental determination of garnet-zircon-monazite-melt trace element partitioning.

Dr J. Hermann with Dr D. Rubatto (Department of Geology, ANU);
Relating zircon and monazite domains to garnet growth zones using trace elements.

Dr J. Hermann with Prof I. Buick and Ms A. Storkey (La Trobe University, Melbourne);
Trace element distribution in high temperature metamorphic minerals present during partial melting.

Dr J. Mavrogenes with Dr T. Ulrich (Department of Geology, ANU)
and colleagues (at James Cook University node of the Predictive Mineral Deposits CRC);
Analysis of fluid inclusions.

Earth Physics

Dr J. Braun with Prof A. Gleadow (University of Melbourne), Prof S. O'Reilly (Macquarie University),
Dr M. Dentith (University of Western Australia); Dr B. Minty, (Geoscience Australia), and Dr C. Beaumont
(Dalhousie University); GeoWulf: An Inference Engine for Complex Earth Systems (ARC–MEC LIEF Project).

Dr J. Braun with Dr P. Cummins (Geoscience Australia) and Prof M. Sandiford (University of Melbourne);
Active Faults and Geomorphology of the Flinders and Mt Lofty Ranges.

Prof R. W. Griffiths with Prof J. Middleton (University of New South Wales, Department of Aviation);
Turbulent flow in wakes in the coastal marine environment and in airflows around hills and buildings.

Prof K. Lambeck with Assoc Prof R. Coleman (University of Tasmania); Looking Back to See the Future (ARC Discovery Project).

PRISE

Mr C.M. Fanning with Assoc Prof C. Fergusson (University of Wollongong) and Prof R. Henderson, (James Cook University);
Tectonics of the Neoproterozoic – Early Palaeozoic margin in eastern Australia.

Mr C.M. Fanning with Prof J. Roberts (University of NSW); The timing of Carboniferous-Permian volcanic rocks in the Tamworth belt, NSW.

Mr C.M. Fanning with Dr K. Knesel (University of Queensland); The timing and protolith history of Cenozoic volcanic rocks from Chile.

Mr C.M. Fanning with Dr M. Rubenach (James Cook University); The geochronology of granitic rocks in north west Queensland.

Dr R. Armstrong with Prof D. Gray (University of Melbourne); Dating ophiolite succession in Oman.

Dr R. Armstrong with Prof D. Gray (University of Melbourne) and Dr B. Goscombe (Geological Survey of Western Australia);
Tectonic and geochronological investigation of the Koaka Belt, Namibia.

Dr G. Yaxley with Dr D. Kamenetsky and Mrs. Maya Kamenetsky (University of Tasmania); Melt inclusions in picrites from
Padloping Island, north western Canada.

Dr G. Yaxley with Dr D. Kamenetsky and Dr G. Nichols (University of Tasmania); The geochemistry and petrogenesis of
carbonatites from Antarctica.

Dr M. Norman with Mr. P. Robinson and Mr. D. Clark (Centre for Ore Deposit Research, University of Tasmania);
Major and trace element analysis of sulphide ores by laser ablation ICPMS.

INTERNATIONAL COLLABORATION

Top of page

Earth Chemistry

Dr V.C. Bennett with Prof M. Garcia (University of Hawaii); Siderophile element systematics and Pb isotopic compositions of the Hawaiian plume.

Dr V.C. Bennett with Dr Adam Kent (Oregon State University); Pb isotopic compositions of melt inclusions.

Dr V.C. Bennett with Prof D. DePaolo and K. Weaver (University of California, Berkeley); Sr isotopic compositions in the early Earth.

Dr V. Bennett and Dr M. Norman with Dr Y. Amelin (Canadian Geological Survey); Hf and Nd compositions of lunar samples.

Dr I.H. Campbell and Dr C. Allen with Dr M. Palin (University of Otago); Dating zircons from the two
youngest caldera-forming ignimbrites of the Yellowstone volcanic field, using the laser ablation ICP-MS.

Dr I.H. Campbell and Dr C. Allen with Prof P. Reiners (Yale University); Double-dating [U/Pb and (Th + U)/He)] of detrital zircons in sedimentary provenance studies.

Dr I.H. Campbell with Dr M. Palin (University of Otago); The use of Ce^{4+}/Ce^{3+} in zircon as a means of determining the oxidation state of felsic rocks.

Prof T.M. Harrison with Prof S.J. Mojzsis (Dept. of Geological Sciences, University of Colorado); Dr F.J. Ryerson
(Lawrence Livermore National Laboratory); Prof K.D. McKeegan (Dept. of Earth and Space Sciences, UCLA);
Prof B.P. Bourdon (Institut de Physique du Globe, Universite de Paris); Professor J.L. Kirschvink
(Geological and Planetary Sciences, Caltech); Dr Y. Amelin (Geological Survey of Canada); Professor A. Yin
(Dept. of Earth and Space Sciences, UCLA), Prof F. Albarède and Dr J. Blichert-Toft, Ecole Normale Superieure de Lyon.

Dr M. Honda with Dr J.W. Harris (University of Glasgow) and Dr P. Cartigny (University of Paris); Noble gas studies in diamonds.

Dr T.R. Ireland with Dr S. Weaver (University of Canterbury) and colleagues at the SHRIMP laboratories (Stanford University,).
Dr T.R. Ireland also visited Canterbury University, New Zealand to work on a paper with Prof S. Weaver and Dr J. Bradshaw.

Dr T.R. Ireland with Prof K. McKeegan (UCLA) and Prof E. Zinner (Washington University,); The history of the early solar system.

Dr A.P. Nutman with Dr F. Kalsbeek, Dr A.A. Garde and Dr P.R. Dawes (Geological Surveys of Denmark and Greenland);
SHRIMP geochronological projects in Greenland.

Dr A.P. Nutman with the Geological Survey of Denmark and Greenland.

Dr A.P. Nutman with Dr C.R.L. Friend (Oxford Brookes University, UK); Archaean crustal evolution in Greenland.

Dr A.P. Nutman with Dr B. Chadwick (University of Exeter, UK); Archaean crustal evolution in India.

Dr A.P. Nutman with Prof U.G. Cordani and Dr M. Basei (University of Sao Paulo, Brazil); Precambrian evolution of South America.

Dr A.P. Nutman with Dr J.A. Gilotti (University of Iowa, USA); Evolution and extent of a Caledonian eclogite province in East Greenland.

Dr A.P. Nutman and Dr V.C. Bennett with Dr D. DePaolo (University of California, Berkeley);
Searching for suites of well-preserved zircons of different ages for Sr isotope studies of their inclusions.

Dr A.P. Nutman with Nunaminerals A/S (a prospecting company associated with the Greenland Homerule Government);
The study of Archaean gold mineralisation in the Nuuk district, West Greenland.

Dr Nutman also established a collaborative arrangement with the SHRIMP Group of the University of Hiroshima,
which will see zircon dating of some Greenland rocks being undertaken as part of a Hiroshima University PhD student project.

Dr I.S. Williams with the Geological Survey of Canada, Ottawa; Hiroshima University, Japan, the National Institute of Polar Research,
Tokyo; the Chinese Academy of Geological Sciences, Beijing; and the All-Russian Geological Research Institute (VSEGEI), St Petersburg.

Dr I.S. Williams with Prof S. Bowring and Dr J. Baldwin (Massachusetts Institute of Technology);
Dating eclogite from Canada using fine zircon grains discovered in thin sections of metamorphic minerals.

Dr I.S. Williams with Dr R. Findlay and Mr G. Kopi (Geological Survey of Papua New Guinea); A study of metamorphic rocks from Papua New Guinea.

Dr I.S. Williams lectured at a 3-day short course in August on granite petrogenesis at Seoul

National University at the invitation of Prof Moonsup Cho,
and in October agreed to commence a collaborative study of the buried East European Craton with Dr J. Wiszniewska (Polish Geological Institute).

Earth Environment

Dr E. Calvo and Dr C. Pelejero with Dr Simó and Dr Marrasé (Marine Sciences Institute CMIMA-CSIC, Barcelona, Spain); Culturing diatoms and coccolitophorae algae.

Dr E. Calvo and Dr C. Pelejero with Prof J.M. Gili (Marine Sciences Institute CMIMA-CSIC, Barcelona, Spain); Isotopic
studies of siliceous sponges from Antarctica.

Dr E. Calvo and Dr C. Pelejero with Dr J. Fornós (Universitat de les Illes Balears, Mallorca, Spain); Geochemistry of phreatic overgrowths
on Mediteranean speleothems.

Dr E. Calvo and Dr C. Pelejero with Dr I. Cacho (Universitat de Barcelona, Spain) and Dr Skinner (Cambridge University, UK);
LA-ICP-MS analysis of foraminifera.

Prof J. Chappell with Prof Wang Pinxian (Laboratory of Marine Geology; Tongji University, Shanghai China); Yangtse River:
sediment fluxes from source to sink.

Prof J. Chappell with Dr A. Heimsath and Mr B. Burke (Dartmouth University, Hanover New Hampshire USA);
Determination of chemical changes during granite weathering.

Dr S. Eggins with Mr A. Sadekov (Department of Palaeontology, University of Moscow, Russia) and Prof P. De Deckker
(Department of Geology, ANU); Mg and Ca distribution in tests of the planktonic foraminifera Orbulina universa.

Dr S. Eggins with Dr M. Ellwood and Dr M. Kelly (National Institute of Water, Hamilton, New Zealand); LA-ICPMS
elemental and isotopic analysis of siliceous marine sponges.

Dr D. Fabel with Dr J. Harbor (Purdue University) and Dr A. Stroeven (stockholm University); Cosmogenic nuclide-base
boundary conditions for numerical ice sheet models: a simulation of the Fennoscandian Ice Sheet through a glacial cycle
(US National Science Foundation project: OPP-0138486).

Dr D. Fabel and Prof K. Lambeck with Drs A. Stroeven, J. Harbor, A. Hubbard, C. Hättestrand, and J-O.Näslund;
Cosmogenic nuclide-based boundary conditions for numerical ice sheet models: a simulation of the Fennoscandian Ice S
heet through a glacial cycle (Vetenskapsradet, Sweden, funded project: G-AA/GU 12034-301).

Dr D. Fabel with Prof T. Gardiner (Department of Geosciences, Trinity University, San Antonio, Texas); Burial dating of
marine sediments using the relative decay of cosmogenic 10Be and 26Al.

Dr D. Fabel with Prof S. Björk (Lund University, Sweden); Cosmogenic exposure dating of Baltic Ice Lake drainage deposits.

Dr M. Gagan and Ms N. Abram and Mr D. Qu with Dr W. Hantoro and colleagues (Indonesian Institute of Sciences);
Quantifying the El Niño-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives (ARC Discovery Project grant).

Dr M. Gagan with Drs T. Correge, G. Cabioch, and L. Ortlieb (Institute for Research and Development, New Caledonia);
Reconstructing tropical palaeoclimates of the southwestern Pacific.

Dr M. Gagan with Prof G. Miller (University of Colorado), Dr M. Fogel (Carnegie Institution of Washington) and
Dr B. Johnson (Bates College); Reconstruction of Australian palaeoclimates and megafauna extinction using carbon-isotope
signatures in emu and Genyornis eggshell.

Dr M. Gagan with Ms N. Grumet and Prof R. Dunbar (Stanford University), Drs W. Beck (University of Arizona); and
Dr T. Guilderson (Lawrence Livermore National Laboratory); High-resolution AMS measurements of nuclear bomb-test
C-14 in Indian Ocean corals.

Dr M. Gagan and Ms R. Berdin with Dr A. Srinigan (University of the Philippines); Extraction of late Quaternary climatic
histories from raised coral terraces.

Dr M. Gagan with Dr H. Kawahata, Dr A. Suzuki, and Ms M. Inoue (Tohoku University); Using the geochemistry of
Indonesian corals to study marine pollution histories.

Prof R. Grün with numerous international scholars, The timing of modern human evolution based on collected hominid samples
from the anthropological sites Cave of Hearths, Hutjiespunt, Swartkrans, and Border Cave South Africa (Prof V.A. Tobias,
Dr L. Berger, Dept of Anatomy, Medical School, University of the Witwatersrand, Prof J. Parkington, Dept of Archaeology, Cape Town University,
Dr F. Thakeray (Transvaal Museum, Pretoria), Skhul, Israel (Dr J. Pilbeam, Peabody Museum, Harvard University and Prof O. Bar-Yosef, Dept of Anthropology, Harvard University), Tabun, Israel (Prof C.B. Stringer, Natural History Museum, London) and Atapuerca, Spain
(Prof J.L. Arsuaga, Dept of Palaeontology, Universidad Compultense, Madrid and Prof J. Bermudes de Castro, Museo de Ciencias Naturales, Madrid), Banyoles, Spain (Prof J. Maroto, Area de Prehistoria, Universitat de Girona), Sale and Thomas Quarry, Marocco (Prof

J.J. Hublin, Laboratoire d'Anthropologie, Université Bordeaux 1).

Prof R. Grün with Dr J. Brink (Bloemfontein); Dating of a range of sites in South Africa, including the newly discovered human site of Cornelia.

Prof R. Grün with Dr A. Pike (University of Oxford); Uranium uptake of bones.

Prof R. Grün with Prof Trinidad de Torres (Escuela Tecnica Superior de Ingenieros de Minas de Madrid);
The calibration of amino acid racemisation in bones, cave bear evolution and dating human material from Sidron.

Prof R. Grün with Prof H. Wopfner, Prof U. Radtke and Dr A. Hilgers (Universität zu Köln); The onset of dune formation in the Stretzlecki Desert.

Dr W. Müller with Dr H. Fricke (Colorado College, USA); The application of stable isotopes to the Iceman.

Dr W. Müller with Prof A. H.alliday (ETH Zurich), Dr P. Tropper (University of. Innsbruck), and Dr E. Egarter-Vigl (Bolzano, Italy); Various aspects of Iceman research.

Dr W. Müller with Dr P. Eichhubl (Stanford University); U-series dating of cyclic seismogenic fault cements to establish earthquake recurrence intervals.

Dr W. Müller with Dr S. Grimes (Royal Holloway University of London); _18O analysis of tooth enamel phosphate.

Dr W. Müller with Dr C. Spötl (University of Innsbruck); In-situ Sr isotopic analysis of alpine speleothems by laser ablation-MC-ICPMS.

Dr W. Müller with Prof K. W. Alt (University of Mainz); Accurate reconstruction of Pb burden in a medieval mining community using
LA-ICPMS analysis of teeth.

Dr W. Müller with Prof G. Rabeder (University of Vienna); U-series dating of cave bear teeth.

Dr B. Pillans is a member of the Subcommission on Quaternary Stratigraphy (SQS) and the working group on the Lower-Middle
Pleistocene Boundary, both for the International Commission on Stratigraphy (ICS). He is also president of the Stratigraphy and
Chronology Commission of the International Union for Quaternary Research (INQUA).

Dr B. Pillans with Dr T. Naish, Dr A. Beu and Dr B. Alloway (New Zealand Institute of Geological and Nuclear Sciences, IGNS),
facilitating collaborative studies of Quaternary sedimentary sequences in the North Island, New Zealand, in his continuing appointment
as a Research Associate of IGNS.

Dr E. Rhodes with Dr A. Bouzouggar (Institut National des Sciences de l'Archéologie et du

Patrimoine, Rabat, Morocco) and
Dr N. Barton (University of Oxford, UK).

Dr E. Rhodes with Prof R. Hedges (University of Oxford), Dr C. Willis and Dr J-L. Schwenninger, Fieldwork at Taforalt, Oujda,
Morocco, as part of a UK NERC-funded EFCHED project.

Dr E. Rhodes with Dr C. Lewis (Los Alamos National Laboratory, Arizona) and Dr C. Sancho Marcen (University of Zaragoza,)
and others; Dating of Pyreneen glaciation, denudation, incision and terrace formation.

Dr E. Rhodes with Dr J. Scourse (University of Wales, Bangor), Dr D. McCarroll (University of Wales, Swansea) and others;
Pleistocene glacial and sea level history of the isles of Scilly, UK.

Dr E. Rhodes with Dr J. Kemp (University of Northumbria); Dating of fluvial and aeolian samples from the Lachlan River, NSW.

Dr E. Rhodes with Dr J. Feathers (University of Washington) and others; Statistical analysis using Bayesian methods of
luminescence dates from an early pre-Clovis site in Virginia, USA.

Earth Materials

Dr A. J. Berry with Drs S. Wimperis (University of Exeter) and Dr S.E. Ashbrook (University of Cambridge); 17O
nuclear magnetic resonance studies of ringwoodite.

Dr A. J. Berry with Dr S.R. Sutton and Dr M. Newville (University of Chicago); The chemical state of metals in fluid
and melt inclusions.

Dr A. J. Berry with Dr N. Métrich (CEA-CNRS, France); The oxidation state of sulfur in quenched silicate melts.

Dr A. J. Berry with Dr S.J. Clarke (University of Oxford); The synthesis of novel phosphides at high pressure.

Prof S. F. Cox with Dr N. Mancktelow (ETH-Zurich, Switzerland), Dr A. M. Boullier (Univertite Joseph Fourier, Grenoble),
Dr .Y Rolland (Universite de Nice, France) and Dr G. Pennachioni (Universita di Padova, Italy).

Prof S. F. Cox with Prof G. Dipple, (University of British Columbia, Canada); Review of aspects fluid flow in hydrothermal
ore systems in the mid- to deep crust for the 100th Anniversary volume of ‘Economic Geology’.

Prof S. F Cox with Dr S. Miller (ETH-Zurich); Modelling of fluid flow in fault networks.

Prof D.H. Green with Prof G.P. Brey, Dr M. Seitz and Dr D. Röhnert (Institut für Mineralogie and Petrologie, Goethe University of Frankfurt);
The genesis of highly undersaturated, intraplate magmas (research supported by the Humboldt Foundation, Germany).

Prof D.H. Green with Prof M.W. Schmidt (ETH, Zürich); Experimental studies of the genesis of island arc magmas under the
influence of melt-fluxing by CO2 + H2O.

Prof D.H. Green with Assoc Prof K. Niida (University of Hokkaido, Japan) and Dr T. Morishita (Kanazawa University, Japan);
The petrogenesis of the Horoman Peridotite, Hokkaido - particularly on evidence for complex mantle recycling of the peridotite
and late-stage channelling by volatile-rich magmas.

Dr J. Hermann with Dr A. Korsakov (Geophysics and Mineralogy, Novosibirsk); on evidence for
carbonatite and silicate melt involvement in the genesis of micro-diamonds in subducted continental crust.

Dr J. Hermann with Prof M. Scambelluri (University of Genova); on constraints on subduction zone fluids from high pressure ultramafic rocks.

Dr J. Hermann with Prof B. Cesare (University of Padova); on primary melt inclusions in andalusite from anatectic graphitic metapelites -
implications for the Al2SiO5 triple point.

Dr J. Hermann with Prof V. Trommsdorff (ETH-Zürich); on zircon metasomatism in a subduction zone garnet peridotite.

Prof G. Lister with Prof R. Companoni (Turin University) and Prof J. Bertrand (CRNS Laboratories, Chambery, France);
Episodicity during Orogenesis Project.

Prof G. Lister with Prof A. Yin (UCLA), Mr A. Webb (UCLA), and Dr C. Dubey (University of New Delhi); Himalaya Project.

Prof I. Jackson with Dr G. Gwanmesia (Delaware State University) and Prof Liebermann (Stony Brook University);
High-temperature measurements of elastic wave speeds and their seismological implications.

Prof I. Jackson with Dr Bejina (University of Toulouse); Diffusion in olivine.

Ms M. Miller with Dr W. Mooney (the US Geological Survey, Menlo Park, California); Crustal thickness maps.

Ms M. Miller with Mr P. White (Dynamic Graphics, Inc., Alameda, California); Three-dimensional visualization and modeling using tomography.

Ms M. Miller with Dr A. Gorbatov (JAMSTEC, Japan); Bulk sound and shear wave speed inversion of the northwest Pacific margin.

Dr E. Tenthorey with Dr C. Hilgers (RWTH Aachen).

Earth Physics

Dr J. Braun is an associate member of the Canadian Institute for Advanced Research, Earth System Evolution Program.

Dr G. F. Davies with Prof H. P. Bunge (University of Munich), and Dr J. Baumgardner (Los Alamos Scientific Laboratory);
Extension of Terra, computer code for modelling three-dimensional flow in the Earth's mantle, to use tracers and lithospheric
plates to investigate the chemical and isotopic evolution of the mantle.

Prof R. W. Griffiths and Dr R.C. Kerr with Prof K.V. Cashman (Department of Geological Sciences, University of Oregon);
Laboratory modelling of the surface solidification in shear flows and lava flows (funded by ARC and NSF research grants).

Prof R. W. Griffiths and Dr R.C. Kerr with Dr N. Stevens (Institute of Geological and Nuclear Sciences, New Zealand);
The dynamics of the emplacement of large andesitic lava flows on Tongariro volcano, New Zealand.

Prof R.W. Griffiths with Dr A.A. Bidokhti (Department of Geophysics, University of Tehran);
The role of internal gravity waves in ocean outflows from gulfs and marginal seas.

Prof R.W. Griffiths with Prof C. Kincaid (Graduate School of Oceanography, University of Rhode Island);
Three-dimensional patterns of circulation and thermal evolution in the mantle wedge above subduction zones.

Dr G.O. Hughes and Prof R.W. Griffiths with Prof W.H. Peterson (EMS Environment Institute, Penn State);
The role of plumes in the global overturning circulation in the oceans.

Dr R.C. Kerr with Dr C. Meriaux (Institut de Physique du Globe de Paris); Experimental modelling of the sheared mantle plumes.

Prof B.L.N. Kennett completed his term as President of the International Association for Seismology and the Physics of the Earth's Interior
(IASPEI) at the General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Sapporo in July. He continues on the
IASPEI Executive as Past-President.

Prof B.L.N. Kennett and Mr S. Fishwick with Dr E. Debayle (University of Strasbourg, France), Dr M. Ritzwoller
(University of Colorado) and Dr K. Yoshizawa, (University of Hokkaido, Japan); Surface

wave tomography.

Prof B.L.N. Kennett with Dr T. Furumura (Earthquake Research Institute, University of Tokyo, Japan);
Issues in seismic wave propagation, particularly propagation of high frequency waves in subduction zones from deeper earthquakes.

Prof B.L.N. Kennett continued support to the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organisation in
Vienna through the operation of the Warramunga Seismic and Infrasound Research Station near Tennant Creek in
the Northern Territory. The seismic and infrasound arrays have been well supported by Mr J. Grant and Mr P. Biggs.
Very high reliability has been achieved with data transmitted continuously to the International Data Centre in Vienna via satellite link. Mr J.
Grant took up the position of infrasound technician with the CTBT in Vienna at the end of August, and Mr P. Biggs has been appointed
as station manager. Mr J. Duan was appointed as a technical officer in November.

Prof K. Lambeck with Drs M. Anzidei (INGV) and F. Antonioli (ENEA, Rome); A study of Roman archaeological sites for
extracting sea level and tectonic information.

Prof K. Lambeck with Dr D. Sivan (Haifa, Israel); A study of ancient well levels in Caesaria, Israel.

Prof K. Lambeck and Dr A. Purcell for Posiva-Finland; A study of Glacial Rebound and Crustal Stress in Finland.

Dr H. McQueen and Prof K. Lambeck with Prof T. Sato (National Astronomical Observatory of Japan); Operating and analysing a Superconducting Gravimeter at Mt Stromlo to monitor dynamic processes inside the Earth.

Dr M. Sambridge with Mr T. Nicholson (University of British Columbia) and Dr O. Gudmundsson (Danish Lithospheric Centre); Aspects of global heterogeneity and its influence on seismic travel times.

Dr M. Sambridge with Prof M. Christie and Dr S. Subbey (Heriot Watt University); Uncertainty estimation in reservoir simulation.

Dr M. Sambridge with Dr E. DeBayle (CNRS and Universite Louis Pasteur, Strasbourg); Surface waveform inversion with variable parameterisations.

Dr M. Sambridge with Dr A. Gorbatov (JAMSTEC, Japan); Tomography in irregular parameterisations and visualization of tomographic models.

Mr R. Stanaway with PNG University of Technology, National Mapping Bureau, Geological Survey of PNG and Rabaul
Volcanological Observatory; Densification and establishment of GPS geodetic monitoring networks in Papua New Guinea:

in support of Dr P. Tregoning's ARC Discovery Grant project, 'Caught in a vice: Modelling crustal deformation in Papua New Guinea'.

Prof J.S. Turner with Prof G. Veronis (Yale University); The influence of double-diffusive processes on the melting of ice in the Arctic Ocean.

Prof J.S. Turner with Prof P.F. Linden (University of California, SanDiego); The production of vortex rings and the application
to the propulsion of aquatic animals.

PRISE

Dr R.A. Armstrong with C. Lana, Prof W.U. Reimold and Dr R. Gibson (University of the Witwatersrand, South Africa);
Geochronology of the Vredefort impact structure.

Dr R.A. Armstrong with Prof S. McCourt (University of Durban-Westville, South Africa) and Prof A.B. Kampunzu (University of Botswana);
The ages of basement rocks, the Kunene Complex and the provenance and correlation of Proterozoic sediments in southern Angola.

Dr R.A. Armstrong with S. Kamo (Royal Ontario Museum, Canada), Prof. A. Wilson (University of Natal, South Africa); The absolute
age and duration of Bushveld Complex mafic magmatism.

Dr R.A. Armstrong with Prof A. Mitchell (University of Durban-Westville, South Africa); The age and geochemistry of the UG2 reef,
Bushveld Complex.

Dr R.A. Armstrong with Prof M. de Wit (University of Cape Town, South Africa); The evolution of the Cape Fold Belt, South Africa.

Dr R.A. Armstrong with Dr. J. Ward (De Beers Exploration, South Africa); The provenance and history of diamond-bearing sediments
from the Orange River, southern Africa.

Dr R.A. Armstrong with Prof D. Reid and Prof R. Baillie (University of Cape Town, South Africa); Geochemistry and geochronology
of the Bushmanland Sequence, South Africa.

Dr R.A. Armstrong with T.J. Majaule, B.K. Paya (Geological Survey of Botswana) and Dr R. Mapeo and
Prof. A.B. Kampunzu (University of Botswana); Geochronological studies of Botswana.

Dr R.A. Armstrong with B. Bene (Eduardo Mondlane University, Mozambique /University of Natal, South Africa);
Tectonic evolution of central Mozambique.

Dr R.A. Armstrong with G. Moen (Council for Geoscience, South Africa), Prof N. Beukes

and Prof H. van Niekerk (Rand Afrikaans
University, South Africa); U-Pb geochronology and provenance studies in eastern Namaqualand.

Dr R.A. Armstrong with J. Mukhopadhyay (Presidency College, India) and Prof N. Beukes (Rand Afrikaans University, South Africa);
The geochronology of Archaean and Early Proterozoic granites and associated sediments from the Bastar Carton, Central India.

Dr R.A. Armstrong with N. Nhleko (Geological Survey of Swaziland/ Rand Afrikaans University) and Prof N. Beukes
(Rand Afrikaans University, South Africa); Further studies on the history of volcanism in the Pongola Group.

Dr R.A. Armstrong with Prof R. Scheepers (Stellenbosch University, South Africa); Geochronology of the Cape Granites, South Africa.

Dr R.A. Armstrong with Dr B. Eglington (University of Saskatchewan, Canada); Development of a geochronological database
for southern Africa.

Dr R.A. Armstrong with Dr. P. Mendonidis (Vaal Traingle Technikon, South Africa), Drs G. Grantham, P. Macey, G. Moen and T. Cloete
(Council for Geoscience, South Africa); Geochronology, stratigraphy and tectonics of critical lithologies in the Namaqual-Natal Belt.

Dr R.A. Armstrong with Dr D-L. Cho (Korea Institute of Geology, Mining and Materials, South Korea); Geochronology and stratigraphy
of the Korean peninsula.

Dr R.A. Armstrong with Prof F. Chemale (Rio Grande do Sul University, Brazil); Geochronology and provenance studies of various
sequences in Brazil and Namibia.

Dr R.A. Armstrong with Dr C. Noce (Universidade Federal de Minas Gerais, Brazil); Isotopic studies on the eastern margin of the
São Francisco Craton and the Araçuai Belt, Brazil.

Dr R.A. Armstrong with D. Broughton (Colorado School of Mines, USA); SHRIMP U-Pb dating of basement rocks to the
Katangan Sequence, Zambian Copperbelt.

Dr R.A. Armstrong with K. Kenyon (Anglogold Limited, South Africa); The geochronology of the Morila Gold Mine, Mali.

Dr R.A. Armstrong with K. Kenyon (Anglogold Limited, South Africa); The source of sediments and maximum age constraints
on deposition and mineralisation of the Crixas gold deposit, Brazil.

Dr R.A. Armstrong with Prof L. Robb (University of the Witwatersrand, South Africa);

Geochronology of selected
granites from the Democratic Republic of the Congo and Zambia.

Dr R.A. Armstrong with Z. Bagai and Prof A. Le Roex (University of Cape Town, South Africa) and Prof H. Kampunzu
(University of Botswana); The geochemistry and geochronology of granite-greenstone belts in NE Botswana.

Dr R.A. Armstrong with Prof J-M. Bertrand (CNRS, France); U-Pb geochronology of the Alpine Gran Paradiso orthogneisses
(Savoy, Aosta Valley, Piemont).

Dr R.A. Armstrong with Dr G. Brandl (Council for Geoscience, South Africa); Dating of lavas from the Soutpansberg succession
and the Pietersburg greenstone belt, South Africa.

Dr R.A. Armstrong with Dr Jean-Paul Liégeois (Africa Museum, Belgium); Deciphering the structure and tectonic history of the Aïr region
(SE Taureg shield) in Niger.

Dr R.A. Armstrong with Dr M Bröcker (Universität Münster, Germany); SHRIMP U-Pb geochronology of the migmatites and granulites
of the Snieznik Mountains, Poland.

Dr. R.A. Armstrong with A. Rogers and Prof M. Meyer (Institut für Mineralogie und Lagerstättenlehre, Aachen, Germany); U-Pb dating
of zircons and titanites from granitoid rocks from the Hutti-Maski Greenstone belt, India.

Dr R.A. Armstrong with J. Konzett, C. Miller and M Thöni (University of Innsbruck, Austria); Metamorphic evolution of the
jadeite-bearing felsic gneisses from the Eclogite Zone, Tauern Window, Eastern Alps, Austria.

Mr C.M. Fanning with Prof P.K. Link (Idaho State University, USA); Changes in provenance of sandstones in the Snake
River plain and environs with the passing of the Yellowstone hot-spot.

Mr C.M. Fanning with Dr B.J. Mahoney (University of Wisconsin-Eau Claire, USA); The Baja-BC conundrum.

Mr C.M. Fanning with Prof F. Hervé (University of Chile, Chile); Geochronology and tectonic evolution of the southern
Patagonian batholith and outboard accreted terranes.

Mr C.M. Fanning with Dr R.J. Pankhurst (British Geological Survey and the NERC Isotope Geosciences Laboratory, UK)
and Dr C.W. Rapela, (Universidad de la Plata, Argentina); Evolution of the north Patagonian massif and the Sierras Pampeanas,

Mr C.M. Fanning with Dr I. Millar (British Antarctic Survey, UK); Evolution of the Antarctic

Peninsula,

Mr C.M. Fanning with Dr A. Cocherie and Dr P. Rossi (Bureau de Recherche Géologique et Miniere, France);
Evolution of Corsica and beyond.

Mr C.M. Fanning with Dr J.A Aleinikoff (US Geological Survey, USA); Timing of events in the New England region, North America.

Mr C.M. Fanning with Dr C. Smith-Siddoway, (Colorado College, USA); Geochronology of granites in the Ross Sea and the timing
of metamorphism in Marie Byrd Land, Antarctica.

Mr C.M. Fanning with Dr K. Shiraishi and Dr K. Misawa (National Institute for Polar Research, Japan); U-Pb reference zircons.

Mr C.M. Fanning with Dr J. Goodge (Southern Methodist University, USA); The geochronology and tectonic evolution of the
East Antarctic Craton, Transantarctic Mountains.

Mr C.M. Fanning with Dr J. Jacobs (University of Bremen, Germany); Geochronology and tectonic evolution of Dronning Maud Land.

Mr C.M. Fanning with Prof D. Gebauer and Dr A. Liati (ETH Zürich, Switzerland); Geochronology and trace element
geochemistry of zircons from Alpine eclogites.

Mr C.M. Fanning with Dr A. Morton (HM Associates, UK); Detrital zircon provenance of Palaeozoic basins in North Sea region.

Mr C.M. Fanning with Prof C. Casquet and Dr C.Galindo (Universidad Complutense, Spain); Sierras Pampeanas and the evolution
of the Argentine PreCordillera.

Mr C.M. Fanning with Prof A. Zelazniewicz (Polish Academy of Sciences, Poland); Detrital zircon provenance of the Polish Sudetes.

Mr C.M. Fanning with Dr M. Suárez (Servicio Nacional de Geologia y Mineria, Santiago, Chile); Late Jurassic magmatism &
transgression of the Austral Basin in the Aysén Region, southern Chile.

Mr C.M. Fanning with Dr E. Puga (Universidad de Granada, Spain); Geochronology and tectonic evolution of the Cordilleras Betic.

Mr C.M. Fanning with Prof F. Munizaga and Dr V. Maksaev (University of Chile, Chile); Timing of mineralisation in the Collahuasi &
Atacama regions.

Dr M.D. Norman with M.O. Garcia (University of Hawaii, USA), J.M. Rhodes (University of Massachusetts, USA), D. Weis

(University of British Columbia, Canada), D. Wanless and K. Kolysko (University of Hawaii, USA), H. Guillou (CEA/CNRS, France),
M. Kurz and D. Fornari (Woods Hole Oceanographic Institution, USA), V. Bennett (ANU), F. Trusdell and S. Schilling
(US Geological Survey, USA), M. Chapman (Morehead State University, USA), and M. Vollinger (University of Massachusetts, USA);
Magmatic Processes and the Nature of the Hawaiian Plume: A Geochemical and Isotopic Study of the Submarine Southwest Rift Zone
of Mauna Loa Volcano, Hawaii.

Dr M.D. Norman with Prof R.A. Duncan (Oregon State University, USA); Identifying impact events within the lunar cataclysm from
40Ar-39Ar ages of Apollo 16 impact melt rocks.

Dr M.D. Norman with Dr K. Righter and Dr A.D. Brandon (NASA Johnson Space Centre, USA); Mineralogy and petrology of
unbrecciated lunar basaltic meteorite LAP02205.

Dr M.D. Norman with Dr C.-T. Lee (Rice University, USA); Geochemical proxies for paleo-fO2 in the mantle during partial melting.

Dr M.D. Norman with L. Borg (University of New Mexico, USA), L. Nyquist and D. Bogard (NASA Johnson Space Centre, USA);
Age and origin of the primitive lunar crust.

Dr M.D. Norman with Dr R.P. Rapp (State University of New York at Stony Brook, USA) and Prof N. Shimizu
(Woods Hole Oceanographic Institution, USA); Composition of the continental crust.

Dr G. Yaxley with Prof Alex Sobolev (Max Planck Institut für Chemie, Mainz, Germany); High pressure phase and melting
relationships of gabbroic compositions.

Dr G. Yaxley with Prof Gerhard Brey (Universität Frankfurt); Partial melting of carbonated-bearing eclogite at high pressures.

Dr G. Yaxley with Dr Alan Woodland and Dr Michael Seitz (Universität Frankfurt); The distribution of Li amongst mantle phases
and its use as an indicator of metasomatic activity

Dr G. Yaxley and Dr Hugh O'Neill with Dr Martin Bizzaro (Danish Geological Museum, Copenhagen); Trace element partitioning
variations with pressure and temperature in a suite of garnet peridotite xenoliths from Greenland.

COOPERATION WITH GOVERNMENT AND INDUSTRY

Top of page

Earth Chemistry

Prof T.M. Harrison member of the National Committee for Earth Sciences Strategic Plan for the Geosciences (74 pp 2003 report)
and a member of the Board of the Australian National Seismic Imaging Resource (ANSIR), a Major National Research Facility
operated as a joint venture of Geosciences and the Research School of Earth Sciences.

Dr I.H. Campbell and Ms A. Stoltze with Placer Granny Smith Pty. Ltd.; Ore-fluid pathways around the mesothermal gold deposits
in the Laverton region, WA using alkali elements and stable isotopes (ARC SPIRT grant).

Mr C. Heath with Kalgoorlie Consolidated Gold Mines; Origin and composition of Ore-forming fluids in the giant Golden Mile gold
deposit, Kalgoorlie, (ARC SPIRT grant to Dr I.H. Campbell).

Dr T.R. Ireland continued close cooperation with Australian Scientific Instruments (ASI) and Geoscience Australia (GA) on SHRIMP
instrument developments and issues.

Dr A.P. Nutman with Dr G. Gibson (Geoscience Australia, GA); The tectonothermal evolution of the Broken Hill area.

Dr R. Page with Predictive Minerals Discovery Cooperative Research Centre (pmdCRC); Geological Survey NSW, Department of
Mineral Resources, Broken Hill, NSW; Geological Survey SA (PIRSA) and Geoscience Australia.

Dr I.S. Williams continued his collaboration with Australian Scientific Instruments Pty. Ltd. in the development, manufacture and
marketing of SHRIMP ion microprobes. He gave an invited lecture to a wider audience at VSEGEI on the geological applications
of SHRIMP analysis. In May Dr Williams spent a week at Hiroshima University assisting with repairs to their SHRIMP II and
presented a lecture. He then visited the Korea Basic Science Institute, Daejeon, to give an invited presentation on SHRIMP
applications and operation.

Dr I.S. Williams and the Ion Microprobe subgroup, continue to maintain a close working relationship with Geoscience Australia
geochronologists. Dr I.S. Williams presented an invited lecture at Geoscience Australia on the accuracy of granite geochronology.

Earth Environment

Ms S.N. Burgess with South Australian Research and Development Institute; Aquatic Sciences and specifically Dr T. Ward, Program Leader;
“Great Australian Bight and Shelf Seas”.

Dr E. Calvo and Dr C. Pelejero with Dr G.A. Logan (Geoscience Australia); Molecular biomarker analysis from marine sediments
and the setting up of carbon and nitrogen isotopes analysis.

Dr D. Fabel has established a cooperative agreement (AMS-02-14) with the Australian Nuclear Science and Technology Organisation
(ANSTO) to measure in situ produced 10Be and 26Al in quartz samples.

Dr M. Gagan with Dr J. Lough (Australian Institute of Marine Science) and Dr G. Meyers (CSIRO Division of Marine Research);
Quantifying the El Niño-Indian Ocean Diploe system using high-resolution coral palaeoclimate archives (ARC Discovery Project Grant).

Dr M. Gagan and Ms K. Lilley with Drs J. Lough, P. Isdale, and D. Barnes (Australian Institute of Marine Science).
Ms Lilley's Honours research is a core project of the AUSCORE (AUStralian COral REcords) initiative and is designed
to document extremes in climate variability in the Great Barrier Reef region.

Ms H. McGregor and Dr M. Gagan with Drs G. Brunskill, J. Lough and D. Barnes (Australian Institute of Marine Science).
Ms McGregor's PhD research is part of Project TROPICS (Tropical River-Ocean Processes in Coastal Settings) and aims
to use corals to reconstruct the mid-Holocene climate of the Western Pacific Warm Pool north of Papua New Guinea.

Dr B. Pillans continued collaborative research on paleomagnetic dating of regolith with personnel from CSIRO, Geoscience Australia,
University of Canberra, and a number of mining companies including Newmount and Perilya.

Dr E. Rhodes is a member of CRC LEME (Cooperative Research Centre for Landscape, Environments and Mineral Exploration)
and part of the CRC LEME research project “History of Aridity”. He has continued with a large research contract from BHP Billiton,
“OSL dating of stone array monuments, Pilbara Desert, WA”, which moved into its second funding phase. Measurements for this are
being made jointly with Dr J. Olley, CSIRO Land and Water. A small archaeological OSL dating contract with OzArc, Dubbo,
was completed in September.

Mr M. Smith is a member of CRC LEME (Co-operative Research Centre for Landscape, Environments and Mineral Exploration).

Dr W. Müller with Dr M. Westaway, National Museum of Australia; The provenance Aboriginal human skeletal remains from
Victoria using stable and radiogenic isotope analysis.

Dr J.G. Wynn collaborated with the CRC for Greenhouse Accounting including the annual contract for Soil Organic Carbon
Inventory Techniques, Applied to Soil Texture.

Earth Materials

Prof S.F. Cox and Dr S. Micklethwaite continued their collaborative research on Yilgarn mesothermal gold systems with a consortium of gold exploration companies, funded by an ARC Linkage grant and AMIRA funding.

Prof S.F. Cox, Mr S. Zasiadczyk, and Dr S. Micklethwaite with Gold Fields Ltd (St Ives Gold Ltd); A structural study of the Minotaur gold deposit.

Dr A.J. Berry and Dr H. O'neillwith Dr G.J. Foran, (Australian Nuclear Science and Technology Organisation); X-ray absorption spectroscopy of metal ions in silicate melts and with Dr M. JAMES, Australian Nuclear Science and Technology Organisation on the high-pressure synthesis of novel perovskite materials.

Dr A. Glikson with Dr A. Hickman, Dr I. Williams and Dr M. Van Kranendonk, (Geological Survey of Western Australia); on the Archaean asteroid impact fallout units, Pilbara craton, Western Australia. He also collaborated with Dr F. Pirajno, (Geological Survey of Western Australia), on the origin of the Shoemaker Impact Structure, Nabberu Basin, Western Australia and with Dr R. Iasky, (Geological Survey of Western Australia), on new Australian impact structures.

Prof D.H. Green was appointed as a Board member of the National Research Facility: Australian National Scientific Imaging Resource (ANSIR).

Prof D.H. Green continued as Director of Ringwood Superabrasives Pty.Ltd. representing the ANU’s interests in the company formed to commercialise patented ultra-hard ceramics based on diamond and cubic boron nitride composites.

Prof G. Lister with Dr R. Smith and Dr C. Swager (Anglogold, Australia), on Tectonics and Gold Mineralisation in the Anakie Inlier. As Chief Investigator, and the Structure Tectonics group collaborated with BHP Billiton on The Evolution of the Proterozoic lithosphere and its bearing of sediment hosted base metal mineralisation (an ARC Linkage funded project).

Prof G. Lister, as Project Director of ACcESS MNRF and the Geodynamics and Tectonic Reconstruction project group: ‘Geodynamics and Tectonic Reconstruction project’ with Dr S. McTaggart, Prof B. Appelbe, Mr S. Quenette and others at the University of Queensland, Monash University, Melbourne University, VPACE and RMIT; The Development of the PlatyPlus software to construct the Virtual Earth.

Dr J. Mavrogenes and Dr C. McFarlane with CSIRO Exploration and Mining; Ore deposits in metamorphic terranes
(jointly funded by CSIRO, Exploration and Mining, and RSES).

Dr S. Micklethwaite and Prof S.F. Cox with five Gold industry partners (Newmont Australia, KCGM Ltd, Goldfields St Ives
Gold, Placer Dome, Anglogold) under the auspices of AMIRA on an ARC Linkage project. Extensive cooperation with various
exploration offices has been essential to the years research; co-operation with staff in organising and running 4 separate field trips
to different sites, presentation of results to exploration staff and training of staff at 2 structural workshops. Dr S. Micklethwaite
wrote a journalistic presentation of research and it's benefits gold exploration for the magazine SIGnificent News (Goldfields Ltd).
Mr D.Wood with AngoGold Australia as part of his PhD thesis.

Earth Physics

Dr J. Braun with Dr P. Cummins (Geoscience Australia) and Prof M. Sandiford (the University of Melbourne); Active Faults and
Geomorphology of the Flinders and Mt Lofty Ranges.

Prof R.W.Griffiths with Australian Scientific Instruments on marketing of the Geophysical Flows Rotating Table. ASI delivered the
latest units to Geology and Geophysics, Yale University, USA, in November and the University of Naples, Italy, in December.

Prof B.L.N. Kennett is Chair of the Academy Committees for Postdoctoral Opportunities in Japan and exchange arrangements with
N.E. Asia (China, Japan, Korea, Taiwan); and Chair of the Committee for the Frederick White Conference Series.

Prof K. Lambeck is Foreign Secretary, a member of the Council and a member of the Finance Committee of the Australian Academy
of Science; a member of the Executive Committee of the International Inter-Academy Panel; Chair of the Antarctic Science Advisory
Committee; a member of an AUSAID Technical Advisory Group; and a member of the Antarctic Climate and Ecosystems Cooperative
Research Centre (ACE-CRC).

Dr H. McQueen collaborated with Mr R. Tracey (Geoscience Australia) on re-establishing local gravity ties around the Mt Stromlo
Gravity Station after fire damage compromised the established connections.

Dr H. McQueen, Dr P. Tregoning and Mr R. Stanaway collaborated with Geoscience Australia, the Department of Administration and
Information Services, South Australia (DAIS), the Department of Primary Industry and Resources, South Australia (PIRSA), and the
New Zealand Institute of Geological and Nuclear Sciences Ltd (IGNS), on establishing a high

precision GPS survey network in the
Flinders and Mt Lofty Ranges, SA, to monitor crustal deformation associated with seismicity in the area.

Dr M. Sambridge continued collaboration with Dr P Cummins (Geoscience Australia) on nonlinear inversion applied to seismic
source studies within the Australian continent.

Mr R. Stanaway provided GPS technical support to Geoscience Australia's seismic hazard monitoring network in South Australia
during April this year.
Australian National Seismic Imaging Resource (ANSIR)

Prof B.L.N. Kennett is Director of the Australian National Seismic Imaging Resource (ANSIR). RSES has responsibility for the
reflection equipment and vibrator sources, as well as the portable instruments that are housed at RSES. The ANSIR equipment is
available via a competitive proposal scheme. In 2003 the following instrumentation was provided:
to the University of Western Australia for studies of the use of mine blasts for seismic refraction; 20 sets of broad-band equipment to
RSES for the Tasman Line experiments;
4 sets of broad-band equipment to pmd*CRC for crustal studies in the Yilgarn craton; and 8 sets of broad-band equipment to
Geoscience Australia for imaging of active faults in the Flinders Ranges

Reflection experiments carried out with ANSIR equipment included Gawler Craton, South Australia (300 km of profile); Curnomona Craton,
South Australia (40 km of profile – to be resumed in 2004); and a number of smaller experiments using the mini-vibrator

PRISE

Mr C.M. Fanning continued collaborations with the Geological Surveys of South Australia and Queensland. He also collaborated
with Mr G. Teale,
Teale and Associates and a number of mineral and petroleum exploration companies.

Dr R. Armstrong has collaborated on a number of projects with scientists from the Geological Surveys of Brazil, Botswana, Namibia,
South Africa, South Korea and Swaziland. A number of geochronological projects for Australian and international exploration companies
and consultants were completed during the year.

Dr G. Yaxley completed several consultative projects for Australian and international diamond exploration companies and for Australian
state geological surveys.

STAFF ACTIVITIES

Editorial Responsibilities

Dr C. Allen, member of the editorial board of the Australian Journal of Earth Sciences.

Dr V.C. Bennett, associate editor of the Journal of Geophysical Research; guest editor of a Special Volume of Chemical Geology (vol. 196, May 2003)
on “Highly Siderophile Elements in the Earth and Meteorites”.

Dr J. Braun, Associate Editor of Journal of Geophysical Research.

Prof S.F Cox, member of the Editorial Advisory Board of Geofluids; and member of the Editorial Advisory Board of Journal of Structural Geology.

Dr J. Fitz Gerald, member of the advisory board of Physics and Chemistry of Minerals; and member of the advisory board of CSEM.

Prof R. Grün, Editor of Quaternary Geochronology (Quaternary Science Reviews); associate editor of the Journal of human Evolution;
member of the Editorial Board of Quaternary International; member of the Editorial Board of Radiation Measurements; Member of reviewers'
panel of Ancient TL; standing member of the scientific committee and editor of the proceedings of the International Conferences on Luminescence
and Electron Spin Resonance Dating (next conference in this series will be in Cologne in July 2005).

Prof T.M. Harrison, member of the Editorial Board, Earth and Planetary Science Letters, and Associate Editor, Geochimica Cosmochimica Acta.

Prof I. Jackson, Associate Editor of the Journal of Geophysical Research; member of the Editorial Board of Physics and Chemistry of Minerals;
member of the Editorial Board of Physics of Earth and Planetary Interiors.

Prof B.L.N. Kennett, Associate Editor of Earth and Planetary Science Letters; Associate Editor of Journal of Geophysical Research (Solid Earth);
and commenced as Editor-in-Chief of Physics of the Earth and Planetary Interiors in November, having previously been an Associate Editor.

Prof K. Lambeck, Editorial Advisory Board Member of Quaternary Science Reviews; and Editorial Advisory Board Member of Earth and
Planetary Science Letters.

Prof G. Lister, member of the Editorial Board, Journal of Structural Geology; Director of the Journal of the Virtual Explorer.

Dr J. Mavrogenes, Associate Editor of Economic Geology.

Dr W Müller, co-Editor (with Dr D. Vance and Dr I. Villa) of a Special Publication of the Geological Society of London “Geochronology:

linking the isotopic record with petrology and textures", a Proceedings volume of a Special session at the Goldschmidt 2002 conference (Davos, Switzerland).

Dr A.P. Nutman is a member of the editorial board of Precambrian Research.

Dr H. O'Neill, member of the Advisory Editorial Board of Earth and Planetary Science Letters; and member of the Editorial Board of Chemical Geology.

Dr B. Pillans, member of the Editorial Board of Catena; member of the editorial board of Quaternary Science Reviews; and member of the Editorial Board of Geology.

Dr E. Rhodes, member of the Editorial Board of Quaternary Science Reviews.

Dr M. Sambridge, Pacific Region Editor for, and responsible for running Pacific Region Office of, Geophysical Journal International.

Mr J.G. Wynn, appointed Associate Editor of Journal of Human Evolution (term begins January 2004).

CONFERENCES AND OUTSIDE STUDIES

Top of page

Earth Chemistry

Dr C. Allen attended the Ishihara Symposium at Macquarie University in Sydney from 21 to 21 July.

Dr V.C. Bennett attended the Goldschmidt Conference in Kirashiki Japan and presented a paper entitled 'Direct constraints on redox compositions in the early (>3.85 Ga) Archean mantle from trace element compositions of peridotites'; and the American Geophysical Union Meeting in December.

Dr C. Bryant was an invited speaker at Macquarie University, discussing geochemical variations in New England granites at the granite symposium in honour of Prof Shunso Ishihara, 22-24 July. She also presented a paper titled 'Li isotope variations in Eastern Australian granites' at the Goldschmidt Conference in Kurashiki, Japan, 7-12 September, and presented a paper titled 'Lithium isotopes and granite petrogenesis' at the Fifth Hutton Symposium on the Origin of Granites and Related Rocks, in Toyohashi, Japan, 2-6 September.

Dr I. H Campbell gave invited talks on 'The Efficiency of Melting in Mantle Plumes' at an international plume meeting in Cardiff and at the IUGG Meeting in Cardiff. He also gave a lecture on mantle plumes at the Danish Lithosphere Centre in Copenhagen, visited the Universities of Cardiff and Bristol, and attended a meeting on carbon sequestration at the British

Petroleum Institute.

Dr W.J. Dunlap attended the field forum ‘Structural controls on magma transport and vertical coupling in the continental lithosphere’, held in
Fiordland, New Zealand from 26 April to 8 May. He also conducted fieldwork in the Jack Hills region of Western Australia from 14-23 June,
and with Mr J. Célérier and others, in northern India from 31 August to 30 September.

Mr T. Fujioka presented a paper entitled ‘Evaluation of nucleogenic component in cosmogenic 21Ne surface exposure dating’ at the
Goldschmidt Conference held in Japan.

Prof T.M. Harrison attended the following conferences and meetings for outside studies: Travelled to Monash for discussions with Prof Gordon Lister
(4 March 2003); conducted fieldwork in the NW Indian Himalaya with new PhD student Mr J. Célérier (12-28 March 2003); attended SHRIMP
workshop at Murramarang Resort, NSW (30 March - 1 April); attended the 18th Himalaya-Karakoram-Tibet Workshop, at Ascona, Switzerland
(2-4 April); attended EGS-AGU-EUG Joint Assembly, Nice, France (6-10 April); visited Manchester University for discussions with Dr Jamie
Gilmour, Department of Earth Sciences on the RELAX mass spectrometer system (10-11 April); held discussions with ARC collaborators at UCLA
(12-15 April; presented an invited talk to Geochemical Earth Reference Model (GERM) workshop at Ecole Normale Superieure de Lyon, France
(17-24 May); conducted fieldwork in Western Australia (20 June - 2 July); gave an invited talk to the Indian Ocean Fan System Workshop in Boulder, Colorado, USA (18-27 July); gave two invited oral presentations to Goldschmidt Conference in Kurashiki, Japan (8-16 September); travelled to Adelaide University for seminar and student recruitment (18 September); and attended and presented a keynote address at 2003 SGTSG Field Meeting in Kalbarri, Western Australia (21-23 September).

Dr M. Honda was an invited keynote speaker for the symposia ‘Unravelling geological processes by noble gas isotopes’ at the Goldschmidt
Conference held in Kurashiki, Japan, and he presented a paper entitled ‘Unusual noble gas compositions in polycrystalline diamonds: preliminary
results from Jwaneng, Botswana’. He also presented a seminar at the Earthquake Research Institute, University of Tokyo.

Dr T.R. Ireland attended the 5th International Symposium on Applied Isotope Geochemistry (AIG-5) held at Heron Island, Queensland, from 26-30
May. Dr Ireland also attended the 66th Annual Meeting of the Meteorical Society in Munster, Germany from 28 July to 1 August, and the Lunar &
Planetary Institute’s Workshop of Cometary Dust, held at Crystal Mountain, USA, from 10 to 15 August. Prof E.I. McDougall participated in a
workshop in Perth entitled ‘Bedout: An end-Permian impact crater, offshore northwestern Australia’ in August, a four-day workshop sponsored by
the Continental Dynamics Program of the US National Science Foundation, consisting of a series of focused presentations, as well as discussions as
to how to further investigate this apparent major impact event. Prof McDougall presented a talk in the workshop on isotopic dating of volcanics, as

such rocks occur in the Bedout structure.

Mr D. Maidment attended the Geological Society of Australia - Specialist Group in Tectonics and Structural Geology Field meeting 22-26 September.
Mr Maidment also attended the International Seminars of Petrology,Venice, Italy 13-18 October, and the Geological Society of America Annual Meeting,
2-5 November.

Dr S. McLaren attended a Specialist Group in Tectonics and Structural Geology field meeting in Kalbarri, Western Australia, in September.

Dr A.P. Nutman was an invited attendee at a workshop in Copenhagen, Denmark during January hosted by Nunaminerals A/S on gold mineralisation
in the Nuuk district of Greenland. Dr Nutman, under the auspices and funding of an ARC Discovery grant, also undertook sampling in the Broken Hill
area, NSW in April.

Dr A.P. Nutman and Dr V.C. Bennett, with new Earth Chemistry PhD student Ms F. Jenner, undertook fieldwork in West Greenland in June and July.
This was mostly funded from an ARC Discovery Grant. The main ARC Discovery focus was late Archaean tectonics, plus Meso- and Palaeoarchaean
mafic rocks were collected for Ms Jenner's project.

Dr A.P. Nutman took overseas development leave in October to visit the U.K. and Japan. In the U.K. he completed two manuscripts with Dr C.R.L.
Friend. In Japan he visited the SHRIMP laboratory of Hiroshima University. There he completed a manuscript, and negotiated a collaborative
project between himself and his hosts. This will bring closer ties between the ANU and Hiroshima SHRIMP laboratories.

Dr R. Page attended the Broken Hill Exploration Initiative Conference (BHEI 2003), Broken Hill, 7-9 July.

Mr S. Paxton attended the Australian Petrographic and Geological Technicians Symposium 2003 held in Corowa from 17-21 November.

Dr I.S. Williams attended the 2003 SHRIMP Workshop, Canberra, March 30-April 4, where he presented a paper on the accuracy of SHRIMP
Pb/U measurements. July 22-24 he spoke at the Ishihara Symposium, Macquarie University, on the problem of measuring the ages of granites accurately.
He was one of four speakers invited to present a 3-day short course on granite petrogenesis at Seoul National University, Korea, 26-28 August.
He then presented a lecture on zircon inheritance at the Hutton V conference in Toyohashi, Japan (29 August- 6 September), and afterwards attended Goldschmidt 2003 in Kurashiki, Japan (September 7-12). November 6 he was an invited speaker at the Selwyn Symposium, Melbourne University,
where he spoke on assessing the accuracy of age measurements of igneous rocks.

Earth Environment

Ms N. Abram attended the EGS-AGU-EUG Joint Assembly in Nice in April where she presented the following two posters: (1) Abram N.J., Gagan M.K., McCulloch M.T., Chappell J. and Hantoro W.S. 'Coral reef death linked to tropical wildfires in Indonesia during the 1997 Indian Ocean Dipole' and (2) Abram N.J., Gagan M.K., Chappell J., McCulloch M.T. and Hantoro W.S. 'Coral records of interannual, century and millennium scale climate dynamics in the tropical eastern Indian Ocean'.

Ms S.N. Burgess made an oral presentation at the Second International Deep-Sea Coral Symposium, Erlangen, Germany 8-13 September.

Dr E. Calvo presented the poster 'Dust-induced changes in phytoplankton composition during the last four glacial cycles' with co-authors Dr C. Pelejero, Dr G.A. Logan, and Dr P. De Deckker, at the 'Euro Conference: Comparison of Ice Core Records with Marine Sediments and Climate Models' in Sant Feliu de Guíxols, Barcelona, Spain, 4-9 October. She also presented the poster '280-year long Sr/Ca and d18O records from Flinders Reef, western Coral Sea' jointly with Dr J.F. Marshall, Dr C. Pelejero and Dr M.T. McCulloch at the fall meeting ofthe American Geophysical Union, San Fransisco, 8-12 December.

Prof J. Chappell presented both 'New determinations of the long-term production and migration of soil, our largest mineral deposit' and 'Archives of environmental history and resources – reflections following CRC LEME Regolith Symposia 2003' at Advances in Regolith: Proceedings of the CRC LEME Regional Regolith Symposia, 2003. He presented the Plenary Address 'Cold, dry and large? Greater Australia through the latter stages of the last Ice Age' at the Australian Archaeologic Association Conference, Jindabyne NSW 2003 and 'Retrospective and prospective changes of climate and environment in northern Australia: implications for sustainable development' as an invited Lecture, 2 Darwin Symposium, Charles Darwin University NT, July; and 'Detailed sea level analysis of coral terraces at Huon Peninsula, PNG: 30-65,000 years BP', at the Sea-levels and Heinrich Events Workshop, Lamont-Doherty Geological Observatory, Columbia University, October.

Dr S. Eggins attended the XVI International Union for Quaternary Research (INQUA) Congress, Reno, 23-30 July, where he presented two posters: (1) 'The distribution of Mg in placktonic foraminifera tests: implications for Mg/Ca paleoseawater thermometry and habitat migration', jointly with Prof De Deckker, Dr J. Marshall; and (2) 'Open-system U-series dating of marine mollusc shells' jointly with Prof R. Grün and Assoc Prof C. Murray-Wallace. Dr Eggins also attended the Victor Goldschmidt Conference, in Kurashiki, Japan, where he presented 'Open-system U-series dating of marine mollusc shells jointly with Prof R. Grün and Assoc Prof C. Murray-Wallace. He also presented an invited lecture 'In-situ U-series dating by laser ablation ICPMS' at the AINSE 3rd Quaternary Dating Workshop, 1-2 October, Lucas Heights.

Ms R. Fraser made a 6 week visit to the Research Laboratory of Archaeology and Art History

at the University of Oxford, United Kingdom,
to undertake stable isotope analysis of samples during September and October.

Mr T. Fujioka gave an oral presentation at the Goldschmidt Conference at Kurashiki, Japan, 8-12 September.

Dr M. Gagan undertook an outside studies program from March to July with the Department of Geological and Environmental Sciences,
Stanford University, USA (hosted by Prof R.B. Dunbar) where he presented the seminar 'Holocene ocean-atmosphere interactions in the
Pacific Warm Pool and the tropical general circulation'.

Prof R. Grün was co-organiser of Session 50, S-30 'New developments in Quaternary numerical dating methods at the 16th INQUA Congress,
23-30 July, Reno, USA. He was invited by the organisers of the Archéométrie meeting, Bordeaux, France (16-19 April, France) to present
'Physical dating methods in archaeology'. Prof Grün was invited by the session organisers 'Dating Methods for Quaternary Geochronology' to
present 'The age of the Border Cave 5 mandible' (with P. Beaumont, P.V. Tobias and S. Eggins) at the 13th Annual V.M. Goldschmidt Conference,
7-12 September, Kurashiki, Japan, and to give two talks at the 12th Workshop on Applied Metrology, 13-14 September, Okayama, Japan, entitled
'The role of ESR dating in the reconstruction of the chronology of modern human evolution and 'Introduction to Quaternary geochronology'. Prof Grün
also presented 'Direct dating of fossil hominids' at Archéométrie 2003, 16-19 April, Bordeaux, France; 'The age of the Border Cave 5 mandible'
(with S. Eggins and P.V. Tobias) at the 16th Congress of the International Quaternary Association, 23-30 July, Reno, and 'ESR dating' at the
AINSE 3rd Quaternary Dating Workshop. 1-2 October, Lucas Heights.

Dr Y. Jia attended the American Geophysical Union Annual Meeting in December in Denver, USA at which he gave a presentation on
'The secular decrease in atmosphere d15N: Atmosphere origin and crustal cycling', and poster on 'Thorium/U systematics of Precambrian
deep-sea pelagic black shales: implications for redox state of the early atmosphere'.

Dr J. Marshall, Mr T. Wyndham and Ms B. Ayling also attended the 80th Annual Conference of the Australian Coral Reef Society in Townsville in September.

Prof M.T. McCulloch attended the 80th Annual Conference of the Australian Coral Reef Society, Townsville, in September at which he
delivered the paper 'Water Quality in the Inner Great Barrier Reef: What were the 'Natural' Levels of Turbidity and Salinity prior to
European Settlement?

Prof M.T. McCulloch, Dr J.M. Lough, and Dr M.K. Gagan, attended the Fall Meeting of the American Geophysical Union, San Francisco,
EEUU, 8-12 December; Eos Trans. AGU, 84(46), Fall Meet. Suppl, Abstract PP52A-0954, 2003.

Dr W. Müller was co-convener of the Special session 'Archaeological Geochemistry: Isotopically Decoding Prehistoric Human Life and Nature' Goldschmidt Conference 2003, Kurashiki (Japan), in which he also made the oral presentation 'In-situ isotopic and trace elemental analysis of teeth by LA-MC-ICPMS' jointly with Dr S. Eggins. Dr Müller was also co-author of a paper 'Resolving the issue of provenance through radiogenic and stable isotope analysis of skeletal materials' by Chatfield, J., Harradine, H., Müller, W., Westaway, M, presented at AAA (Australian Archaeological Association) Conference, December, Jindabyne, NSW, and of the paper 'Resolving the issue of provenance through stable isotope analysis' by Harradine, H., Müller, W., Westaway, M., presented at WAC-5 (World Archaeological Congress, Washington, D.C., USA), June.

Dr C. Pelejero presented the poster 'Synchronous climatic response in the south-western Pacific and Antarctica during Stage 5e' jointly with Dr E. Calvo, Dr G.A. Logan, and Prof Prof De Deckker at the Euro Conference: Comparison of Ice Core Records with Marine Sediments and Climate Models, in Sant Feliu de Guíxols, Barcelona, Spain, 4-9 October. Dr C. Pelejero also attended the Fall Meeting of the American Geophysical Union, San Francisco, EEUU, 8-12 December where he presented the poster 'Marine Isotope Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inference' jointly with Dr E. Calvo, Dr G.A. Logan, and Prof P. De Deckker; Eos Trans. AGU, 84(46), Fall Meet. Suppl, Abstract PP32A-0278, 2003. He also gave a seminar entitled 'Multicollector Mass Spectrometry, Applications in Earth and Marine Sciences' in the Marine Sciences Institute (CMIMA-CSIC) in Barcelona (Spain), 26 September.

Dr B. Pillans presented papers at the following conferences: Geological Timescales Conference, Mt Tremblant, Canada, 15-18 March; Regolith and Landscapes in Eastern Australia, Canberra, 21-23 November; and the XVI International Union for Quaternary Research (INQUA) Congress, Reno, 23-30 July.

Dr E. Rhodes organised a one-day informal meeting for luminescence dating specialists within RSES 29 August, with around 25 attending. He was an invited speaker at 'Modern Human Origins: Australian Perspectives', held at UNSW, 29-30 September, presenting a paper entitled 'Early Australian settlement: The non-radiocarbon chronology', which was subsequently reported in Science. He attended the Quaternary Dating Workshop, at ANSTO, Lucas Heights, 1-2 October. At the CRC LEME Eastern Regolith Symposium, ANU, 19-21 November, and the CRC LEME Western Regolith Symposium, Curtin University, 27-28 November, he presented a paper entitled 'Age and mobility of regolith: assessment by luminescence dating method', jointly with Prof J. Chappell & Dr N. Spooner and Dr B. Pillans.

Mr M. Smith presented the paper 'U - Pb dating of anatase in silcrete' at 2003 CRC LEME symposia: Advances in Regolith in Canberra and Perth, October-November.

Ms J. Trotter presented a paper at the 9th International Symposium on the Ordovician System (ISOS), San Juan, Argentina, August (reference above), and attended post-symposia field excursion to the Andes.

Dr J.G. Wynn presented High Spatial and Temporal Resolution Paleoenvironmental Records from Paleosols of Kenya and Ethiopia at the Pardee Symposium Paleoenvironmental and Paleoclimatic Framework of Human Evolution. Geol. Soc. Am. Abstracts with Programs (Annual Meeting, Seattle, WA), paper 73 - 4. He also presented a Report on the extension of soil organic carbon and carbon isotope inventories to soils of variable texture, co-authored with Bird, M.I., Vellen, L., Grand-Clement, E. to the CRC for Greenhouse Accounting Annual Science Meeting, May, 2003, Murramurang, NSW. Dr J.G. Wynn co-authored the paper 'Stone age archeological survey in the Busidima region, Ethiopia', presented by Riel-Salvatore, J., Alemseged, Z., Reed, D., Wynn, J.G., at the Paleoanthropology Society Annual Meeting, April. He was also co-author of the paper Krull, E., Skjemstad, J., Wynn, J.G., Burrows, W., Bray, S., 'Time course of vegetation change from grassland (C4) to woodland (C3) in central Queensland: Evidence from d13C and 14C of soil organic matter', presented at the 18th International Radiocarbon Conference, Wellington, NZ.

Earth Materials

Prof S. F Cox presented a keynote lecture at the meeting of the Specialist Group in Tectonics and Structural Geology of the Geological Society of Australia at Kalbarri (WA) in September. At that conference, he also co-authored another oral presentation with Dr S. Micklethwaite, and co-authored three poster presentations. Prof S.F Cox also gave an invited presentation at a Kyoto University conference in December.

Ms Katie Dowell attended the CRC Leme conferences in Canberra and Perth, the Opal symposium in Quilpie, Queensland and the Opal seminar at Sydney University.

Dr J. Freeman attended the VUESC Conference where he presented a paper titled 'Non-Newtonian Stagnant Lid Convection with a Water Ice Rheology'. This work was done in collaboration with Prof L. Moresi (Mathematical Sciences, Monash University) and

Dr D. May (Computational Scientist, Victorian Partnership for Advanced Computing). This work has also been submitted to Geophysical Research Letters (not yet accepted).

Prof D.H. Green continued research in Germany from mid March to late July supported by Humboldt Foundation Research Prize. He was hosted by Prof D. Dingwell at Ludwig Maximillian University of Munich and delivered a short course on 'Magma Genesis in the

Earth's Mantle'. He was also an invited lecturer at Universities of Nancy (France), Utrecht (Netherlands), Heidelberg, Bayreuth (Germany), Vienna (Austria) and Budapest (Hungary). He presented a paper at the combined European Union of Geosciences/American Geophysical Union in Nice (France) in April. From 24-29 August, Prof D.H. Green was an invited speaker and participant in the Penrose Conference 'Plume IV: Beyond the Plume Hypothesis' held near Reykjavik, Iceland. He presented evidence for compositional buoyancy and mantle inhomogeneity, rather than a deep-seated thermal plume, as the cause of 'Hot-Spot' volcanism. This was followed by an extended visit to MIT, Cambridge, Massachusetts, and Woods Hole Oceanographic Institute, Woods Hole, Massachusetts, during which he collaborated with Prof F.A. Frey (MIT) and Prof N. Shimizu (WHOI) on geochemistry and petrogenesis of Hawaiian magmas. During this visit Prof Green gave a seminar course to graduate students from both institutions. Prof Green was an invited lecturer at MIT, WHOI, Brown University (Providence, RI, USA) and Yale University (New Haven, Conn, USA).

Mr A. Hack attended the AGU Fall Meeting in San Francisco where a poster entitled 'Copper solubility and speciation in mineral-buffered fluids at crust to upper mantle conditions' was presented.

Dr J. Hermann attended the Geological Society of America Annual Meeting in Seattle, USA from 2-5 November where he gave a keynote lecture in the Pardee Symposium on 'Modeling Metamorphism: Petrology, Geochemistry and Tectonics'. Dr Hermann talked about rates of high grade metamorphic processes. He also gave a second talk on carbonate melts and diamond formation in subducted continental crust.

Prof I. Jackson attended the EUG/EGS/AGU conference Nice, April; presented two papers at the IUGG Sapporo, Japan, July; co-presented a paper with Dr U. Faul at the AGU December; and visited Ehime University May-August for outside studies.

Dr J. Mavrogenes attended the Geological Society of America Fall Meeting in Seattle, USA. He also presented seminars at the University of Melbourne, Auckland, Waikato and Victoria Universities in New Zealand where he, with students, presented recent results on sulfide partial melting. At the University of British Columbia, Canada he presented a seminar on the effects of metamorphism on ore deposits. He was an invited contributor to a short course entitled: Metallogenesis and Metallogeny of Magmatic NiS and PGE Deposits, held at the University of Western Australia in February. Dr Mavrogenes contributed to a short course on fluid inclusions sponsored by the Predictive Mineral Deposits CRC held in Canberra.

Dr C. McFarlane attended the Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting in Vancouver, BC in May and presented a paper called 'Redistribution of Pb via high-T recovery of lattice strain in zircon'.

Dr S. Micklethwaite presented an oral paper at the annual international conference of the Structural Geology and Tectonics Study Group (SGTSG). This was held at Kalbarri Beach Resort, Western Australia 21-27 September. Dr S. Micklethwaite attended the pre-conference workshop on Electron Backscatter Diffraction Analysis (EBSD), run by Prof D. Prior and Dr S. Reddy (20th September).

Ms M. Miller attended the 17th Victorian Universities Earth Sciences Conference, Monash University, Melbourne, Vic, September where she presented a paper on three-dimensional slab structure of the Northwest Pacific margin and the American Geophysical Union Annual Fall Meeting, San Francisco, CA, USA, December where she gave a paper on three-dimensional slab structure of the Izu-Bonin-Mariana arc system.

Dr H. O'Neill attended a workshop on 'Mantle structure, composition and phase transitions at Fréjus, France, 2-6 April where he presented a paper on the origin of chrome-diopside pyroxenites and their significance for the determination of the composition of the mantle. He also attended the joint EAG-EUG-AGU meeting in Nice, France from 6-11 April. Dr H. O'Neill conducted field work sampling ophiolites, in New Caledonia from 14 to 19 August. He also visited the Laboratoire Pierre Süe, CEA/CNRS, Paris, on 10 November and travelled to Grenoble to conduct experiments from 12-18 November at the ESRF on tracking the effects of composition, oxygen fugacity, pressure and cooling on sulfur speciation in quenched silicate melts by µXANES.

Dr T. Sharp attended the American Geophysical Union Annual Fall Meeting where he presented a paper co-authored by Dr H. Jung, J. Fitz Gerald and Dr S. Karato on 'Dislocation Microstructures in Deformed Olivine Displaying the C-type and B-type Fabrics'.

Mr D. Wood attended the 17th Victorian Universities Earth Sciences Conference, Monash University, Melbourne, VIC, September where he gave a paper titled 'Evidence for Metamorphic Core-Complex formation in central-east Queensland'.

Mr J. Wykes attended the GSA Annual meeting in Seattle in November where he presented a paper based on his Honours thesis research.

Earth Physics

Dr J. Braun attended the following conferences and seminars: Penrose Conference on Tectonics, Climate and Landscape Evolution, 13-17 January, Taroko National Park, Taiwan; EGS-AGU-EUG 2003 Joint Assembly, 6-11 April, Nice, France. Earth System Evolution Programme of the Canadian Institute for Advanced Research, first bi-annual meeting, 3-4 June, Montreal, Canada; ACCESS workshop, Brisbane, 27-29 October; Brownian landscapes, Seminar series, School of Earth Sciences, University of Melbourne, 5 November ; Earth System Evolution Programme of the Canadian Institute for Advanced Research, second bi-annual meeting, 6-7

December, San Francisco, USA; AGU Fall
meeting, 8-12 December, San Francisco, USA; Gilbert Club, University of Berkeley, 13 December, Berkeley, USA. He also visited
Laboratoire de Geodynamique des Chaines Alpines, Universite Joseph Fourier de Grenoble, France, 17-26 August.

Dr G.F. Davies presented an invited paper at the European Geophysical Society conference, 6-11 April in Nice, France, on Stirring and
Stratification in the Early and Late Mantle. He also presented a paper at the Second Workshop on Mantle Structure, Composition and Phase
Transitions, 2-6 April in Frejus, France, organised by the Ecole Normale Superieur de Lyon. Subsequently he visited and gave seminars at
Princeton University, Harvard University, the Los Alamos Scientific Laboratory and the University of California at Santa Cruz.

Prof R.W. Griffiths attended the International Union of Geodesy and Geophysics (IUGG) Congress in Sapporo, Japan, 29 June-6 July and
presented a paper on processes governing the ocean thermohaline circulation. He also attended and gave two lectures at the Geophysical
Fluid Dynamics Summer Program at the Woods Hole Oceanographic Institution, USA, 7-19 July.

Prof B.L.N. Kennett travelled to Germany in January to visit the GeoforschungZentrum in Potsdam and deliver an invited paper at the
memorial symposium for Prof G. Mueller in Frankfurt. In March he went to Boulder, Colorado, for the SEAP meeting on enhancing seismic
studies in Antarctica and developed a model for improved coverage using semi-permanent and portable stations. In late March he visited the
University of Cambridge and the University of Leeds giving seminars on seismic structure beneath Australia, and then travelled to Nice for the
joint meeting of the European Geoscience Union and the American Geophysical Union. He gave presentations on the nature of deep mantle
heterogeneity from global tomography and on the synthesis of body wave and surface wave studies for Australia. He then visited the University
of Utrecht and initiated collaboration on global studies of higher mode surface waves. In July he attended the General Assembly of the
International Union of Geodesy and Geophysics and gave the IASPEI Presidential Address on developments in strong-ground-motion seismology
and presented another paper. In September he was a Keynote Speaker at the Goldschmidt Conference in Kurashiki, Japan with a presentation
on the nature of mantle heterogeneity. After the conference he visited the Earthquake Research Institute, University of Tokyo to continue
collaboration with Dr T. Furumura on seismic wave propagation problems.

Dr A.E. Kiss attended the Tenth Australian Meteorological and Oceanographic Society National Conference, University of Western Australia,
Perth, 10-12 February and presented a paper on the dynamics responsible for western boundary current separation. He also attended the
International Union of Geodesy and Geophysics (IUGG) Congress in Sapporo, Japan, 30 June-11 July and presented a paper on this topic.

He also delivered an invited seminar on this topic at the Australian Meteorological and Oceanographic Society Symposium on Rotating Fluids,
Melbourne, 2 October.

Prof K. Lambeck visited the Ente per le Nuova Technologie, l'Energia e l'Ambient (ENEA) and Istituto Nazionale di Geofisica e Vulcanologia
(INGV) in Rome and examined Roman fish tanks along theTyrrhenian coast in March and May.

Prof K. Lambeck attended the Inter-Akademie-Symposium, Akademie der Wissenschaften und der Litertur Mainz, Mainz from 3-5 September.
He presented a paper 'Sea level change through the last glacial cycle: geophysical, glaciological and palaeogeographic consequences.'

Prof K. Lambeck also attended the Karthaus Summer School from 9- 20 September, Glaciers and ice sheets in the climate system.
During the course of the School he gave three lectures: 'Geodynamics - Introduction', 'Interaction between ice sheet and solid earth' and
'What can we learn from glacial rebound'. He also visited the Alfred-Wegener-Institut für Polar-und Meeresforschung, Bremerhaven
between the 7-8 September, where he gave a seminar 'Constraints on the ice history of Northern Europe from sea-level and crustal-rebound data'.

Prof Lambeck attended Puglia 2003: International Conference on 'Quaternary coastal morphology and sea level changes', September 21-28,
Otranto, Puglia Italy. He presented a paper 'Sea level change and shoreline migration along the Italian coast from the Last Glacial Maximum to
the present.'

Prof K. Lambeck, in his role as Foreign Secretary, Australian Academy of Science, attended the Inter Academy Panel (IAP) Executive
Committee meetings in Rome at the Academie Linceia, in May, and the IAP Conference and General Assembly 'Science for Society',
held in Mexico City, from 1-5 December.

Dr H. McQueen attended the 23rd Assembly of the International Union of Geodesy and Geophysics in Sapporo, Japan, in July and took
part in meetings of the Global Geophysics Program.

Dr N. Rawlinson attended the Fall Meeting of the AGU, San Francisco, 7-12 December.

Dr M Sambridge attended the joint AGU-EGS-EUG meeting in Nice, France, where he gave presentations on `Empirical travel time
estimation' and `Fast marching approaches toseismic wavefront simulation'. He also visited the University of Copenhagen and gave a
seminar at the Niels Bohr Institute. While there he served as an external examiner of a Ph.D defence.

Mr R. Stanaway attended the 23rd IUGG Symposium in Sapporo, Japan. He presented a Poster 'Implementation of a Dynamic Geodetic datum: A Case Study in Papua New Guinea'.

Dr Paul Tregoning attended the EGU conference in Nice, France in April where he made two oral presentations, 'Using geodetic data to disentangle the co- and post-seismic deformation caused by three large earthquakes in Papua New Guinea' and 'Application of the Arrival Pattern method to aftershock relocation using teleseismic data' and one poster presentation, 'Rates of Present-day uplift near the Lambert Glacier, Antarctica, derived from GPS observations.

PRISE

Mr C.M. Fanning co-convened a session on the 'Isotopic Determination of Sediment Provenance' and presented a poster at the Annual meeting of the Geology Society of America in Seattle in early November. He presented a paper at the IV South American Symposium on Isotope Geology (SSAGI IV) in Salvador, Bahia, Brazil in la 8 June, 2005 on Antarctic Earth Sciences (ISAES IX) in Potsdam, Germany in mid September. He presented two invited Keynote papers at a workshop on SHRIMP U-Pb geochronology in Wroclaw Poland, and an invited talk at the University of Bremen, Germany, both in early September. He presented an invited paper at the Broken Hill Exploration Initiative meeting in Broken Hill, in early July and conducted field work in the Olary Block of the Curnamona Province. He presented a seminar at Melbourne University in late July. Mr Fanning conducted field work in the Chilean region of Patagonia during March.

Mr C.M. Fanning and Drs R.A. Armstrong and G. Yaxley attended the SHRIMP Workshop at Murramurang, NSW in April, where Mr Fanning presented a paper.

Dr R.A. Armstrong presented a Keynote Address at the IV South American Symposium on Isotope Geology (SSAGI) in Salvador, Brazil in August. He also co-authored a number of papers presented at the symposium. Results of collaborative research were presented by co-workers at a number of international conferences this year, including EUG 2003 (Nice, France), SCAR 2003 (Potsdam, Germany) and Geoforum 2003 (Johannesburg, South Africa).

Dr G. Yaxley attended the Goldschmidt Conference held in Kurashiki, Japan in September, where he presented a paper entitled 'Petrological Constraints on Carbonated Eclogite as a Source of Carbonatites and Kimberlites'. Following the conference he attended a one day workshop on Mantle Heterogeneities held at Kurashiki. He then visited the Japanese Marine Science and Technology institute in Yokosuka where he presented a seminar entitled 'Phase and melting relations of carbonate-bearing eclogite assemblages - Implications for carbonatite petrogenesis'.
He also attended the International Diamond Conference held in December in Perth, WA, where he received an update of Australian and International diamond exploration projects and held discussions regarding possible commercial and

collaborative projects between industry and PRISE.
He presented a briefing to exploration geologists at Rio Tinto Exploration in Perth regarding diamond related projects and the capabilities of
PRISE in this area.

Dr M. Norman attended the American Geophysical Union in San Francisco where he presented papers entitled 'Magnesium Isotopes in
the Earth and Moon by Laser Ablation MC-ICPMS' and 'No Core Contribution in Mantle Plumes: New Evidence From Tungsten Isotopes'.

OUTREACH AND WORKSHOPS

Top of page

Ms N. Abram was one of sixteen early career scientists selected to present her research to the media and the general public at the Melbourne
Museum as part of the 'Fresh Science' National Science Week. As a 'Fresh Science' finalist, she also completed an 'Econnect' media-training course.

Dr A. J. Berry is a member of the Instrument Advisory Team (IAT) for the powder neutron diffraction beamlines (HRPD and HIPD) at the
new Replacement Research Reactor at Lucas Heights; Coordinator of a special interest group called GEOSYNC designed to educate, inform
and represent Australian geoscientists on all matters relating to synchrotron science; and a member of the organising committee
of Photons@Work, Australian Synchrotron Summer School.

Dr J. Braun coordinated a high school student visit to RSES in November.

Prof J. Chappell participated with the National Committee for Earth Sciences in the development of a National Strategic Plan for the Geosciences.

Prof J. Chappell presented the field class "Rivers in time: geomorphology and the ancient past of the Lachlan River" Environment
Workshop, Institute of the Arts ANU 19-20 March, and participated in the Workshop exhibition at Grenfell 5-9 June (personal
contribution, sculpture "Dammed Rivers"), and the major exhibition "Landscape Gold & Water" at Orange (personal contributions, sculptures
"Dammed Rivers" and "Water Stress").

Prof J. Chappell organised and supervised as part of the CSIRO-ANU Student Research Scheme two student projects,
"Monte-carlo simulation of soil creep" (student, Alison Sham, Merici College), and "Floodwater signals in coral growth bands"
(jointly with Dr J Marshall RSES) (student, Ben Huntley, Canberra Grammar)

Prof S.F. Cox and Dr S. Micklethwaite made a number of presentations to geoscientific staff of Gold Fields Ltd, Kalgoorlie
Consolidated Gold Mines, Newmont, Placer Dome Ltd and AngloGold as part of their ARC/AMIRA-funded Yilgarn stress
transfer modelling project.

Ms R. Fraser made a day visit to St Thomas the Apostle primary school, Kambah to talk about to three junior classes about
Australian megafauna fossils.

Dr J. Fitz Gerald, CSEM hosted a lecture and workshop on Convergent Beam Electron Diffraction 11-13 June by Prof Jean-Paul Morniroli,
Laboratoire de Métallurgie Physique et Génie des Matériaux, Universite de Lille I, France.

Prof D.H. Green presented a short course on Magma Genesis in the "Earth's Mantle" at L.-M. University of Munich, Germany,
with graduate students attending from Italy, Denmark, Slovakia, Czech Republic and Austria, as well as German graduate students.
A similar seminar series was presented to graduate students and post-docs in the joint geochemistry program run by M.I.T.,
and Woods Hole Oceanographic Institution.

Dr T.R. Ireland convened the inaugural SHRIMP Workshop in March, a week-long meeting which was attended by
Prof T.M. Harrison, Emeritus Prof W. Compston, Dr I.S. Williams, Dr J.J. Foster, Dr P. Holden, Dr A.P. Nutman, several SHRIMP
technical staff, Geoscience Australia staff and a number of national and international delegates involved in SHRIMP research and development.

Dr W. Müller presented the results of his recent Iceman research, "Origin and Migration of the Neolithic Alpine Iceman, Ötzi"
at the Australian Academy of Science, Dinner Club, 27 February. "Aus dem Zahnschmelz des Eismannes seine Herkunft ablesen…"
(in German) at the South Tyrol Museum of Archaeology ('Iceman Museum'), 1 July; Origin and Migration of the Alpine Iceman at the
Swiss Federal Institute of Technology (ETH) Zürich, 3 July, and the University of Vienna, 8 July; Origin and Migration of the Alpine
Iceman Ötzi at the Goethe Society, Canberra, 23 October; Isotopes, Iceman and Insights into Anthropology/Archaeology at RSES
seminar series, 30 October; and A paradigm shift in using teeth as archives of chronology, diet, and place of origin" at the Royal Holloway
University of London, 13 November.

Dr W. Müller was interviewed by ABC radio and TV following publication of Müller et al. (2003), 'Origin and Migration of the
Alpine Iceman' in Science; and more than 30 articles subsequently appeared in Australian and overseas several newspapers including;
The Canberra Times, The Age, Sydney Morning Herald, The Australian Financial Review, New Scientist, Scientific American, Italian
Television (RAI), Austrian Radio, National Public Radio (USA), New York Times, Washington Post, Die Presse, Tiroler Tageszeitung,
The Seattle Times, Die Welt etc.

Dr S. McLaren presented a Research Seminar, "Some speculations on the nature of Proterozoic tectonics in Australia", at Geoscience Australia, in August.

Dr E. Rhodes made two TV appearances in UK concerning OSL dating of Wilmington Long Man, Sussex, UK, and dating of a large standing stone, The Cove, Avebury, UK.

Dr S. Micklethwaite and Prof S.F. Cox organised and ran 2 industrial workshops on the implications of seismological observations and the application of advanced structural techniques to mineral exploration, at Kalgoorlie, WA, for geoscientists from Newmont Australia, KCGM, Goldfields St Ives, Placerdome and Anglogold (May & November). After each workshop, Dr S. Micklethwaite ran a short half-day field trip to key outcrops on local mine sites, providing informal advice in the field to the attendees.

Dr S. Micklethwaite contributed general scientific information and was interviewed twice for the Sunday science program "Fuzzy Logic" broadcast on 2XX, a local community radio station (98.3FM). He is a member of the Geological Society of Australia's committee (ACT division), in which capacity he has arranged and organised seminars for the wider public and geological community, and promoted geoscience at schools.

Dr E. Tenthorey participated in the CSIRO Student Research Scheme, in which he supervised two year 11 students undertaking a laboratory-based project.

Dr I.S. Williams and Prof D.H. Green hosted seven science teachers from Narrabundah College during January to learn from about research in isotope geochronology and experimental petrology.

Dr I.S. Williams with Prof B.W. Chappell (Macquarie University), Emeritus Prof A.J.R. White (La Trobe University) and Dr P.L. Blevin (PetroChem Consultants Pty. Ltd.) presented a 3-day short course on granite petrogenesis at Seoul National University, Korea.

Mr D. Wood attended a workshop in Perth at AngoGold Australia, who provide field support for his research.

TEACHING ACTIVITIES

Top of page

Dr J. Braun and Dr G. Davies taught the Physics of the Earth Honours course ‘Plate Tectonics and Mantle Dynamics’.

Prof J. Chappell gave a two week lecture course and associated laboratories to classes GEOL 2007 and GEOL 3019 at the Department of Geology, ANU. He also gave two lectures and a laboratory class to 1st year and advanced students, during April at the Department of Geology, University of Papua New Guinea, Port Moresby.

Prof S.F. Cox taught structural geology and tectonics courses at 2nd and 3rd year levels, and contributed to three other courses
at 1st to 3rd year levels as part of his joint appointment at RSES and the Department of Geology, ANU.

Dr G. F. Davies taught a one-week intensive unit on Dynamics of the Earth's Mantle (PEAT8001) as part of the RSES Honours
programme in Physics of the Earth.

Prof R.W. Griffiths lectured half the third year unit (Physics 3034: Physics of Fluid Flows) within the undergraduate Physics curriculum.

Prof R. Grün gave a lecture series on topics of Quaternary geochronology to students of the Department of Archaeology and
Anthropology, The Faculties, ANU.

Prof T.M. Harrison presented a short course (2-5 February) MSc lecture at Centre for Global Metallogeny, UWA:Orogenic and
Intrusion-related Gold Deposits.

Prof T. M. Harriosn presented a short course (24-29 April) on Deformation and Metamorphism of the Crust (ESC3201)
for The Great Debate: The Himalayas at Monash University.

Prof T.M. Harrison travelled to Los Angeles, USA, for the periods 28 September-25 October and 29 October-1 December during
which time he taught a graduate course on Advanced Interpretive Methods in Geochronology and supervised students and projects at UCLA.

Prof I. Jackson presented a graduate short course 'Elasticity and anelasticity of geological materials: theoretical background, experimental
techniques and selected seismological applications', Ehime University, Matsuyama, Japan, July.

Prof B.L.N. Kennett prepared the online courses: 'Introduction to Geophysical Continuum Mechanics' for RSES Honours students; and
'Imaging the Earth's Interior'
for Master of Contemporary Science, Faculty of Science

Dr A.E. Kiss, Prof R.W. Griffiths and Dr G.O. Hughes taught the Physics of the Earth Honours course 'Dynamics of the Oceans'
(PEAT8005).

Dr A.E. Kiss was a guest lecturer for the ANU Bachelor of Computational Science course, 18 August.

Prof K. Lambeck participated in the honours teaching program 'Physics of the Earth'.

Dr J. Mavrogenes taught 3rd year Economic Geology, 30 % of 2nd year Resources and

Environmental Geochemistry, and 20 %
of the 1st year course.

Dr S. Micklethwaite accompanied Prof S.F. Cox on the Bermagui structural field trip, demonstrator, a weekend long, 2nd Year
undergraduate field trip, during which students were trained in field-based structural skills. Dr S. Micklethwaite also undertook
informal and formal training of industrial geoscientists throughout the year at the workshops mentioned above (see also 'Outreach and workshops')
and during different mine site visits.

Dr W Müller was a guest Lecturer at Environmental Archaeology, ANU (Prof Matthew Spriggs), May.

Dr B. Pillans gave lectures in regolith geology courses in Department of Geology, ANU, and School of Applied Science, University of Canberra.

Dr N. Rawlinson, Dr M. Sambridge and Dr A. Reading co-lectured a short course on seismology as part of Earth Physic honours course.

Dr M. Sambridge, Dr N. Rawlinson and Dr A. Reading took part in the Physics of the Earth Honours year and delivered an intensive
lecture course on `Seismology and Seismic imaging'.

Ms J. Trotter, demonstrated for GEOL2008 Palaeobiology & Palaeoenvironments, Semester 2, Department of Geology,

ANU.HONOURS SUPERVISION

Top of page

Prof S.F Cox, Dr S. Micklethwaite, and Dr I.S. Williams supervised Mr S. Zasiadczyk (Department of Geology, ANU) in his SHRIMP
study of the age of dykes from the Minotaur/North Revenge mine near Kambalda.

Dr M. Gagan co-supervised (with Dr B. Opdyke, Department of Geology, ANU) the Honours thesis work of Ms K. Lilly on the topic:
'Coral reconstruction of extreme El Niño events in the Australian Great Barrier Reef'.

Dr G.O. Hughes and Prof R.W. Griffiths supervised the Honours project of Ms M. Coman ('Convective exchange between two connected chambers')
in the GFD Group for the Physics of the Earth Honours Program.

Dr J. Mavrogenes supervised the Honours projects of Mr J. Wykes (Department of Geology, ANU) on water solubility in sulfide melts, and
Ms H. Sparks (Department of Geology, ANU) on sulfide partial melting at Broken Hill.

Prof G. Lister jointly supervises Ms K. Bishop, Ms C. Gregory, Mr J. Clulow, and Mr A. Reed (Department of Geology, ANU).

OTHER MATTERS

Top of page

Dr V.C. Bennett, was co-author of a successful proposal to the Australian Academy of Science to host a Fredrick and Elizabeth White Conference on 'Planetary Timescales: Stardust to Continents'.

Dr I.H. Campbell, member of the Commission for Igneous and Metamorphic Petrogenesis, a subcommission of the International Union of Geological Sciences; councillor of the International Mineralogical Association; and co-leader of the Commission for Large Igneous Provinces (LIP).

Prof S.F. Cox, served on the Federal Government appointed panel reviewing the first year of research activity in the CRC for Predictive Mineral Discovery.

Prof R.W. Griffiths served as a member of the Advisory Board, Centre for Complex Systems, ANU; chaired the Sir Frederick White Prize Committee, Australian Academy of Science; was a member of the Academy's Section Committee 4 (Earth Sciences); served on the Section Fellows Committee (VGP), American Geophysical Union; Chair of the ACT Centre of the Australian Meteorology and Oceanography Society (AMOS); member of the national AMOS Council; and member of the Program Committee for the 2005 Australian Institute of Physics Congress.

Dr T.R. Ireland, attended a site inspection of the Cairns Convention Centre in Queensland from 26-29 June in relation to the proposal for the 2008 Annual Meeting of the Meteorical Society to be held in Australia.

Dr J. Mavrogenes, served on the Board of the Faculties (ANU) and on the Board of the Faculty of Science (ANU).

Dr S. McLaren, member of the Committee of the Geological Society of Australia ACT Division.

Dr H. O'Neill, a member of the Geochemical Fellows Selection Committee of the Geochemical Society; and Chairman of the ACT branch of the Geological Society of Australia.

Dr N. Rawlinson, RSES seminar convener. He organized weekly seminars, post-seminar dinners, food and drink, etc (annual budget ~$8,500).

Mr R. Stanaway presented two seminars in October: 'Lae, a deforming city' at PNG University of Technology, and 'PNG & Gazelle Regional Tectonics, A brief overview of ANU and RVO's collaboration 1996- 2003' at the Rabaul Volcanological Observatory.

PRISE

In 1989 ***PRISE*** was established as a joint venture between ANUTECH and the Research School of Earth Sciences. Initially, the aim was for a research scientist to establish and carry out U-Pb zircon single grain TIMS analyses as supported by external funds. As the years progressed, the role of ***PRISE*** changed to encompass the handling of disparate externally funded projects in the areas of geochronology, isotope geochemistry and trace element geochemistry, and provide external access to the Research School's specialised equipment and expertise in these areas. After twelve years highlighted by significant growth in size and scope, ***PRISE*** was transferred from ANUTECH to the ANU in May 2001, with the staff and operation forming a unique entity within RSES.

During 2002 ***PRISE*** has continued to compete successfully in an increasingly competitive market. SHRIMP projects still comprise by far the largest proportion of the work undertaken by ***PRISE*** staff, although LA- and solution ICPMS components have been significant and TIMS analyses have also contributed.

Collaborative research has been undertaken with colleagues from Europe, southeast Asia, southern Africa and both North- and South America as well as that conducted with staff of other Australian universities and institutions. A small proportion of purely commercial work has been carried out, mainly for Australian clients.

***PRISE* hosted the following visitors to the School during 2002:**

Dr J. Cocker, ARAMCO, Dhahran, Saudi Arabia
Dr R. Pankhurst, British Antarctic Survey, Keyworth, United Kingdom
Dr C.W. Rapela, Centro de Investigaciones Geologicas, Universidad de la Plata, Argentina
Dr J. Jacobs, Fachbereich Geowissenschaften, Universität Bremen, Germany
Dr L. da Silva, Serviço Geológico do Brasil, Brazil
Dr G. Whitmore, University of Natal, Durban, South Africa
Dr F. Chemale, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil
Dr R. Anma, University of Tsukuba, Japan
Mr S. Boger, Monash University, Victoria
Dr A. Cocherie and Dr P. Rossi, Bureau de Recherche Géologique et Miniere, Orleans, France
Mr N. Nhleku, Rand Afrikaans University, South Africa
Dr M. Pimentel, Instituto de Geosciências, Universidade de Brasilia, Brazil
Dr G. Teale, Teale and Associates, Prospect, South Australia
Ms C. Augustsson, Westfälische Wilhelm-Universität, Germany
Mr A. Bisnath, Universities of Cape Town & Durban-Westville, South Africa
Ms R. Boshoff, Rand Afrikaans University, South Africa
Ms S. de Vries, Universiteit Utrecht, Netherlands
Messrs M. Schwarz, G. Ferris and A. Burtt, Primary Industry and Research, South Australia
Dr P. Link, Idaho State University, USA
Dr B. Mahoney, University of Wisconsin – Eau Claire, USA
Dr G. Hall, Geological Survey of Canada, Ottawa, Canada
Dr D. Lawie, Anglo American, Victoria
Dr Vadim Kamenetsky, Max-Planck-Institut für Chemie, Germany
Prof. M. Garcia, University of Hawaii, USA
Prof. J. Foden, Adelaide University, South Australia
Dr. David Belton, University of Melbourne, Victoria
Mr. Matevz Lorencak, University of Melbourne, Victoria

GROUP: ***PRISE***

CONFERENCES AND OUTSIDE STUDIES

Mr C.M. Fanning co-convened a session on the 'Isotopic Determination of Sediment Provenance' and presented a poster at the Annual meeting of the Geology Society of America in Seattle in early November 2003. He presented a paper at the IV South American Symposium on Isotope Geology (SSAGI IV) in Salvador, Bahia, Brazil in late August and a paper the International Symposium on Antarctic Earth Sciences (ISAES IX) in Potsdam, Germany in mid September. He presented two invited Keynote papers at a workshop on SHRIMP U-Pb geochronology in Wroclaw Poland, and an invited talk at the University of Bremen, Germany, both in early September. He presented an invited paper at the Broken Hill Exploration Initiative meeting in Broken Hill, in early July and conducted field work in the Olary Block of the Curnamona Province. He presented a seminar at Melbourne University in late July. Mr Fanning conducted field work in the Chilean region of Patagonia during March.

Dr R.A. Armstrong presented a Keynote Address at the IV South American Symposium on Isotope Geology (SSAGI) in Salvador, Brazil in August. He also co-authored a number of papers presented at the symposium. Results of collaborative research were presented by co-workers at a number of international conferences this year, including EUG 2003 (Nice, France), SCAR 2003 (Potsdam, Germany) and Geoforum 2003 (Johannesburg, South Africa).

Dr G. Yaxley attended the Goldschmidt Conference held in Kurashiki, Japan in September, where he presented a paper entitled 'Petrological Constraints on Carbonated Eclogite as a Source of Carbonatites and Kimberlites'**.** Following the conference he attended a one day workshop on Mantle Heterogeneities held at Kurashiki. He then visited the Japanese Marine Science and Technology institute in Yokosuka where he presented a seminar entitled **'**Phase and melting relations of carbonate-bearing eclogite assemblages - Implications for carbonatite petrogenesis**'.** He also attended the International Diamond Conference held in December in Perth, WA, where he received an update of Australian and International diamond exploration projects and held discussions regarding possible commercial and collaborative projects between industry and PRISE. He presented a briefing to exploration geologists at Rio Tinto Exploration in Perth regarding diamond related projects and the capabilities of PRISE in this area.

Dr Marc Norman attended the American Geophysical Union in San Francisco where he presented papers entitled 'Magnesium Isotopes in the Earth and Moon by Laser Ablation MC-ICPMS' and 'No Core Contribution in Mantle Plumes: New Evidence From Tungsten Isotopes'.

COOPERATION WITH AUSTRALIAN UNIVERSITIES

Tectonics of the Neoproterozoic – Early Palaeozoic margin in eastern Australia, Mr C.M. FANNING with Assoc. Prof. C. Fergusson, (University of Wollongong) and Prof. R.

Henderson, (James Cook University)
The timing of Carboniferous-Permian volcanic rocks in the Tamworth belt NSW, Mr C.M. FANNING with Professor J. Roberts, (University of NSW)
The timing and protolith history of Cenozoic volcanic rocks from Chile, Mr C.M. FANNING with Dr Kurt Knesel, (University of Queensland)
The geochronology of granitic rocks in north west Queensland, Mr C.M. FANNING with Dr Michael Rubenach, (James Cook University)

Dating ophiolite succession in Oman, Dr R. ARMSTRONG with Prof. David Gray (University of Melbourne)
Tectonic and geochronological investigation of the Koaka Belt, Namibia, Dr R. ARMSTRONG with Prof. David Gray (University of Melbourne) and Dr B. Goscombe (Geological Survey of Western Australia)

Melt inclusions in picrites from Padloping Island, north western Canada, Dr G. YAXLEY with Drs Dima Kamenetsky and Maya Kamenetsky (University of Tasmania)
The geochemistry and petrogenesis of carbonatites from Antarctica, Dr G. YAXLEY with Dr Dima Kamenetsky and Dr Geoff Nichols (University of Tasmania)

Major and trace element analysis of sulphide ores by laser ablation ICPMS, Dr M. NORMAN with P. Robinson and D. Clark (Centre for Ore Deposit Research, University of Tasmania)

COLLABORATION WITH INDUSTRY AND GOVERNMENT

Mr C.M. Fanning continued collaborations with the Geological Surveys of South Australia and Queensland. He collaborated with Mr G. Teale, Teale and Associates and a number of mineral and petroleum exploration companies.

Dr. R. Armstrong has collaborated on a number of projects with scientists from the Geological Surveys of Brazil, Botswana, Namibia, South Africa, South Korea and Swaziland. A number of geochronological projects for Australian and international exploration companies and consultants were completed during the year.

Dr G. Yaxley has completed several consultative projects for Australian and international diamond exploration companies and for Australian state geological surveys.

INTERNATIONAL COLLABORATION

Mark Fanning:

Changes in provenance of sandstones in the Snake River plain and environs with the passing of the Yellowstone hot-spot, Mr C.M. FANNING with Prof. P. K. Link (Idaho State University, USA)

The Baja-BC conundrum, Mr C.M. FANNING with Dr B.J. Mahoney (University of Wisconsin-Eau Claire, USA)

Geochronology and tectonic evolution of the southern Patagonian batholith and outboard accreted terranes, Mr C.M. FANNING with Professor F. Hervé (University of Chile, Chile)

Evolution of the north Patagonian massif and the Sierras Pampeanas, Mr C.M. FANNING with Dr R.J. Pankhurst (British Geological Survey & the NERC Isotope Geosciences Laboratory, UK) and Dr C.W. Rapela, (Universidad de la Plata, Argentina)

Evolution of the Antarctic Peninsula, Mr C.M. FANNING with Dr I. Millar (British Antarctic Survey, UK)

Evolution of Corsica and beyond, Mr C.M. FANNING with Dr A. Cocherie & Dr P. Rossi, (Bureau de Recherche Géologique et Miniere, France)

Timing of events in the New England region, North America, Mr C.M. FANNING with Dr J.A Aleinikoff (US Geological Survey, USA)

Geochronology of granites in the Ross Sea and the timing of metamorphism in Marie Byrd Land, Antarctica, Mr C.M. FANNING with Dr C. Smith-Siddoway, (Colorado College, USA)

U-Pb reference zircons, Mr C.M. FANNING with Dr K. Shiraishi and Dr K. Misawa (National Institute for Polar Research, Japan)

The geochronology and tectonic evolution of the East Antarctic Craton, Transantarctic Mountains, Mr C.M. FANNING with Dr J. Goodge, (Southern Methodist University, USA)

Geochronology and tectonic evolution of Dronning Maud Land, Mr C.M. FANNING with Dr J. Jacobs (University of Bremen, Germany)

Geochronology and trace element geochemistry of zircons from Alpine eclogites, Mr C.M. FANNING with Prof. D. Gebauer and Dr A. Liati, (ETH Zürich, Switzerland)

Detrital zircon provenance of Palaeozoic basins in North Sea region, Mr C.M. FANNING with Dr A. Morton, (HM Associates, UK.)

Sierras Pampeanas and the evolution of the Argentine PreCordillera, Mr C.M. FANNING with Prof. C. Casquet and Dr C.Galindo (Universidad Complutense, Spain)

Detrital zircon provenance of the Polish Sudetes, Mr C.M. FANNING with Prof. A. Zelazniewicz, (Polish Academy of Sciences, Poland)

Late Jurassic magmatism & transgression of the Austral Basin in the Aysén Region, southern Chile, Mr C.M. FANNING with Dr M. Suárez (Servicio Nacional de Geologia y Mineria, Santiago, Chile)

Geochronology and tectonic evolution of the Cordilleras Betic, Mr C.M. FANNING with Dr E. Puga, (Universidad de Granada, Spain)

Timing of mineralisation in the Collahuasi & Atacama regions, Mr C.M. FANNING with Prof. F. Munizaga and Dr V. Maksaev (University of Chile, Chile)

Rich Armstrong:

Geochronology of the Vredefort impact structure, Dr R.A. ARMSTRONG with C. Lana, Professor W.U. Reimold and Dr R. Gibson (University of the Witwatersrand, South Africa)

The ages of basement rocks, the Kunene Complex and the provenance and correlation of Proterozoic sediments in southern Angola, Dr R.A. ARMSTRONG with Professor S. McCourt (University of Durban-Westville, South Africa) and Professor A.B. Kampunzu (University of Botswana)

The absolute age and duration of Bushveld Complex mafic magmatism, Dr R.A. ARMSTRONG with S. Kamo (Royal Ontario Museum, Canada), Professor A. Wilson (University of Natal, South Africa)

The age and geochemistry of the UG2 reef, Bushveld Complex, Dr R.A. ARMSTRONG with Professor A. Mitchell (University of Durban-Westville, South Africa)

The evolution of the Cape Fold Belt, South Africa, Dr R.A. ARMSTRONG with Professor M. de Wit (University of Cape Town, South Africa)

The provenance and history of diamond-bearing sediments from the Orange River, southern Africa, Dr R.A. ARMSTRONG with Dr. J. Ward (De Beers Exploration, South Africa)

Geochemistry and geochronology of the Bushmanland Sequence, South Africa, Dr R.A. ARMSTRONG with Professor D. Reid, R. Baillie (University of Cape Town, South Africa)

Geochronological studies of Botswana, Dr R.A. ARMSTRONG with T.J. Majaule, B.K. Paya (Geological Survey of Botswana) and Dr R. Mapeo and Professor A.B. Kampunzu (University of Botswana)

Tectonic evolution of central Mozambique, Dr R.A. ARMSTRONG with B. Bene (Eduardo Mondlane University, Mozambique / University of Natal, South Africa)

U-Pb geochronology and provenance studies in eastern Namaqualand, Dr R.A. ARMSTRONG with G. Moen (Council for Geoscience, South Africa), Professor N. Beukes and H. van Niekerk (Rand Afrikaans University, South Africa)

The geochronology of Archaean and Early Proterozoic granites and associated sediments from the Bastar Carton, Central India, Dr R.A. ARMSTRONG with J. Mukhopadhyay (Presidency College, India) and Professor N. Beukes (Rand Afrikaans University, South Africa)

Further studies on the history of volcanism in the Pongola Group, Dr R.A. ARMSTRONG with N. Nhleko (Geological Survey of Swaziland/ Rand Afrikaans University) and Professor N. Beukes (Rand Afrikaans University, South Africa**)**

Geochronology of the Cape Granites, South Africa, Dr R.A. ARMSTRONG with Professor R. Scheepers (Stellenbosch University, South Africa**)**

Development of a geochronological database for southern Africa, Dr R.A. ARMSTRONG with Dr B. Eglington (University of Saskatchewan, Canada)

Geochronology, stratigraphy and tectonics of critical lithologies in the Namaqual-Natal Belt, Dr R.A. ARMSTRONG with Dr. P. Mendonidis (Vaal Traingle Technikon, South Africa), Dr G. Grantham, P. Macey, G. Moen and T. Cloete (Council for Geoscience, South Africa)

Geochronology and stratigraphy of the Korean peninsula, Dr R.A. ARMSTRONG with Dr Deung-Lyong Cho (Korea Institute of Geology, Mining and Materials, South Korea)

Geochronology and provenance studies of various sequences in Brazil and Namibia, Dr R.A. ARMSTRONG with Professor F. Chemale (Rio Grande do Sul University, Brazil)

Isotopic studies on the eastern margin of the São Francisco Craton and the Araçuai Belt, Brazil, Dr R.A. ARMSTRONG with Dr C. Noce (Universidade Federal de Minas Gerais, Brazil)

SHRIMP U-Pb dating of basement rocks to the Katangan Sequence, Zambian Copperbelt, Dr R.A. ARMSTRONG with D. Broughton, Colorado School of Mines, USA)

The geochronology of the Morila Gold Mine, Mali, Dr R.A. ARMSTRONG with K. Kenyon (Anglogold Limited, South Africa)

The source of sediments and maximum age constraints on deposition and mineralisation of the Crixas gold deposit, Brazil, Dr R.A. ARMSTRONG with K. Kenyon (Anglogold Limited, South Africa)

Geochronology of selected granites from the Democratic Republic of the Congo and Zambia, Dr R.A. ARMSTRONG with Professor L. Robb (University of the Witwatersrand, South Africa)

The geochemistry and geochronology of granite-greenstone belts in NE Botswana, Dr R.A. ARMSTRONG with Z. Bagai, Professor A. Le Roex (University of Cape Town, South Africa) and Professor H. Kampunzu (University of Botswana)

U-Pb geochronology of the Alpine Gran Paradiso orthogneisses (Savoy, Aosta Valley, Piemont), Dr R.A. ARMSTRONG with Professor J-M. Bertrand (CNRS, France)

Dating of lavas from the Soutpansberg succession and the Pietersburg greenstone belt, South Africa, Dr R.A. ARMSTRONG with Dr. G. Brandl (Council for Geoscience, South Africa)

Deciphering the structure and tectonic history of the Aïr region (SE Taureg shield) in Niger, Dr R.A. ARMSTRONG with Dr. Jean-Paul Liégeois (Africa Museum, Belgium)

SHRIMP U-Pb geochronology of the migmatites and granulites of the Snieznik Mountains, Poland, Dr R.A. ARMSTRONG with Dr. M Bröcker (Universität Münster, Germany)

U-Pb dating of zircons and titanites from granitoid rocks from the Hutti-Maski Greenstone belt, India, Dr. R.A. ARMSTRONG with A. Rogers and Professor M. Meyer (Institut für Mineralogie und Lagerstättenlehre, Aachen, Germany)

Metamorphic evolution of the jadeite-bearing felsic gneisses from the Eclogite Zone, Tauern Window, Eastern Alps, Austria, Dr R.A. ARMSTRONG with J. Konzett, C. Miller and M Thöni (University of Innsbruck, Austria)

Greg Yaxley:

High pressure phase and melting relationships of gabbroic compositions, Dr G. YAXLEY with Prof Alex Sobolev (Max Planck Institut für Chemie, Mainz, Germany)

Partial melting of carbonated-bearing eclogite at high pressures, Dr G. YAXLEY with Prof Gerhard Brey (Universität Frankfurt)

The distribution of Li amongst mantle phases and its use as an indicator of metasomatic activity, Dr G. YAXLEY with Drs Alan Woodland and Michael Seitz (Universität Frankfurt)

Trace element partitioning variations with pressure and temperature in a suite of garnet peridotite xenoliths from Greenland, Dr G. YAXLEY with Dr Martin Bizzaro (Danish Geological Museum, Copenhagen) and Dr Hugh O'Neill (RSES)

Marc Norman:

Magmatic Processes and the Nature of the Hawaiian Plume: A Geochemical and Isotopic Study of the Submarine Southwest Rift Zone of Mauna Loa Volcano, Hawaii, Dr M.D. NORMAN with M.O. Garcia (University of Hawaii, USA), J.M. Rhodes (University of Massachusetts, USA), D. Weis (University of British Columbia, Canada), D. Wanless and K. Kolysko (University of Hawaii, USA), H. Guillou (CEA/CNRS, France), M. Kurz and D. Fornari (Woods Hole Oceanographic Institution, USA), V. Bennett (ANU), F. Trusdell and S. Schilling (US Geological Survey, USA), M. Chapman (Morehead State University, USA), and M. Vollinger (University of Massachusetts, USA).

Identifying impact events within the lunar cataclysm from 40Ar-39Ar ages of Apollo 16 impact melt rocks, Dr M.D. NORMAN with R.A. Duncan (Oregon State University, USA)

Mineralogy and petrology of unbrecciated lunar basaltic meteorite LAP02205, Dr M.D. NORMAN with K. Righter and A.D. Brandon (NASA Johnson Space Centre, USA).

Geochemical proxies for paleo-fO2 in the mantle during partial melting, Dr M.D. NORMAN with C.-T. Lee (Rice University, USA)

Age and origin of the primitive lunar crust Dr M.D. NORMAN with L. Borg (University of New Mexico, USA), L. Nyquist and D. Bogard (NASA Johnson Space Centre, USA).

Composition of the continental crust Dr M.D. NORMAN with R.P. Rapp (State University of New York at Stony Brook, USA) and N. Shimizu (Woods Hole Oceanographic Institution, USA)

OUTREACH AND WORKSHOPS

Mr C.M. Fanning and Drs R.A. Armstrong and G. Yaxley attended the SHRIMP Workshop at Murramurang, NSW in April, where Mr Fanning presented a paper.

Dr Yaxley continued activities relating to updating the RSES web-site to conform with new ANU wide style guidelines, and chaired an internal committee examining introduction of a 4-D and MySQL database management system for the web-site.

GRANTS

Dr M.D. Norman was awarded an ARC Discovery Grant of $120,000 over three years for the project “Early Evolution of the Solar System: A Planetary Perspective”.