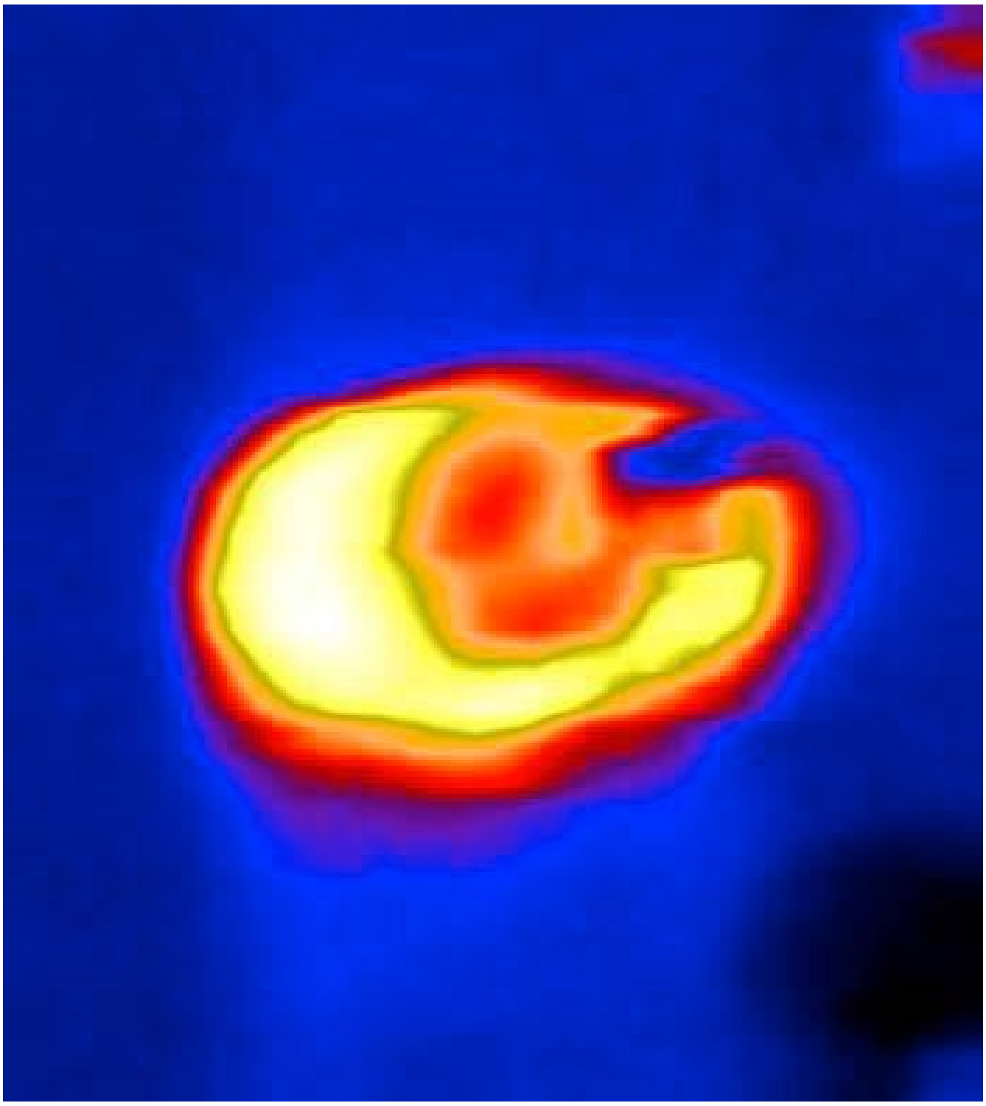
Research School of Earth Sciences

2002 Annual Report



Synchrotron X-ray fluorescence map of copper
distribution in a 30 micron fluid inclusion
from the Mole Granite, NSW.

THE AUSTRALIAN NATIONAL UNIVERSITY

Annual Report 2002 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 certainly the nation's premier centre for basic research in the physics, chemistry, material properties and environmental conditions of the Earth. Our role is to conduct research at the highest international level and take a leadership role in defining new research directions in geophysics and geochemistry – particularly those that have relevance to the geologic setting and needs of Australia.

In 2002, we devolved budgetary control of most non-infrastructure support to four divisions, each led by an Area Coordinator, that span the research themes within the School – Earth Physics, Earth Chemistry, Earth Materials and Earth Environment. This system proved effective, in particular permitting a high degree of local coordination in planning the substitution of block grant support with external funding.

Indeed, in the first year in which the entire School was eligible to contest ARC funds we were extraordinarily successful. Nearly 60% of our Discovery and LIEF grants were funded, realizing a total of $5.7M. For 2003 alone, the $2.0M raised represents a 400% return on our levy.

We joined with the Research School of Astronomy and Astrophysics in 2002 to propose creation of a joint institute to study the fundamental nature of planetary systems. Such an initiative recognizes the great strengths of both units and the potential for fundamental discovery in the fields of planetary and extra-solar planetary science. Seed funding was allocated to the recurrent 2003 bases of both Schools to recruit the first two positions in what is envisioned to be a centre of five to six faculty.

In 2002, the Australian National Seismic Imaging Resource (ANSIR) consolidated at RSES. This Major National Research Facility is the country's premier facility for sub-surface imaging, a field explicitly recognized as a national research priority. These and other aspects of School activity are highlighted below.

Key Statements

Enhancing our national and international roles

· RSES has the nations premier concentration of basic research facilities in experimental and observational geophysics, providing our community, government agencies, and industry with access to nationally and internationally unique capabilities vital to the welfare of Australian geoscience research.

· RSES is home to the Australian National Seismic Imaging Resource (ANSIR), the country's principal facility for sub-surface imaging.

· Completion of IPC-funded Environment appointments provides ANU with internationally unsurpassed facilities for Quaternary dating (e.g., establishing timescales of climate change).

Improving the educational experience of our students

· The Vice Chancellor has indicated his support for our proposal to move the Department of Geology to a new facility adjacent RSES. The close proximity of the Geology staff will broaden our graduate training environment while permitting our faculty greater participation in undergraduate teaching and mentoring.

Enhancing our research performance

· Devolution of budgetary control closer to individual investigators.

· Establishment of a Planetary Sciences Institute in conjunction with RSAA.

· Integration of the new Director's research component within existing School and University programs.

Enhancing our role in research training

· 'Physics of the Earth' MSc and honours program implemented to commence enrolments in 2003.

· Participation in unsuccessful DEST/EU proposal for 15 institution, Europe-Australia cotutelle MSc.

Continuing to develop our staff

· Continuing commitment to upgrade the skills of support staff through attendance at IT and other relevant courses and through formal technical and professional study.

· Sponsorship of a Centre for Public Awareness in Science workshop attended by 12 RSES personnel, including academic staff, students, laboratory technicians, and the Director.

· Investment in developing the advanced technical skills required by the School through employment and support of trainee technical officers and apprentices.

Seeking appropriate partnerships and alliances, both academic and business

· Continued strong linkages with Geoscience Australia, involving a growing corps of GA staff working within the School.

· Partnership with CSIRO to jointly fund RSES faculty positions in the field of ore genesis.

· Continuing close cooperation with ASI Ltd in the development of SHRIMP ion microprobes and other experimental apparatus.

Diversifying funding base

· Investigation of international opportunities (e.g., Earthscope); location of ANSIR at RSES; an aggressive response to ARC entry; CoE bid with RSAA.

· Partner in three CRCs — Greenhouse Accounting, Landscape Evolution and Mineral Exploration (LEME), and Antarctica.

· In 2002, RSES became a major shareholder in a new company, Ringwood Superabrasives Pty Ltd, which manufactures and develops applications for super-abrasive materials.

Budget Performance

The School's operating grant in 2002 of $8.67 million was supplemented by transfers from other areas in the University, student fee income and other external income totalling $1.44 million. This result included the transfer of $254,000 of Long Service Leave funds back to the School. The School's net cash operating position was $934,142, with a cash surplus of $202,945 for the year adding to the cash carry forward from 2001.

The School regards this as a prudent surplus, given the twin challenges of unfunded salary increases resulting from a new round of enterprise bargaining and decreased recurrent funding in 2004. Approximately 73% of the School's recurrent expenditure budget was taken up by salaries. This result was unchanged from 2001 despite the full effect of the 4.5% salary increase of September 2001 and incremental creep - reflecting in large measure the effectiveness of the School's policy of substitution of 30% of recurrently funded technical salaries by external funding.

Total income to the School in 2002 from sources external to the University was $4.08 million. 38% of the School's total expenditure for the year was funded from external sources - including 59% of all expenditure for both equipment and travel and fieldwork, and 40% of students' expenses.

Gender Equity Performance

The School's gender profile did not change significantly in 2002. At the end of the year, 22 (29%) of general staff were women. Of the 11 School staff at ANUO9 or above, two were women. The small number of female academics continues to be of concern. Five (11%) of 46 academic staff were women, of which only one held 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 female applicants.

Significant Achievements in Research and Teaching

Data from the Institute of Scientific Information (ISI) place ANU geosciences in the top 10 universities worldwide in total number of citations. Of the 22 fields covered by ISI, **geosciences at ANU is the highest ranked university program in the nation**.

ISI recently introduced Highly Cited Researchers, a designation that identifies scientists in the top 0.5% of cited researchers worldwide. Of the 11 Australian geoscientists cited, seven are from RSES. Indeed, RSES alone represents 15% of Australian Highly Cited Researchers across *all* 20 science disciplines.

Some highlights from each of the thematic areas were:

Earth Environment

· A 400-year coral record from the Great Barrier Reef indicates that sea surface temperature and salinity were higher in the 1700's than today. An abrupt freshening after 1870 occurred simultaneously throughout the SW Pacific, coinciding with cooling tropical temperatures. Thus the global Little Ice Age may have been driven, in part, by greater poleward transport of water vapour from the tropical Pacific.

· We have obtained clear evidence that sediment fluxes into the Great Barrier Reef increased five to tenfold after 1870 – following the beginning of European settlement. This supports new government initiatives to reduce sediment and nutrient loads to the GBR, both of which can have deleterious effects on coral reefs.

Earth Chemistry

· We commissioned a multi-collector for SHRIMP II that increases effective sensitivity by a factor of five. First applications were improving Pb isotope analysis precision for small samples, and rapid age characterization of detrital zircons, the oldest known terrestrial minerals. A five second analysis is now sufficient to screen for >4 Ga zircons, potentially allowing 1000 zircons to be characterized in one day.

· We showed that 70% of the modern continental crust had formed by three billion years ago (the Earth is 4.5 billion years old). This is the first quantitative estimate of the amount of continental crust that was present on the early Earth and should resolve a 35 year controversy regarding the rate of formation of the continents.

Earth Materials

· We explored of the role of aqueous fluids on fault strength and permeability, showing that the faults underwent dramatic strength recovery due to hydrothermal cementation and compaction of fault gouge. This provides a potentially effective mechanism for the build-up of fluid pressure in crustal fault zones.

· Studies of the influence of partial melting on seismic wave properties suggest that the reduced speed of shear waves and increased attenuation are due to grain-boundary sliding facilitated by a mixture of elastic distortion of mineral grains and grain boundary diffusion. These new insights will improve our understanding of the thermal structure of the Earth's upper mantle with implications for plate tectonics.

Earth Physics

· Numerical simulations indicate that the tectonic evolution of south-eastern Australia can be linked to continuous subduction along a single subduction zone. This result contrasts with previous models which assume that multiple, separate subduction zones were active between 450-350 million years ago and has implications for the deep crustal structure of SE Australia.

· We successfully completed a major seismological campaign providing high density coverage across northern Tasmania for tomographic imaging of the underlying mantle system. Field work continued in Antarctica which should lead to a vastly improved understanding of East Antarctica.

Student Numbers

At the end of 2002 the School had 26 postgraduate students enrolled (24 PhD and two MPhil). 20 were in the Earth Sciences Graduate Program and six in the Quaternary and Regolith Studies Program. The most popular broad areas of study were Earth Environment (eleven students) and Earth Physics (seven students). The popularity of environmentally focused studies is steadily increasing, particularly amongst Australian students.

During 2002, nine students commenced postgraduate study (compared with six in 2001) and four students submitted their theses.

I note that examination of our records indicates that 80% of our graduates from 1971-2002 remain engaged in full-time research in the geosciences.

Major Prizes, Honours and Awards

Staff

· Professor M. McCulloch was made a Fellow of the American Geophysical Union for major contributions to understanding the origin and evolution of the Earth's continental crust and mantle and environmental science and climate change.

· Professors Compston, Green, Harrison, McCulloch, McDougall and Drs Campbell and Williams were identified as Highly Cited Researchers by the Institute of Scientific Information. This designation is restricted to scientists in the top 0.5% of cited researchers worldwide.

· Dr A.E. Kiss was awarded the Australian Meteorological and Oceanographic Society Federation PhD Prize.

Students

· Ms E. Hendy was awarded the RSES Robert Hill Memorial Prize in recognition of her interdisciplinary research and effective communication in the Earth Sciences.

· Ms H. McGregor was awarded the Australasian Quaternary Association Travel Prize to attend the NCCR Swiss International Climate Summer School, Grindelwald, Switzerland, September 2002.

· Ms E. Potter and Ms P. Treble were joint recipients of the Mervyn and Katalin Paterson Fellowship in 2002.

· Ms J. Trotter was awarded a Paleontological Society Grant-in-Aid Award, granted by the Paleontological Society and a certificate for Outstanding Research Proposal for being one of the top two ranked applicants in an international field of 50.

· Mr J.P. Bernal - awarded the CONACyT (Consejo Nacional de Ciencia y Tecnologia) Prize by the Mexican Council for Science and Technology.

New Grants

This section reports grants awarded in 2002. ARC grants are reported in their year of commencement.

Australian Research Council grants (commencing in 2002)

Discovery grants

Dr S. McLaren; Argon thermochronometers and the effects of recrystallization (APD Fellowship).

2002: $84,962 2003: $80,337 2004: $69,947

Professor I. Jackson; Seismic wavespeeds and attenuation in upper-mantle rocks: a laboratory study of the effect of partial melting.

2002: $53,000 2003: $67,000 2004: $64,000

Professor M. McCulloch, Dr J.M. Lough; The coral record of environmental impacts in the great barrier reef: quantification of anthropogenic fluxes.

2002: $95,000 2003: $112,000 2004: $88,000

Professor M. McCulloch, Dr P.J. Hearty, Professor A. N. Halliday; Sea levels, sea surface temperatures and El Nino variability during warm interglaciations.

2002: $100,000 2003: $80,000 2004: $56,000

Professor M. Sambridge, Professor B. Kennett; Data Adaptive Geophysical Inversion.

2002: $60,000 2003: $83,000 2004: $65,000

Linkage grants

Professor S. Cox; Development and Application of Stress Transfer Modelling for Area Selection in Mesothermal Gold Systems.

2002: $65,000 2003: $65,000

Dr P. Tregoning, Associate Professor R. Coleman, Professor K. Lambeck, Dr H. McQueen; GPS receivers and support equipment for geophysical observatories in Antarctica.

2002: $190,000

Other Grants commencing in 2002

Drs A.J. Berry, J. Mavrogenes and Mr A. Hack - grant from the Access to Major Research Facilities Program to study synthetic fluid inclusions at GSECARS, Advanced Photon Source, Argonne National Laboratory, USA.

Dr A.J. Berry in collaboration with Dr H. StC. O'Neill - grant from the Australian Synchrotron Research Program to continue their work on oxidation states in silicate glasses and melts at the Australian National Beamline Facility, Tsukuba, Japan.

Dr J. Lindsay received a grant from the Department of Industry, Science and Resources Technology Diffusion Program for the project "Stable Isotopes as a Key to Understanding the Earth's Biosphere - a Global Framework for Mineralisation".

Professor I. McDougall was awarded a grant from the Australian Institute of Nuclear Science and Engineering to facilitate fast neutron irradiations of geological samples in the HIFAR nuclear reactor, operated by the Australian Nuclear Science and Technology Organization, in relation to the isotopic dating of rocks by the $^{40}Ar/^{39}Ar$ method.

Ms H. McGregor received a Goldschmidt 2002 Organising Committee Grant to attend the Goldschmidt 2002 Geochemical Conference, Davos, Switzerland, August 2002.

Drs H. StC. O'Neill, S. Kesson and M. Gagan were successful with a major equipment proposal to purchase a new powder X-ray diffractometer.

Dr A. Reading – awarded an Australian Antarctic Science Grant by the Australian Antarctic Division for her project on "The deep structure of East Antarctica from broad-band seismic data".

Dr S. Redfern was awarded a grant from the Australian Institute of Nuclear Science & Engineering to conduct high-T neutron powder diffraction experiments using the HIFAR nuclear reactor at Lucas Heights.

Dr P. Tregoning – awarded an Australian Antarctic Science Grant by the Australian Antarctic Division to continue the project "Crustal Rebound in the Lambert Glacier Area".

Dr J.G. Wynn was awarded grants by the Cooperative Research Centre for Greenhouse Accounting for "Program B2(c) Continuation of Soil Organic Carbon Inventory Techniques" and "Program B2(c) Soil Organic Carbon Inventory Techniques, Applied to Soil Texture".

Major Equipment Committee

Dr M. Gagan - Stable Isotope Microanalytical Facility for Palaeoclimate Systems and Global Change Research.

2002: $149,000

Professor B. Kennett - Broad-Band Seismic Recording Equipment for Antarctica Deployment.

2002: $312,000

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. During 2002 we participated in a number of Institution activities. Professor John Chappell presented a public lecture and a floor talk as part of the NIE's *Factor of Ten Exposition* as well as a lecture in the NIE Lecture Series. He was also a NIE participant in NITA's Landscape: Gold and Water exhibition. Ms Nerilie Abram gave a lecture as part of NIE's Student Forum. Professor Ross Griffiths aided in developing the NIPS brochure and Director Harrison led the NIPS Working Group on Publicity and Lobbying.

Future Directions

Research

The geosciences figured prominently in the National Research Priorities, released by Cabinet in November 2002. In particular, priority goals *An Environmentally Sustainable Australia* (transforming use of our land, water, mineral and energy resources; developing deep earth resources) and *Frontier Technologies for Building and Transforming Australian Industries* (geo-informatics; complex systems; advanced materials) are central to School activities. The same broad priorities were identified by ANU in its submission to the review.

Over the next five years, the School will evolve consistent with the structural adjustments put in place in 2002. We look to both our Planning Fund (see 2001 Report to Council) and success in ARC competitive grants to further align our research with School, university, and national priorities. The former will be used to maintain support for those high risk, long term activities of national significance for which the block grant is properly used. Our goals for success in winning national competitive grants will ensure that our efforts are broadly focused in areas of national importance.

During 2002 we undertook the initial stages of identifying and prioritizing initiatives to be supported by the Planning Fund. Five proposals were advanced ("Computational quantum mechanics in mineral physics", "A multi-disciplinary center for modelling and data inference in the geosciences", "Towards a microanalytical capability for stable isotopes", "A search for millenial-scale climate instabilities in the southern hemisphere", and "The future of satellite geodesy") that will be further scrutinized by our Advisory Board in 2003.

Students and Teaching

We were granted University approval in 2002 for our Honours curriculum in Physics of the Earth. This program will allow physical science graduates to gain specialist knowledge in geophysics for which the School has unique national strengths.

The School will give priority to increasing student numbers, particularly domestic students. My target remains a progressive increase to a student load of around 40. 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. Beginning this year, I am providing an internal incentive for student enrolments by including a student load factor in the formula for internal allocation of funds. This is consistent with my belief that recruitment activity by individual staff using personal contacts and networks is more effective than School or University-wide campaigns.

Mark Harrison

Director

March 12, 2003

ACADEMIC STAFF

Director and Professor:

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

Professors:

J.M.A. Chappell, BSc NZ, MSc *Auck*, PhD *ANU*, FAAS

S.F. Cox, BSc *Tas*, PhD *Monash*

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

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

B.L.N. Kennett, MA PhD ScD *Camb*, FRAS, FAA

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

M.T. McCulloch, MAppSc *WAIT*, PhD *CalTech*

Senior Fellows:

J. Braun, LicSc *Liège*, PhD *Dalhousie*

I.H. Campbell, BSc *WAust*, PhD DIC *Lond*

G.F. Davies, MSc *Monash*, PhD *CalTech*

T. Esat, MSc *Canada*, PhD *ANU*

M. Honda, MSc PhD *Tokyo*

T.R. Ireland, BSc *Otago*, PhD *ANU*

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

R.C.Kerr, BSc *Qld*, PhD *Camb*, FAIP

F.E.M. Lilley, BSc *Syd*, MSc PhD *WOnt*

H.St.C. O'Neill, BA *Oxf*, PhD *Manc*

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 *CalifLosAngeles*

M.I. Bird, BSc *Syd*, PhD *ANU*

S. Eggins, BSc (Hons) MSc *Melb* PhD *Tas*

C.M. Fanning, BSc *Adel*

M.K. Gagan, BA *CalifSantaBarbara*, PhD *JamesCook*

R.R. Loucks, BS *Colorado*, PhD *Harvard*

M.Norman, BS *Colorado*, PhD *Harvard*

A.P. Nutman, BSc PhD *Exeter*

N.Spooner, BSc MSc *Adel*, PhD *Oxon* (until 16 August 2002)

I.S. Williams, BSc PhD *ANU*

Research Fellows:

A.J. Berry, BSc *Syd*, DPhil *Oxf*

W.J. Dunlap, BA *CarletonColl*, MS PhD *Minn*

F.G. Fabel, BSc PhD *Melb*

H.U. Faul, Vordiplom Ulm, PhD *UOregon*

G. Hughes, BE ME *Auck*, PhD *Camb*

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

C. Meriaux, BPhys *Paris XI*, PhD *Paris VII*

A. Reading, BSc *Edin*, PhD *Leeds*

P. Tregoning, BSurv, PhD *NSW*

G. Yaxley, BSc PhD *Tas*

Postdoctoral Fellows:

C. Alibert, MSc *Paris* VII, PhD *CRPG* (from 3 June 2002)

J.R. Ballard, BSc ICSTM *UK*, (until 7 May 2002)

C. Bryant, BSc *UNE*, PhD *ANU*

A. Gorbatov, BSc *Moscow,* BSc PhD *UNAM*

J. Hermann, Diplom PhD *ETH Zürich*

A.Kiss, BSc PhD *ANU*

J.F. Marshall, BSc *UNSW*, MSc *ANU* (from 22 May 2002)

S.N. McLaren, BSc, PhD *Adelaide* (from 20 February 2002)

S. Micklethwaite, PhD *Leeds* (from 28 October 2002)

N.Rawlinson, BS *Monash*

D. Rubatto, BSc MSc *Turin*, PhD *ETH Zürich*

E. Tenthorey, BSc *McGill* MSc *Florida* PhD *Columbia*

VISITING FELLOWS ON Faculty DURING 2002:

Dr C. Alibert (RSES)

Profressor J. Avouac (Ecole Normale Superieure, Paris France)

Dr M. Basei (Institute of Geoscience, Sao Paolo Brazil)

Dr L.P. Black (Geoscience Australia)

Professor K. Cashman (University of Oregon, USA)

Dr J. Claoué-Long (Geoscience Australia)

Professor A. Cooper (University of Otago, New Zealand)

Dr P. Cummins (Geoscience Australia)

Dr E. Debayle (Institue de Physique du Globe de Strasbourg, France)

Dr M. Elliot (Columbia University, USA)

Professor E. Eriksson (Virginia Polytechnical Institute, USA)

Dr T. Esat (Geology, Faculty of Science, ANU)

Dr G.L. Fraser (Geoscience Australia)

Dr S. Frederiksen (University of Aarhus, Denmark)

Dr. C. Friend (Oxford Brookes University, GBR)

Mr C. Foudoulis (Geoscience Australia)

Professor Y. Fukao (University of Tokyo, Japan)

Dr A. Glikson (GeoSpectral Research, ACT)

Professor D. Green (RSES)

Dr R.W. Henley (Consultant)

Dr A.M. Heimsath (University of California, Berkeley)

Dr J. Hermann (RSES)

Dr Y. Jia (University of Saskatchewan, Canada)

Dr M. Idnurm (Geoscience Australia)

Associate Professor T. Iidaka (University of Tokyo, Japan)

Dr G. Kaufmann (German Research Society Fellow)

Professor H. Kwakatsu (University of Tokyo, Japan)

Professor P.C Link (Idaho State University, USA)

Dr R.R. Loucks (RSES)

Dr P.L. McFadden (Geoscience Australia)

Dr C. Montross (Ringwood Super-Abrasives ACT, Australia)

Dr L.N. Moresi (CSIRO)

Dr W. Müller (ETH Zurich, Switzerland)

Dr K. Niida (Hokkaido University, Japan)

Dr M. Obayashi (Marine Science and Technology Center Kanagawa, Japan)

Dr R. Page (Geoscience Australia)

Professor H. Palme (University of Cologne, Germany)

Dr A. Pike (University of Oxford, GBR)

Dr M. Pimentel (University of Brasilia, Brazil)

Dr D. Rubatto (ETH, Zurich)

Professor R.W.R. Rutland (RSES)

Dr N. Spooner (RSES)

Dr C. Stafford (Tohoku University Sendai, Japan)

Dr S. Vergniolle de Chantal (Institute de Physique du Globe, Paris)

Professor D. Walker (RSES)

Dr T. Watanabe (National Science Museum, Tokyo)

Professor S. Weaver (Universtiy of Canterbury, New Zealand)

Dr S. Webb (Geology, The Faculties ANU)

Associate Professor A. White (Flinders University Adelaide, Australia)

Dr J. Wynn (University of Oregon, USA)

Professor A. Yaghubpur (Teacher Training University Tehran, Iran)

Professor L. B. Zhu (Peking University Beijing, China

SCHOOL VISITORS ON FACULTY FOR 2002:

Dr A.Anma from the University of Tsukuba, Japan, visited the PRISE Group for one week with the aim of establishing the absolute ages for a number of Miocene plutons in Japan through SHRIMP U-Pb dating of zircons, as well as establishing the ages of inherited zircons and cores.

Ms C. Augustsson from the Westfaische Wilhelms Universitat, Germany, visited the PRISE Group for ten days to work on "The detrital zircon project" and carry out analyses using SHRIMP.

Dr J. Ballard, ANU was a visitor with the Earth Chemistry Group for two months for the purpose of continuing collaboration on the research project "Predictive Guides to Copper and Gold Mineralisation at Circum-Pacific Convergent Plate Margins".

Professor C. Beamont of the Dalhousie University, Canada, visited for six weeks to develop new methods to solve large-scale tectonic problems in three-dimensions, working with the Geodynamics, Earth Physics Group.

Mr A. Bisnath of the University of Durban, South Africa visited the PRISE Group for 12 days to carry out analyses using SHRIMP.

Ms R. Boshoff of the Rand Afrikaans University South Africa, visited the PRISE Group for one month to work on SHRIMP U-Pb zircon measurements to establish the timing of the Limpopo Orogeny.

Dr I. Buick of the La Trobe University Vic, Australia, visited for four days to work with Dr Joerg Hermann into REE and trace element constraints of high-pressure processes using the RSES laser (La-) ICPMS facility.

Ms S. DeVries from the Utrecht University, The Netherlands, visited the PRISE Group for three weeks to carry out analyses using SHRIMP as part of the research in relation to the Barberton Mountain Land.

Ms K. Durand from the University of Newcastle, Australia, visited for four days on two occasions for the purpose of using the Group's stable-isotope mass spectrometer to make collaborative measurements on freshwater bivalves from the Gregory River, North Queensland and to investigate the late Quaternary climatic history of northern Australia.

Ms T. Ewing from the University of Canterbury, New Zealand, visited for four days for the purpose of continuing research for the project "Provenance and depositional settings of the Loch Burn Formation, Eastern Fjordland: Implications for the Median Tectonic Zone".

Dr A. Fioretti from the Institute of Geoscience Padova, Italy, visited for two months to collaborate with Dr Lance Black from Geoscience Australia and the Geochronology and Isotope Geochemistry Group, RSES.

Dr S. Frank from the Institute of Climate Impact Research Potsdam, Germany, visited the Isotope Geochemistry Group for two days to present a seminar at RSES with the provisional title of *"Modeling the long-term evolution of the ecosphere."*

Dr T. Fujioka ANU, was a visitor for fourteen weeks to pursue his interests in utilising cosmogenic noble gases in relation to exposure ages of the Earth's surface.

Mr P. Fullsack from the Dalhousie University Halifax, Canada visited for six weeks to develop new methods to solve large-scale tectonic problems in three-dimensions, working with the Geodynamics, Earth Physics Group.

Professor M. Garcia ANU was a visitor for ten days to develop new methods for solving large-scale tectonic problems in three-dimensions, working with the Geodynamics, Earth Physics Group.

Dr S. Gardiner from Alligator Creek Qld, visited for 12 months. The purpose of the visit was to work with Professor Malcolm McCulloch.

Mr L. Gemmer from the Dalhousie University Halifax, Canada, visited for six weeks to develop new methods to solve large-scale tectonic problems in three-dimensions, working with the Geodynamics, Earth Physics Group.

Mr F. Gesto ANU was a visitor for four months to improve his skills in Fortran programming.

Dr R. Gillespie ANU was a visitor for two weeks to perform extracts from rare Thylacoleo specimens recovered by the Museum of WA.

Mr R. Huismans from the Dalhousie University Halifax, Canada, visited for six weeks to develop new methods to solve large-scale tectonic problems in three-dimensions, working with the Geodynamics, Earth Physics Group.

Ms J. Kapp ANU visited the Earth Chemistry Group for eight days.

Mr R. Kemp from Victoria, visited the Earth Chemistry Group for eleven days.

Ms K. Lilly visited the Earth Environment Group for ten months for the purpose of undertaking Honours research (preliminary title: *Retrospective analysis of climate extremes in the Australian Great Barrier Reef*), using the Group's stable-isotope facilities.

Dr T. Matsumo from the Osaka University, Japan, visited with Dr M. Honda for one week to exchange research interests, in particular, on the mantle evolution model developed by the Osaka Group.

Ms J. McDonald from East Maitland, NSW, visited the Earth Environment Group for five week to undertake U-Th dating as part of her thesis.

Associate Professor B. Mahoney from the University of Wisconsin-Eau Claire, USA, visited for three weeks to carry out various detrital zircon projects, as supported by NSF and other grants.

Mr N. Nhelko from the Rand Afrikaans University, South Africa, visited the PRISE Group for five days to work on a SHRIMP U-Pb zircon provenance study of sediments of the Pongola Group in Southern Africa, on a collaborative basis.

Mr M. O'Leary from the James Cook University Townsville, visited for two months for the purpose of working with Professor Malcolm McCulloch on a joint ARC project.

Dr R. Pankhurst from the British Geological Survey, England, visited for six weeks to carry out work on the Sierras Pampeanas project in collaboration with Dr Casquet and Dr Rapela, as well as to carry out analyses as part of the Southern Patagonian Batholith project with Professor Hervé, Santiago, Chile.

Professor I. Parsons from the University of Edinburgh, UK, visited the Earth Physics Group for two months to undertake TEM work on feldspars with Dr John Fitz Gerald.

Dr C. Rapela from the Universidad Nacional La Plata, Argentine, visited the PRISE Group during September to carry out work on the Sierras Pampeanas project in collaboration with Dr Casquet and Dr Pankhurst.

Dr N. Stevens from the Gracefield Research Centre, New Zealand, visited to establish a collaboration on the project titled "The eruptive behaviour of the large channeled Tongariro andesite lava flows" with the Geophysical Fluid Dynamics Group.

Ms K. Selway fromSouth Australia, visited Dr Lilley and other members of the Seismology and Geomagnetism group for four days to discuss her honours results.

Ms A. Storkey from the La Trobe University Vic, Australia, visited for four days to work with Dr Joerg Hermann into REE and trace element constraints of high-pressure processes using the RSES laser (La-) ICPMS facility.

Dr C. Turney from the University of London, UK, visited the Environmental Processes Group, between June and September. The visit was in relation to applying ABOX radiocarbon techniques to dating early human occupation in Australia.

Dr G. Whitmore from the University of Natal, South Africa, visited the PRISE Group for nine days to undertake SHRIMP zircon dating of detrital zircons from the heavy mineral deposits along the east coast of South Africa and Mozambique.

Professor E. Zinner from the Washington University, USA, visited for six weeks for the purpose of collaboration on the ARC Discovery Project titled "Lithic Astonomy: The age and origin of the elements and their incorporation in the solar nebula."

Research Officers:

D.R. Christie, MA *Tor*, PhD *ANU*

P. Holden, BSc *Lancaster*, PhD *St. Andrews*, (from 27 February 2002)

S.E. Kesson, BSc *Syd*, PhD *ANU*

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

N.G. Ware, MSc *Durh*

Research Assistants:

A. Arcidiaco, BApp Sc, Grad Dip *SA Inst*

B.J. Armstrong, BSc *UNISA*

I.T. Harman, BSc Applied Math Uni *Armidale*(from 27 May 2002)

R.W.L Martin, BSc *ANU*

A. Purcell, BSc PhD *ANU*

R. Stanaway, BAppSc *Qld Utech*

L. Weston, BSc *Macquarie*

Post-graduate Students

PhD Candidates:

N. Abram, BSc Hons *Syd*

B. Ayling, BSc Victoria University *NZ*

S. Fishwick, BSc Uni of *Edinburgh*

L.M. Glass, BSc *WA*

R. Fraser, Btech BSc *Flin*

A.C. Hack, AssocDi App Sc *CIT*, BSc *ANU*

C.J. Heath, BSc *Monash*

F. Herman, Civ Eng, *Belgium*

T.-K. Hong, BSc MSc, *Seoul National*

B. Jenkins, BSc, UTS *Sydney*

X. Liu, MS, *ChineseAcSci*, BSc *ChinaUnivGeosci*

A. Lyman, BSc, MSc, *Arizona State*

H.V. McGregor, BSc *JamesCook*

D. Maidment, BSc *UNSW*

I. McCulloch, BSc *UNSW*, Grad Dip *ANU*

J. Mullarney, BA *Cambridge* MSc *Bristol*

T.A. Nicholson, BSc *Vict Well*

E.-K.M. Potter, BSc *Woll*, BSc *ANU*

D. Qu, Petroleum Inst *Jianghan*, MSc Acadamy of Sciences *China*

P. Rustomji, BSc *ANU*

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*

P. Treble, BSc *Woll*, BSc *ANU*

J. Trotter, BSc and MSc *Macq*

T. Wyndham, BSc *ANU*

K. Yoshizawa, MSc *Hiroshima*

Y. Zhou, BSc MSc *Chengdu Inst Tech*

Masters Candidate:

R. Stanaway, BAppSc, *Qld UTech*

Hales Honours Year Scholar:

T. Burgess

K. Procko

GENERAL STAFF

Executive Officer:

B.A. Payne, BA *ANU* (until 1 September 2002)

G. Kretschmer, BSc *Flind*, Phd *ANU* (from 2 September 2002)

Assistant Executive Officer:

G. Kretschmer, BSc *Flind* Phd *ANU* (until 1 September 2002)

M. Murphy, (from 4 November 2002)

Technical Officers:

C. Allen, AB *Princeton* MS *Oregon*, PhD *VirginiaTech*

J.T.A. Arnold, BSc (Agr) *Syd*, GradDipElect *CCAE*

A.R. Beasley, AssocDipMechEng *CIT*

V. Baek-Hansen

P. J. Biggs

J. Cali, BAppSc *QIT*

D.L. Corrigan

J.A. Cowley, BSc *ANU*

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

A.W. Forster

J.J. Foster, BSc *Syd*, MSc PhD *ANU*

J.H. Grant

W.O. Hibberson, BAppSc *CCAE*

N. Hill, BA *ANU*

I. Iatsevitch, BEng *Tashkent Polytec Inst*, PhD *Russian Academy of Sciences*

B. Jenkins, BASc *UTS*

D. Kelleher, Assoc Dip Cartog *CIT*

L.P.J. Kinsley, BSc GradDipSc *ANU*

H. Kokkonen, BAppSc *CCAE*

C. Krayshek

J. Lanc

A. Latimore

R.E. Maier

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G.E. Mortimer, BSc PhD *Adelaide*

J. Mya, BSc *Mandalay*

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N. Schram, Dip EIE *SAIT*

D. Scott

H. Scott-Gagan, BSc *Syd*

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S.P. Sirotjuk, AssocDipEng (Electronics) *Gordon TAFE*

L. Taylor, BA *ANU*

D.B. Thomson

R.M. Waterford

G. Watson

A.R.W. Welsh, BAppSc *CCAE*

R.E. Willison

A. Wilson

G.F. Woodward

R. Wylde-Browne (until 18 July 2002)

X. Zhang, PhD *LaTrobe*

Trainee Technical Officer:

B. Ferguson (from 14 October 2002)

C.A. Saint (from 19 March 2002)

Apprentice:

B. Taylor, (from 27 November 2002)

Information Technology

D. Bolt, BSc *Syd*

S. Robertson, DipAppPhys *Gordon Inst Tech*, MSc BSc *ANU*

School Librarian - Librarian's Staff:

S. Jackson, BA *ANU*, Grad Dip Lib Inf Man *UC*

C. Harney, DipLibInfStud *CIT*

Administration:

F. Chivas (until 29 November 2002)

T. Coombes (until 12 July 2002)

C.J. Cullen (from 14 August 2002)

P. Delatorre, (from 17 June 2002)

J.A. Delhaize (until 21 February 2002)

P.A. Gillard (until 1 April 2002)

V.M. Gleeson

W.A. Hampton

M. Hooper

D.H. Kelly

M. Lukatela, BA Mod. Lang, Grad Dip Lib, *CCAE*

M. McDonald, BAppSc (Phys) *CCHS*, GradDipAccount, *Monash*

R. MacPherson

R. A. Petch, (from 20 May 2002)

K. Provins

M. C. Turner, DipMan *CIT* (from 23 September 2002)

E. Ward

Research School of Earth Sciences Advisory Committee

Professor Lovering (Chair), Emeritus Professor, Flinders University and University of Melbourne.

Professor T. Mark Harrison, Director, RSES

Professor J. Hearn, Deputy Vice- Chancellor (Research), ANU

Professor B.L.N. Kennett, RSES

Dr H. StC. O'Neill, RSES

Professor R. Griffiths, RSES

Dr B. Schmidt, RSAA

Professor S. O'Reilly, Director, Department of Earth and Planetary Science, Macquarie University

Dr C. Pigram, Geoscience Australia

Professor N. Phillips, CSIRO

Mr G. Hall, Chief Geologist, Placer Dome Asia Pacific

THESES SUBMITTED IN 2002

PhD

Name	Thesis Title	Supervisor/ Advisor
Ms L.M. Glass	Petrogenesis and geochronology of the north Australian Kalkasingji low-tide continental flood basalt province	*Supervisors:* Dr H. O'Neill and Dr V. Bennett (RSES) *Advisors:* Dr I. Campbell and Dr I. Williams (RSES)
Mr T.A. Nicholson	Development and application of new techniques for global travel times and source location	*Supervisors:* Dr M. Sambridge (RSES) *Advisors:* Professor B.L.N. Kennett (RSES)
Ms E. M. Potter	Sea level, ice sheets and climate during marine isotope sub-stages 5a and 5c	*Supervisor:* Professor K. Lambeck (RSES) *Advisors:* Professor J. Chappell, Dr T. Esat and Dr. H McQueen
Mr B.D. Rohrlach	Tectonic evolution, petrochemistry, geochronology and palaeohydrology of the Tampakan porphyry and high sulphidation epithermal Cu-Au deposit, Mindanao, Philippines	*Supervisor:* Dr I. Campbell (RSES) *Advisors:* Dr R. Loucks, Professor I. McDougall and Dr M. Palin
Mr K. Yoshizawa	Development and application of new techniques for surface wave tomography	*Supervisor:* Professor B. Kennett (RSES) *Advisors*: Professor I. Jackson and Dr M. Sambridge (RSES)

POSTGRADUATE AWARDS AND SCHOLARSHIPS

Australian National University Scholarship:

Mr F. Herman

Mr A. Lyman

Mr M. Smith

Australian Postgraduate Award:

Mr I. McCulloch

Ms J. Trotter

Mr T. Wyndham

Graduate School Scholarship:

Ms B. Ayling

International Postgraduate Research Scholarship:

Mr D. Qu

Admission Only - Postgraduate Research

Mr B. Jenkins

A.L. Hales Honours Year Scholarship:

Mr T. Burgess - Australian National University

- *Project:* An investigation into the use of fast marching methods for global seismology
- *Supervisors*: Dr M. Sambridge and Dr N. Rawlinson

Ms T. Milczarek - Australian National University

- *Project:* Receiver function studies of the upper mantle
- *Supervisor:* Professor B.L.N. Kennett

Ms K Procko - Australian National University

- *Project:* Interstation methods for surface waves
- *Supervisor*: Professor B.L.N. Kennett

SUMMER RESEARCH SCHOLARSHIPS

Shaun Barker - University of Otago

- *Project*: U-Th-He dating of Tuross Gorge
- *Supervisor*: Dr J. Dunlap

Katrina Brown - University of Waikato

Project: Stable isotopes in faunal remains from the Burra megafauna site

Supervisors: Professor R. Grun and Dr M. Gagan

Melissa Coman - Australian National University

· *Project*: Experimental project in GFD Lab

· *Supervisor*: Professor R. Griffiths

Simon Granville - University of Wellington

· *Project*: The effect of partial melting of the seismic wave speeds in olivine

· *Supervisor*: Professor I. Jackson

Tennille Mares - University of New South Wales

· *Project:* Determining sediment inputs into the central Great Barrier Reef using coral records

· *Supervisor:* Professor M. McCulloch

Adam McKinnon - University of Western Sydney

· *Project:* Isotope chemistry of pre-solar material

· *Supervisor:* Dr T. Ireland

Nora Patterson

· *Project*: Melting history of Lambert glaciers

· *Supervisors:* Professor K. Lambeck, Dr H. McQueen and Dr T. Purcell

Nicholas Tailby - Australian National University

· *Project:* Oxidation state of Fe in silicate melts

· *Supervisors*: Dr J. Mavrogenes

Suzannah Toulmin - University of Wellington

· *Project:* Recent tectonics of the New Britain area PNG, using earthquake locations in association with GPS measurements

· *Supervisors:* Dr P. Tregoning

HONOURS AND AWARDS

Academic Staff

Mr J.P. Bernal was awarded the CONACyT (Consejo Nacional de Ciencia y Tecnologia) Prize by the Mexican Council for Science and Technology.

Professor M. Harrison was named a Highly Cited Researcher by the Institute for Scientific Information, placing him in the top 0.5% of all publishing researchers over the past 20 years.

Dr J. Hermann qualified for appointment as an Assistant Professor in Petrology, at an examination held in Urbino, Italy.

Dr A.E. Kiss was awarded the Australian Meteorological and Oceanographic Society Federation PhD Prize.

Professor M.T. McCulloch was elected as a Fellow of the American Geophysical University on in 2002 for major contributions to understanding the origin and evolution of the Earth's continental crust and mantle and environmental science and climate change.

Students

Ms E. Hendy, a PhD student, was awarded the RSES Robert Hill Memorial Prize in recognition of her interdisciplinary research and effective communication in the earth sciences.

Ms H. McGregor was awarded recipient of the Australasian Quaternary Association Travel Prize to attend the NCCR Swiss International Climate Summer School, Grindelwald, Switzerland, September 2002.

Ms E. Potter and Ms P. Treble were awarded the Mervyn and Katalin Paterson Fellowship.

Ms J. Trotter was awarded a Paleontological Society Grant-in-Aid Award, granted by the Paleontological Society and funded by the Mid-America Paleontological Society. Her research proposal was 1 of the 2 top-ranked applicants in an international field of 50, and so was also awarded with a certificate for Outstanding Research Proposal.

Research Activities

Earth Chemistry Area: Introduction

Dr T.R. Ireland

Research within the Earth Chemistry Area is directed primarily toward understanding how the Earth works, using radiogenic isotopes to determine the nature and timing of geological events and processes. Broad fields of enquiry include the origins of our solar system through to formation and differentiation of the early Earth, crustal evolution and recycling, magma genesis, metamorphic processes, the tectonic evolution of orogenic belts, sediment provenance, and time scales for the evolution of plants and animals, including hominids.

Processes range in scale from the size of the solar system down to the diffusion lengths of elements at the microscopic level. Isotopic abundances are measured as tracers of the age and nature of the processes involved to yield information on such diverse events as high-temperature (>2000K) fractionation of elements in the solar nebula, the nature of EarthÕs earliest crust and atmosphere, the chemical differentiation of ore deposits, and the uplift history of eastern Australia.

The Earth Chemistry Area at RSES consists of two broad research groups, Geochronology & Isotope Geochemistry (comprising the Ion Probe, Noble Gas Geochemistry, and Noble Gas Geochronology and Thermochronology sub-groups) and Ore Genesis. In addition RSES has a long-standing association with Geoscience Australia to allow access to analytical facilities primarily within Earth Chemistry.

Research activities within Geochronology & Isotope Geochemistry focus on the application of geochronological and geochemical techniques to geological problems addressing fundamental questions concerning the origin and evolution of the Earth, especially the EarthÕs crust. Study areas range from the formation of the Earth from its primordial constituents through to the history of the Earth as a dynamically evolving planetary body, increasing the body of knowledge about how the Earth works and providing important insights into the history of the Earth and the Solar System. Research techniques are primarily focused on variations in isotopic abundances that can be used for radiometric age dating as well as tracers of processes affecting the Earth. Additional information is derived from geochemical characteristics of rocks as well as their mineralogy and petrology, and when appropriate, field geology.

Research interests of the Ion Probe sub-group include the nature of material making up the Early Solar System and the processing of that material into planetary bodies; the origin and chemical evolution of the Earth; early Archaean geology; Precambrian tectonics; and zircon geochronology and itsÕ application to the development of the Australian continent and once contiguous areas of Gondwana. Noble Gas studies on old mantle-derived materials have continued to research the origin and evolution of the EarthÕs atmosphere, crust, mantle and core. Noble Gas Geochronology and Thermochronology research in 2002 has focused on low-to-medium temperature isotopic dating studies and the development of a mostly automated helium dating line instrument, with new research in surficial studies and exhumation studies being initiated late in the year.

Analytical facilities for Geochronology & Isotope Geochemistry research include the SHRIMP ion microprobes and the noble gas mass spectronometers, which are also available to external researchers via the SchoolÕs commercial entity Precise Radiogenic Isotope Services (PRISE). In addition, collaboration with Geoscience Australia (GA) optimises the ion probe facilities for geochronology research, in particular, U-Pb SHRIMP geochronology and more recently Ar-Ar geochronology.

Ore Genesis research is centred on the formation of ore systems, utilising laser ablation ICP-MS for the refinement of U-Th-Pb in zircon dating for radiogenic isotopes to trace the source of ore fluids associated with porphyry copper and epithermal gold deposits. This research continues to have important implications for copper and gold ore exploration in particular. Ore Genesis research in 2002 has included studies of a fossil volcano-centred copper- and gold-ore-forming hydrothermal system; the origin and composition of ore-forming fluids in the Golden Mile gold deposit, Kalgoorlie WA; a carbonatite source for alteration fluids at the Wallaby Gold Deposit, Laverton, WA; and melting rates and efficiencies in mantle plumes.

The success of our research effort owes much to the excellent support provided by the technical staff within the group, as well as by members of the SchoolÕs mechanical and electronic workshops, and sample preparation laboratories. Without such support, much of our research simply would not be possible.

Geochronology and Isotope Geochemistry

Ion Probe Summary Ð Dr T.R. Ireland

2002 saw the successful implementation of the SHRIMP II Multiple Collector, a device that allows simultaneous collection of up to 5 ion beams. A commercial version of the Multiple Collector was also installed on a SHRIMP II destined for St Petersberg, Russia. First applications on our SHRIMP II have included multiple collector Pb isotope work allowing better precision to be obtained on small samples, and rapid characterization of ancient detrital zircon populations that are the source of the oldest terrestrial minerals known. A 5 second analysis is sufficient to screen for 4Ga zircons, allowing hundreds of zircons to be screened in a day.

The SHRIMP RG has continued to show improved analytical capabilities. Ultimate resolution of 40,000 M/ΔM has been achieved and a new field controller (FC3) has allowed unprecedented setting of the magnetic field at the sub-ppm level. Applications utilizing the higher mass resolution include trace-element abundance analyses, Hf-W systematics of meteoritic zircons, and Fe group element isotope compositions in refractory inclusions.

SHRIMP I continues to provide high quality data to analogue users.

We are in the process of evaluating the potential for a SHRIMP dedicated to stable isotope analysis, primarily through the measurement of negative secondary ions. Such a development is very exciting and would allow capabilities not possible on SHRIMP II.

High temperature processing of refractory inclusions

Dr T.R. Ireland

Refractory inclusions are the earliest known objects formed in the solar nebula with absolute ages of approximately 4.567 Ga. They contain anomalies in the isotopic compositions of a variety of elements, indicating formation from materials that had not been substantially homogenized in the solar nebula. Refractory inclusions are often referred to as calcium, aluminium-rich inclusions (CAI) because of the abundance of these highly refractory elements as oxides. In addition, other refractory trace elements indicate high-temperature processing with differential evaporation/condensation causing large fractionations between elements of different volatility.

Hibonite [$CaAl_{12}O_{19}$] inclusions contain some of the largest anomalies yet found in Fe group elements, notably Ca and Ti with anomalies in the heaviest isotopes ^{48}Ca and ^{50}Ti of +10% and +27% respectively.

Other elements from the Fe group also have anomalies and so it is of interest to evaluate the possibility of carrying out measurements of these elements by ion microprobe on highly anomalous hibonite inclusions. The SHRIMP RG ion microprobe can operate with high sensitivity and mass resolution allowing rapid evaluation of isotopic compositions.

The measurement of isotopic compositions of other elements of the Fe group will be difficult. V, Cr, and Fe ion abundances are 2 orders of magnitude below the level of Ti (ca. 2 wt %), while Mn is a further order of magnitude lower. Co and Ni levels are of order parts per million. Surprisingly, Cu and Zn concentrations are of a similar level to Cr. Of these elements, Cr is perhaps the most accessible but suffers from isobaric interferences from ^{50}Ti and ^{54}Fe on ^{50}Cr and ^{54}Cr respectively. It also appears that Cr and Fe may be related to later alteration of the hibonite crystals, some of which have possible metasomatic alteration rims that have produced a region more closely of spinel composition. This is also the likely cause of the elevated Cu and Zn abundances. It is likely that most intrinsic Fe group elements apart from the most refractory Ca and Ti have been lost during high temperature processing in the early solar system.

The low intrinsic levels of those elements, and the high mass resolving power required for separation of atomic isobars will preclude straightforward isotopic analysis by ion microprobe.

Using lithium isotopes to constrain granite petrogenesis

C.J. Bryant, B.W. Chappell[1], V. Bennett and M.T. McCulloch

[1.] Dept. of Earth Sciences, Macquarie University

The element lithium is composed of two stable isotopes, ^{6}Li and ^{7}Li. These light isotopes undergo significant fractionation during low temperature processes. For example during chemical weathering ^{6}Li is preferentially retained in clays, whereas ^{7}Li ultimately becomes concentrated in the ocean. This results in rocks that have experienced extensive chemical weathering being isotopically light (having lower ^{7}Li/^{6}Li ratios) than less weathered materials. As many granites contain large amounts of sediments, lithium isotopes potentially provide a sensitive monitor of the specific types and histories of the supracrustal components involved in the genesis of granites. These crustal components may be introduced either during partial melting or through assimilation at shallow levels. Furthermore, as Li is a stable isotopic system and has no age dependency, it may be used to provide new controls on source components in young crustal domains in which there are limited resolution available from the long half life Sm-Nd and Rb-Sr isotopic systems. Although the potential of lithium isotopes to provide constraints on granite petrogenesis has been previously recognized, at present there are only a handful of measurements and most of these are from rock standards, rather than representing systematic investigations.

Figure 1: Bald Rock, near Tenterfield, northern N.S.W.; outcrop of fractionated Moonbi Supersuite granites from the southern New England Orogen.

This yearÕs activities had three main objectives; (i) developing suitable methods for accurate, high precision determination of Li isotopic compositions using ion exchange chemistry combined with analysis using the Neptune multicollector-inductively coupled plasma-mass spectrometer (MC-ICP-MS), The results of this phase of the work have demonstrated that high precision data can be obtained on the Neptune using Òcool plasmaÓ conditions combined with careful control of solute and acid concentrations (Bryant et al, JAAS, submitted) (ii) conducting a detailed review of the geochemistry of granites of New England Batholith (NEB), including a review of existing classification schemes and identifying more specific groupings within individual supersuites, and (iii) determining the Li isotopic composition of a diverse range of NEB granites to ascertain if there is a systematic relationship between source rock type and isotopic composition.

The New England Batholith was selected for this study as it contains five major supersuites ranging from classic cordierite-bearing S-type granites (Bundarra), S-type granites with transitional I-type characteristics (Hillgrove), I-type granites with significant sedimentary input (Uralla), high-K I-type granites (Moonbi; Fig. 1), and isotopically primitive low-K I-type granites that are chemically equivalent to intraoceanic arc magmas (Clarence River); the involvement of strongly weathered sedimentary components decreases from a maximum in the Bundarra Supersuite to a minimum in the Clarence River Supersuite.

This study is the first to combine Li isotopic data with detailed major and trace element chemical variations. The NEB granites are isotopically diverse, with d^{7}Li (this is the ^{7}Li/^{6}Li ratio presented in per mil variations from a standard; low numbers are isotopically light and high values are isotopically heavy) ranging from 0 to +8 ä; Fig.2. The highest values (Clarence River) are equivalent to those reported in the fluid-dominated, sediment-poor intraoceanic arc systems (Fig.2). Moonbi Supersuite granites also have high d^{7}Li, consistent with an infracrustal origin. The lower d^{7}Li for Uralla (I-type) is consistent with a significant sedimentary component. The Bundarra granites, which are derived from strongly weathered source rocks have the lowest d^{7}Li, overlapping with those of shales and oceanic sediments. The diversity observed thus far for Hillgrove (S-I type transitional suite) are particularly interesting in that the lowest value overlaps with sediments and the highest is equivalent to arc lavas. These results are consistent with an immature, greywacke source in which there is limited weathering, along with possible seawater contributions (d^{7}Li$_{seawater}$ = +31±2ä). I- and S-type granites of the New England Batholith are systematically heavier than those of the Lachlan Fold Belt, supporting the contention that they are derived from fundamentally different types of crustal materials.

These new results provide the clearest demonstration that lithium isotopic ratios are correlated with granite chemistry and thus provide a sensitive monitor of sedimentary inputs to crustal growth.

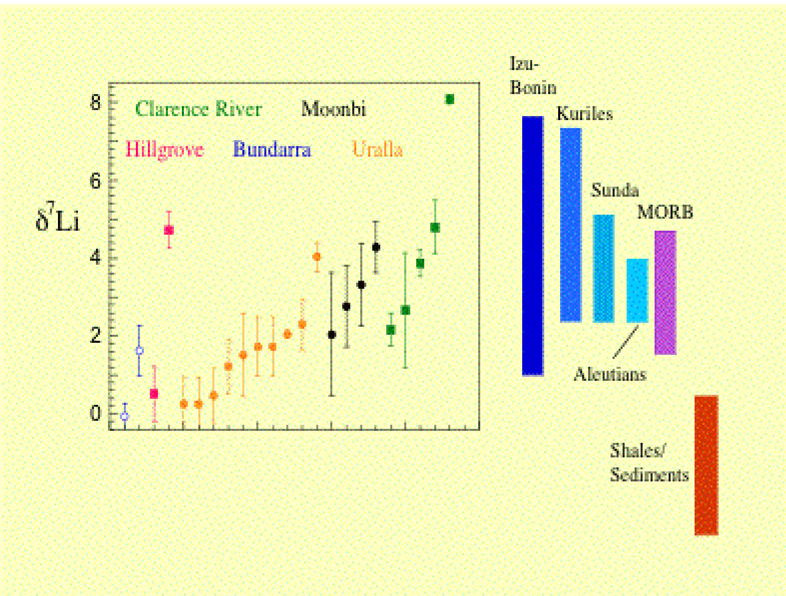

Figure 2: Lithium isotopic compositions of New England Batholith granites vary greatly (~8ä d^{7}Li), reflecting the strong compositional diversity of the source rock components. The strong overlap observed between Moonbi

and Clarence River granites with arc lavas suggests that the Li isotopic compositions are not significantly modified during partial melting processes. However, at the same time Li isotopes are very sensitive to the incorporation of supracrustal components. Arc, MORB and sediment data from Moriguti & Nakamura (1998, *Earth. Planet. Sci. Lett.* 163, 167-174.) and Tomascak et al. (2002, *Earth. Planet. Sci. Lett.* 196, 227-238).

U-Pb Zircon Studies of Enclaves from the S-type Jillamatong Granodiorite, Lachlan Fold Belt, SE Australia.

Roger Kemp[1], Ian Williams, Janet Hergt[1] and Jon Woodhead[1]

[1]VIEPS School of Earth Sciences, University of Melbourne

The mafic S-type Jillamatong Granodiorite, which crops out south of Jindabyne, NSW, contains abundant enclaves. Most appear to be metasedimentary. Some are extremely biotite rich (~50 wt % SiO_2). A few are rounded and microgranular with igneous-like or Òpseudo-doleriticÓ texture. These have a silica content more like that of the host granodiorite (~63 wt %).

In preparation for a study of the Hf isotopic composition of zircon from the various enclaves, we have measured the U-Pb ages of zircon from three microgranular and two metasedimentary enclaves using the ANU SHRIMP RG. Contrary to expectations, there appear to be differences in the age of the melt-precipitated zircon in these enclaves. Where as the new-grown zircon in the microgranular enclaves in all cases yields ~435 Ma, indistinguishable from the age of melt precipitated zircon in the host granite, the new zircon in the metasedimentary enclaves has a range of ages up to 10 m.y. higher. It is possible that the latter records a thermal event in the granite source that preceded mobilisation of the magma. Somewhat similar, although smaller, age differences between enclave and host zircon growth have previously been reported in the S-type volcanic rocks of southern Spain.

Both types of enclave contain abundant inherited zircon with a spectrum of ages that closely resembles that of the inherited zircon in the host granite. If the protolith of the microgranular enclaves was an igneous rock, either it contained abundant detrital zircon similar to that in the graniteÕs sedimentary source rocks, or zircon has been introduced to the enclave while it was in a partially molten state. Perhaps the microgranular enclaves also are metasedimentary? Th Hf isotopic analyses will answer this question.

High-grade metamorphic equivalents of the Centralian Superbasin in the Harts Range region, central Australia.

David Maidment, Ian Williams & Martin Hand[1]

[1] Department of Geology & Geophysics, The University of Adelaide

A SHRIMP study of detrital zircon ages is being undertaken to assess possible correlations between high-grade metasediments from the Harts Range region, east of Alice Springs, and adjacent low-grade sediments of the Amadeus and Georgina Basins. Recent work has suggested that the upper amphibolite to granulite facies Irindina Supracrustal Assemblage (ISA) of the Harts Range is not Palaeoproterozoic, as has previously been assumed, but as young as Cambrian. Neoproterozoic to Early Ordovician stratigraphic units in the Georgina and Amadeus Basins have been sampled to test whether their detrital zircon age patterns are the same as any in the ISA metasediments.

Four units from the southern Georgina Basin have been analysed: the Grant Bluff Fm (Late Neoproterozoic); Mt Baldwin Fm (Early Cambrian); Arrinthrunga Fm (Late Cambrian) and the Tomahawk Beds (Cambro-Ordovician). The detrital zircon ages cluster at ~2.5 Ga, 1.9Ð1.7 Ga and 1.2Ð1.0 Ga, consistent with derivation from sources in the Arunta and Musgrave Inliers. These groupings are very similar to those that have been found in ISA metasediments, suggesting that both sequences shared a similar source. A particularly close correlation is evident between the detrital zircon spectra of the Tomahawk Beds and the amphibolite facies Brady Gneiss.

The Georgina Basin and ISA sequences also share a common change in provenance over time, further supporting correlation between the two. The late Neoproterozoic to Late Cambrian units of the Georgina Basin contain no zircons younger than ~800 Ma, whilst the Cambro-Ordovician Tomahawk Beds has abundant zircons younger than 800 Ma. Similarly, the structurally lowest units of the ISA are also poor in <800 Ma zircons, whilst the upper units show an increasing abundance of 550-800 Ma zircons.

Similar maximum depositional ages, provenance ages and changes in provenance thus indicate that the high-grade metamorphics of the Harts Range region are correlatives of Neoproterozoic to Cambro-Ordovician sediments in the Georgina Basin. Early results from the eastern Amadeus Basin are consistent with this interpretation. The ISA sediments were rapidly buried to about 30-35 km by 480-

460 Ma and metamorphosed to granulite-facies. This probably occurred within an intracratonic rift setting, concurrent with the formation of the Larapintine Seaway.

Timing of tectonothermal events in the Nuuk District: gold and late Archaean terrane assembly

A.P. Nutman and C.R.L. Friend[1]

[1]Department of Geology, Oxford Brookes University, Oxford, U.K.

For many years Nunaminerals A/S have had access to results from our mapping of late Archaean structural and U/Pb zircon dating studies. These studies provide constraints on the timing of both thermal and tectonic events. This contribution (I) sets the background to structural evolution in the Nuuk district, including independent confirmation of our tectonostratigraphic terrane model (II) summarises presently recognised post-2800 Ma tectonothermal events and (III) presents our latest dating, highly relevant to the Stor⁻ gold occurrence, with discussion of a testable model.

Tectonothermal history of the Nuuk district

In the mid 1980s, starting in the south of the region around Tre Br⁻dre and F¾ringehavn, we mapped folded, Archaean mylonites separating gneisses of different late Archaean metamorphic history (Friend et al. 1987). In the late 1980s, our reconnaissance mapping of the extensive coastline throughout the region found that individual Archaean mylonites could be followed over considerable distances (up to 100 km), plus old-style bulk zircon dating by H. Baadsgaard demonstrated that they separated rocks of not only different metamorphic history, but of different age as well (e.g., Nutman et al., 1989). This led to our model that the whole of the Nuuk region consists of different blocks of gneisses (tectonstratigraphic terranes), which were only brought together towards the end of the Archaean (e.g. Friend et al. 1996). This year, our model/interpretation has been independently-tested and confirmed by structural mapping and single-crystal zircon dating (Crowley, 2002). Thus at present the tectonostratigraphic terrane assembly model remains the best one to try and formulate late Archaean tectonics in the district. Archaean mylonites of several ages and adjacent low strain domains may provide a framework understanding the gold mineralisation in the region.

Chronology of late Archaean mylonites and thermal events in the Nuuk district

We have amassed a large amount of SHRIMP U/Pb zircon ± monazite dating that is providing ever-tighter controls on the age of different mylonites and thermal events. This program will continue over the next 3 years, with funding from the Australian Research Council (ARC). Presently we can document the following chronology:

- ca. 2760 Ma - Metamorphism (highest P?), which might be broadly coeval with the earliest, most complexly-folded mylonites. May relate to a major collisional event.
- ca. 2730 Ma - Extensive, folded mylonites with regional amphibolite facies metamorphism culminating in deep crustal melting to produce crustally-derived granites and areas of migmatite. May relate to extensional collapse and core complex formation in over thickened crust.
- ca. 2690 Ma - post mylonite granite sheets, migmatite formation and regional metamorphism. Presently not linked to any tectonic event.
- ca. 2610 Ma - granite sheets, migmatite formation and regional metamorphism. Presently not linked to any tectonic event.
- ca. 2550 Ma - subvertical, not folded, amphibolite facies shear zones and granite emplacement, including intrusion of the 2550 Ma Q™rqut granite complex.
- ca. 2530 Ma - major subvertical lower amphibolite facies shear zone, with interconnecting flatter lying jogs, which can be followed for >100 km.

Stor¯ gold in a tectonothermal context

The Stor¯ and neighbouring gold occurrences are close to the major shear zone we have dated at 2530 Ma, and is also close to the late kinematic 2550 Ma Q™rqut granite complex with its associated array of amphibolite facies shear zones active at 2550 Ma. Large mafic-ultramafic supracrustal units are also present as a possible source of metals. A model to be tested by further mapping and ARC-funded geochronology is a link between the gold mineralisation, the 2550-2530 Ma shear zones for accommodation and fluid transport, plus the Q™rqut granite as a continuing heat source.

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Understanding eclogites and syn-extension granulite facies events in the E. Greenland Caledonian orogen: a zirconocentric perspective

When CL-guided U/Pb zircon geochronology is combined with detailed field observations, LA-ICPMS zircon trace element geochemistry and zircon inclusion petrography, a further level of linkage can be made between U/Pb geochronology and tectonothermal/crustal evolution (e.g. Hermann et al., 2001).

The northern half of the East Greenland segment of the Caledonides is mainly composed of Palaeoproterozoic orthogneisses and metagranitic rocks, with subordianate proportions of supracrustal rocks. All granitic rocks in this part of the orogen have yielded Palaeoproterozoic dates, mostly 1750 – 2000 Ma (SHRIMP U-Pb zircon data; Kalsbeek et al., 1993); no granites of Caledonian age have been recognised with certainty (Kalsbeek et al., 1999). Further south, in the area between 72°N and 76°N, similar orthogneisses (south of 72û40ÕN of Archaean age) are overlain by a succession of late Mesoproterozoic or very early Neoproterozoic medium to high-grade metasedimentary rocks, the 'Krummedal supracrustal sequence' (Higgins, 1988). In this area Caledonian granites occur in abundance; they are S-type muscovite-bearing leucogranites, formed by fusion of Krummedal lithologies (Kalsbeek et al., 2000). Therefore, they are not present within the crystalline basement, but are restricted to the Krummedal sequence, from where they locally intrude into the lowermost part of the overlying Neoproterozoic Eleonore Bay Supergroup (see below). Only in the southernmost part of the East Greenland Caledonides, 70û30ÕN - 71û30ÕN, Caledonian I-type granitoids (granites, granodiorites, quartz-diorites etc.) are present. These rocks were subjected to a complex series of tectonothermal events, including Caledonian eclogite facies metamorphism in the north of the belt (e.g., Brueckner et al., 1998). This contribution presents an integrated SHRIMP U/Pb zircon dating and LA-ICPMS trace element analysis case study of metamorphic zircons in eclogites and granulite facies partial melt segregations and crustally-derived granite to underscore the complexity of metamorphism in the belt.

~400 and ~360 Ma eclogite facies metamorphisms, northern Caledonides

Eclogite facies relicts were examined from the recently documented UHP (coesite grade – Gilloti & Krogh-Ravna, 2002) terrane east of the Germania Land Shear Zone (1 sample), and from the HP terrane west of the shear zone (3 samples). The sample from east of the shear zone is a kyanite eclogite and yielded ovoid zircons devoid of Precambrian cores. In CL images they are dominated by bright (low U), homogeneous to sector-zoned zircon, containing <5 µm inclusions of kyanite, omphacite and garnet. One silica inclusion in zircon was also found, and is presently undergoing Rhaman spectroscopy to see if it is coesite. Around this zircon can be partial thin shells of higher U homogeneous zircon. All analyses were undertaken on the lower U zircon with HP inclusions, and they yielded a weighted mean $^{206}Pb/^{238}U$ date of 356±6 Ma. The zircons show only moderate enrichment in HREE over LREE, with no Eu anomalies. Thus 356 Ma is the date of the UHP metamorphism, not exhumation. Three eclogite samples from the west of the shear zone yielded metamorphic zircon, with one also containing inherited Palaeoproterozoic zircon as well. Metamorphic zircon in these samples yielded $^{206}Pb/^{238}U$ dates of 414±13, 401±7 and 394±10 Ma, all within error of each other. All metamorphic zircon has eclogite-style REE patterns (only moderate HREE enrichment over LREE and no negative Eu anomalies). Sm-Nd mineral isochrons on the same samples from either side of the shear zone (H. Breuckner) give the same differences in ages. Thus the age of eclogite facies metamorphisms on either side of the shear zone is ~50 million years different.

430-420 Ma extensional shear zones and partial melting, southern Caledonides

In western Renland, Scoresbysund, a package of ~920 Ma augen granites and their host/source Mesoproterozoic metasediments were affected by Caledonian tectonothermal events (Leslie and Nutman, in press). Within pelitic parts of the metasediments garnet–bearing partial melt neosome patches are developed, metabasite dykes have two pyroxene granulite facies assemblages, and garnet-bearing neosomes also develop in the 920 Ma augen granites. Neosome development is coeval with extensional, west to the top shear zones. Thus garnetiferous melt patches can both be deformed or overgrow extensional shears. Furthermore, shear zones can be occupied by sheets of garnet-free granitoid. Zircons from neosome patches in metapelite commonly have inherited cores of Mesoproterozoic to Archaean zircon, surrounded by rims of oscillatory zoned to homogeneous zircon. In addition there are some structureless oval zircons. SHRIMP $^{206}Pb/^{238}U$ dates on the rims and oval grains yielded dates which scatter beyond analytical error. Statistical analysis of the data suggest main growth at 432±6 Ma, with a later event at ~400 Ma (the $^{206}Pb/^{238}U$ date obtained on monazites), which could involve either just disturbance or further zircon growth. REE patterns of the ~430 Ma zircons show strong negative Eu anomalies, and moderate to high HREE enrichment (Lu= ~9000 chondrite-normalised). These patterns are consistent with growth from melts in the presence of plagioclase and garnet.

A sheet of garnet-free granitoid occupying an extensional shear zone contained mostly oscillatory-zoned magmatic zircon with only a few inherited cores. The SHRIMP $^{206}Pb/^{238}U$ date for the magmatic zircon is 434±5 Ma. REE patterns of the ~430 Ma zircons show strong negative Eu anomalies, and moderate to high HREE enrichment (Lu= ~9000 chondrite-normalised) - just like for the *in situ* partial melts in equilibrium with garnet, described above. Thus granitoid sheets were generated at least in part from local melting equilibrated with garnet, in an extensional (high heat flow) environment.

>100 million years of high-grade tectonothermal events in the East Greenland Caledonides

The events described above are just examples of the >100 million-years-long sequence of high grade events displayed in the orogen:

- The oldest $^{206}Pb/^{238}U$-dated Greenland Caledonian intrusive is a 466±8 Ma granodiorite from Milneland - speculative sign of vestiges of an Ordovician arc in east Scoresbysund.
- At 430 Ma (Silurian) in western Scoresbysund there was basement extension with high heat flow leading to granulite facies. This is concommittant with emplacement of

431±9, 444±8 and 434±8 Ma quartz monzonites and leucogranites in the east (e.g. Milneland).

- In the north of the orogen there is clear evidence for 2 eclogite facies events, one at ~400 Ma (lower Devonian), and the other at 356 Ma (lower Carboniferous).

These results reinforce notions of the complexity of the orogen, with more than one "collision" causing HP metamorphism and probably several important extensional events with the potential high temperature metamorphism at depth coupled with (partial) drowning of the orogen. This is in no means surprising, in the light of the similar complexities of the New Zealand to Spain (Alpine-Himalayan) neo-orogenic system.

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The abundances and isotopic compositions of the noble gases, helium, neon, argon, krypton and xenon from mantle-derived samples provide useful and unique information concerning the origin and evolution of the Earth including its differentiation into core, mantle, crust and atmosphere. It is critically important to determine if there is any systematic variation in mantle noble gas composition with time. This evidence is particularly relevant to current debates on mantle geodynamics. Noble gas data for mantle-derived samples of different ages could be used to evaluate the degree to which the upper mantle has interacted with the lower mantle over time and allow further refinement of models concerning two-layered convection vs. whole mantle convection and mass transport in the mantle. To better constrain the evolution of noble gas compositions in the mantle we have been undertaking noble gas studies on old mantle-derived materials, including diamonds and early Archaean materials from Greenland. We have also undertaken research projects on cosmogenically-produced noble gases in rocks at the EarthÕs surface in relation to exposure ages and erosion rates in close association with Prof. J. Chappell (the Environmental Processes Group). Summaries of some of the studies undertaken are given in the following sections.

We have developed the techniques necessary to undertake the research projects as outlined above. In particular, during the year we have progressed the development of full automation of noble gas analysis with the ultrahigh vacuum noble gas handling system on-line with the VG5400 mass spectrometer principally through the efforts of I. Iatsevitch. We believe that this will result in a marked increase in both productivity and efficiency.

Neon isotope compositions in framesites from Jwaneng, Botswana

M. Honda, D. Phillips[1] and J. W. Harris[2]

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

[2] Division of Earth Sciences, University of Glasgow, UK

As part of a wider investigation into the evolution of the noble gases through time, we continued to undertake noble gas analyses of polycrystalline framesite diamonds from the Jwaneng kimberlite pipe, Botswana. These samples yielded complex, multiple noble gas components (mantle, crustal, atmospheric and in-situ radiogenic/fissiogenic), which were successfully deconvoluted by combining vacuum crushing and step-heating experiments and examining a full suite of noble gas isotope and elemental abundances.

The most striking observation is the presence of crustal nucleogenic neon, released on graphitisation of the framesites. In Figure x, the neon isotopic results from the Jwaneng framesites are plotted in $^{20}Ne/^{22}Ne$ Ð $^{21}Ne/^{22}Ne$ space. Neon data plot close to a mixing line between atmospheric and crustal nucleogenic neon. Crustal nucleogenic neon, which has been found in natural gases and brines, comprises a mixture of nucleogenic neon produced from nuclear reactions [$^{18}O(a,n)^{21}Ne$ and $^{19}F(a,n)^{22}Na$¨^{22}Ne] in crustal material with a constant O/F (atomic) ratio of about 100. It is unlikely that the crustal nucleogenic neon observed in the Jwaneng framesites is a product of in-situ nuclear reactions in the samples, because the quantities of nucleogenic neon involved require abundant oxygen and fluorine with an O/F abundance ratio specific to crustal material. Therefore, the nucleogenic neon observed in the Jwaneng framesites is likely to have been produced in the crust and subsequently incorporated into the framesites during their crystallisation in the sub-continental mantle. The framesites also exhibit MORB-like xenon compositions, as evidenced by large excesses of ^{129}Xe relative to atmospheric ratios. This may indicate that noble gases produced in the crust, such as nucleogenic neon, were introduced into the sub-continental mantle source during ancient subduction-related processes. If correct, some parts of the mantle may contain significant quantities of crustal noble gases.

In this regard, the unusual carbon isotopic and mineral intergrowth compositions of Jwaneng framesites indicates that these diamonds formed under carbon supersaturation conditions during subduction of oceanic sediments and intercalated slab components. The incorporation of subducted crustal material into the mantle is an attractive explanation for the presence of crustal noble gases in diamonds. Although the paragenesis of the framesites in this study were not examined, they were likely to be eclogitic, as eclogitic diamonds are generally believed to have been formed from recycled carbon. Recent Re-Os analyses of eclogite xenoliths and eclogitic inclusions in diamonds from several southern African kimberlites suggest that subduction-related crustal recycling may have been a viable process during continent formation in the Archean (~2.9 Ga) and resulted in widespread formation of eclogitic diamonds at that time. If this is true, crustal noble gases could have been introduced into the mantle at a very early stage in Earth history.

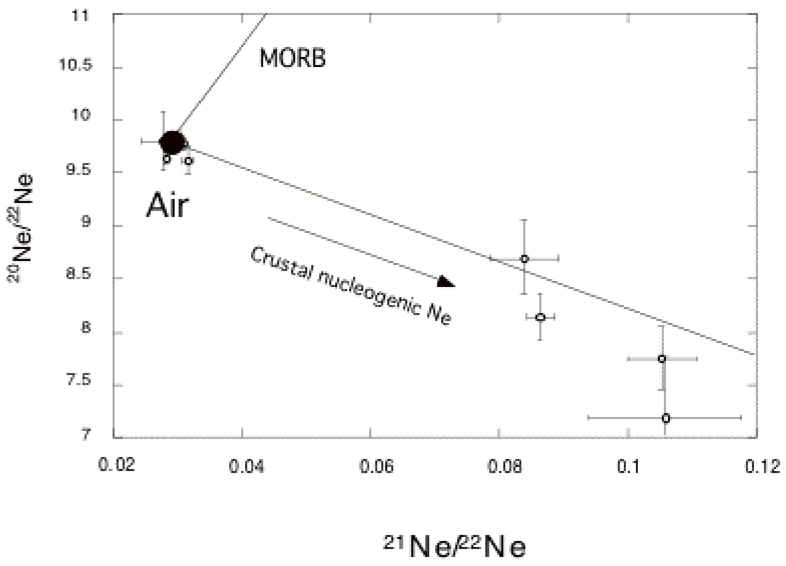

Figure x. Neon isotope diagram, showing the results from four Jwaneng framesites. The MORB correlation line is also plotted. Neon data lie close to a mixing line between atmospheric neon and crustal nucleogenic neon. The nucleogenic neon observed in the Jwaneng framesites is likely to have been produced in the crust and subsequently incorporated into the samples.

Cosmogenic ^{21}Ne and ^{3}He in clinopyroxene from New Zealand

D.B. Patterson[1] and M. Honda

[1] Universit‡t TŸbingen, Deutchsland

Spallation interactions between cosmic-ray produced particles (primarily neutrons) and geological material can produce observable quantities of the stable cosmogenic nuclides ^{3}He and ^{21}Ne, resulting in $^{3}He/^{4}He$ ratios greater than 1 x 10^{-4} and $^{21}Ne/^{22}Ne$ ratios greater than 0.2. The production rate of cosmogenic species in a geological sample is a function of geographic location (as the shielding effects of the earthÕs magnetic field varies in a complex fashion between the equator and poles), altitude, and depth below surface. Despite these complexities, the accumulation of cosmogenic ^{3}He and ^{21}Ne can be used as a chronometer of geological events such as the surface exposure of a sample by retreating ice sheets, catastrophic landslides and floods, with important implications for paleoclimatology and geomorphology.

We have measured all five noble gases (He, Ne, Ar, Kr, Xe) extracted from two samples of subduction-related augitic clinopyroxene from the Alexandra Volcanic Province within the Waikato Region of the western North Island, New Zealand (ANU# 88247, 88248). Elemental and isotopic compositions were determined in the RSES Noble Gas Facility using standard experimental protocols for gas extraction, processing and mass spectrometric analysis.

The samples are noteworthy for having high $^{3}He/^{4}He$ ratios of between 17.3 x 10^{-6} and 21.4 x 10^{-6}, and clearly non-atmospheric $^{21}Ne/^{22}Ne$ ratios of 0.0380 to 0.0394, but have $^{20}Ne/^{22}Ne$, $^{38}Ar/^{36}Ar$ and $^{40}Ar/^{36}Ar$ ratios that are close to atmospheric values. The combination of high helium and $^{21}Ne/^{22}Ne$ with atmospheric argon and $^{20}Ne/^{22}Ne$ ratios is interpreted as the unique fingerprint of in situ production of cosmogenic ^{3}He and ^{21}Ne within volcanic samples that equilibrated with atmospheric noble gases during eruption. The observed ^{21}Ne abundances provide cosmogenic exposure ages that are, within uncertainties, consistent with the known eruption ages and surface exposure histories. Based on our results we obtain a best estimate for the cosmogenic $^{3}He/^{21}Ne$ production ratio in these samples to be between 4.2 and 4.9. We also note the possible presence of a significant component of ^{21}Ne generated by muon-related reactions in a deeply shielded sample.

Algorithm for automated tuning of a Nier-type ion source for mass spectrometric analysis of noble gases

I. Yatsevich, A. Latimore and M. Honda

An algorithm for automated real-time beam optimization of a Nier-type ion source for static mode mass spectrometry must satisfy the following conditions: (a) effective optimization of the two ion source half-plate voltages for a ridge shaped beam intensity function, (b) stability and reliability at low count rates, and (c) reasonably fast optimization to minimize ion consumption in the source before actual measurement begins. We have developed a suitable algorithm for automated ion source tuning of the VG5400 noble gas mass spectrometer. We are able to reduce the two-dimensional optimization problem of a ridge-shaped beam intensity function to two independent one-dimensional line searches in mutually-orthogonal directions. The algorithm uses Golden Section minimization technique with initial bracketing, and it requires approximately 8 measurement cycles per optimization scan. Test runs with the Yellowstone helium standard and the heavy noble gas standard demonstrated satisfactory performance of the algorithm. The total time required to optimize half-plate voltages to within less than 0.25% of the value was 15-20 sec for Faraday and Daly collectors (He, Ne and Ar analyses). For Kr and Xe with the pulse counting system the total beam optimisation time was about 40-50 sec. We also have developed two other optimisation algorithms, one utilizing recursive implementation of buffered Finite Impulse Response Filter (FIR) and another using full-interval Infinite Impulse Response Filter (IIR). The FIR version with buffered seven-point Moving Average Filter proved adequate for noble gas analysis noise suppression and is considerably (> 5 times) faster than the current algorithm. The IIR version, being slower, guarantees the statistically correct localization of the beam maximum.

Noble Gas Geochronology and Thermochronology Summary Đ Dr W.J. Dunlap

The year 2002 was a year of transitions for the Noble Gas Geochronology and Thermochronology laboratory at RSES. The close involvement of Prof. Mark Harrison and Dr Geoff Fraser with the lab, along with the arrival of Dr Sandra McLaren, has resulted in the development of a "critical mass" in terms of interest in low-to-medium temperature isotopic dating studies. These changes have refocussed our efforts on both the scientific and administrative fronts. On the scientific front we have moved toward a more even distribution of academic, government, and industry work, to allow for changing needs and expectations.

Perhaps the most exciting development this year has been the commissioning of the (U+Th)/He dating line. The helium dating line is now mostly automated, thanks to Xiaodong Zhang, with computer control of valves, including those on the 3He and 4He standard tanks. Recently the ^{3}He standard tank was tested against weighed aliquots of Durango apatite (~31.5-32.0 Ma), at present the most widely used and best understood apatite available. Using the Durango apatite as an unknown we have calculated ages on four separate aliquots, which yield a mean age of 32.4 ± 1.7 Ma. Although Durango apatite is not a perfect standard, it is relatively homogeneous. We found satisfactory reproducibility in uranium and thorium contents of this apatite at U= 9.24 ppm ± 4.4%, and Th = 181.6 ppm ± 3.1%, and these values compare well with those in the literature. We are presently trying to commission a new laser extraction system on the helium dating line. With this apparatus we hope to obtain very low blank levels, and perhaps even realise single crystal analyses within the next few months. Two Ph.D projects involving helium dating were initiated at the end of 2002, one in surficial studies (Martin Smith) and another in exhumation studies (Frederic Herman), and we hope to generate some exciting science as the new year progresses.

The K-Feldspar thermochronometer: a test of the recrystallisation hypothesis

W. J. Dunlap

K-feldspars are one the most widely used geochronometers in earth science research because they are common in continental crustal rocks, and they retain radiogenic argon quantitatively in a variety of situations. Sanidines from silicic volcanics, for example, do not exhibit age gradients, and their ages can in most cases be interpreted as the age of eruption. Slowly cooled K-feldspar from granites and gneisses, on the other hand, almost always exhibit evidence for internal age gradients. The multidomain theory of K-feldspar thermochronometry was developed to explain the strong age gradients commonly observed in the $^{40}Ar/^{39}Ar$ age spectra of slowly cooled K-feldspars (cf. Lovera et al. 1989). Despite the apparent success of this method in elucidating crustal thermal histories, an alternative theory refutes the basis of the multidomain method and holds that the age gradients are a direct reflection of late-stage low temperature recrystallization of a large percentage of the original lattice (Parsons et al., 1888). In recent this has been one of the most hotly debated issues in geochronology.

The effect of recrystallization on the K-feldspar thermochronometer has been assessed by comparing $^{40}Ar/^{39}Ar$ and textural data for two samples from Toftoy, Norway, where feldspathic gneisses are cut by later epidote-filled fractures. Fracture opening was accompanied by discolouration and recrystallization of adjacent wallrock K-feldspar within 3-5 cm of the fracture. Although light microscopy clearly shows that the outline of the original (millimetre scale) gneissic grains remain intact, SEM studies of the recrystallised K-feldspar indicate that a network of crystallographically controlled dissolution channels developed, mostly probably along high strain zones during deformation (Figure x). The remaining K-feldspar between the channels was pervasively twinned and recrystallised on a very fine scale.

The recrystallized K-feldspar yields an age spectrum with ages between ~230-290 Ma, and a bulk age of 282 Ma (Figure xx). In contrast, the unrecrystallized, cryptoperthitic K-feldspar from the unaffected gneiss only centimeters away preserves ages between ~280-430 Ma, and a bulk age of 393 Ma. The differences in age and texture between the gneissic and recrystallized K-feldspars are most readily explained by argon loss related to dissolution, recrystallisation and pervasive checkerboard twinning of the remaining K-feldspar during deformation. I believe that the original K-feldspar lattice remains, although it has probably been swept through by microstructures that have allowed, at least locally, complete escape of accumulated radiogenic argon. Moreover, the younger age limit of single fragment fusion ages for the recrystallised sample coincides with the suspected age of fracture initiation, during formation of the immediately adjacent Viking Graben and opening of the North Sea (Figure xxx).

In the absence of significant optical evidence for recrystallization, the age gradients preserved in slowly cooled K-feldspars are most simply and elegantly interpreted as resulting from multiple diffusion domains that record detailed thermal closure to argon loss. It is not a coincidence that a large fraction of slowly cooled K-feldspars analysed by the $^{40}Ar/^{39}Ar$ method yield ages between higher temperature (K-Ar of micas) and lower temperature (Fission track) thermochronometers. This indicates that low-temperature recrystallisation, although an acknowledged and well-documented process, is generally not volumetrically significant enough to affect the $^{40}Ar/^{39}Ar$ thermochronometer of most fresh, "garden variety", crustal K-feldspars.

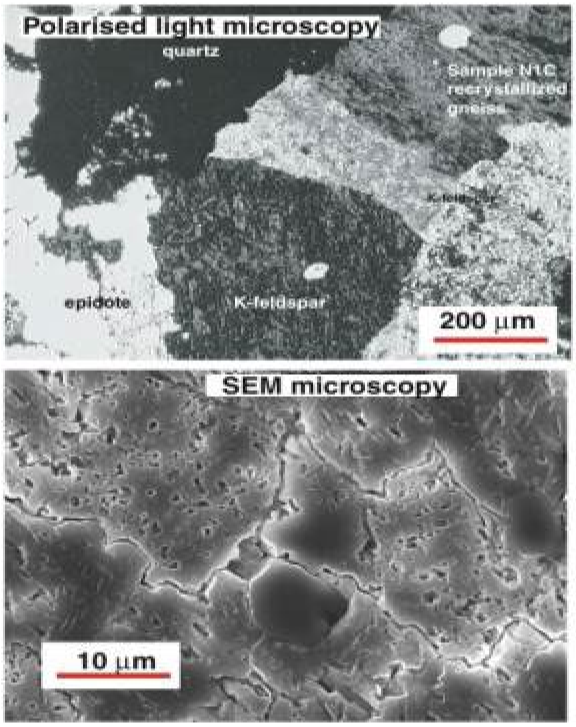

Figure x: SEM studies of the recrystallised K-feldspar indicate that a network of crystallographically controlled dissolution channels developed, mostly probably along high strain zones during deformation.

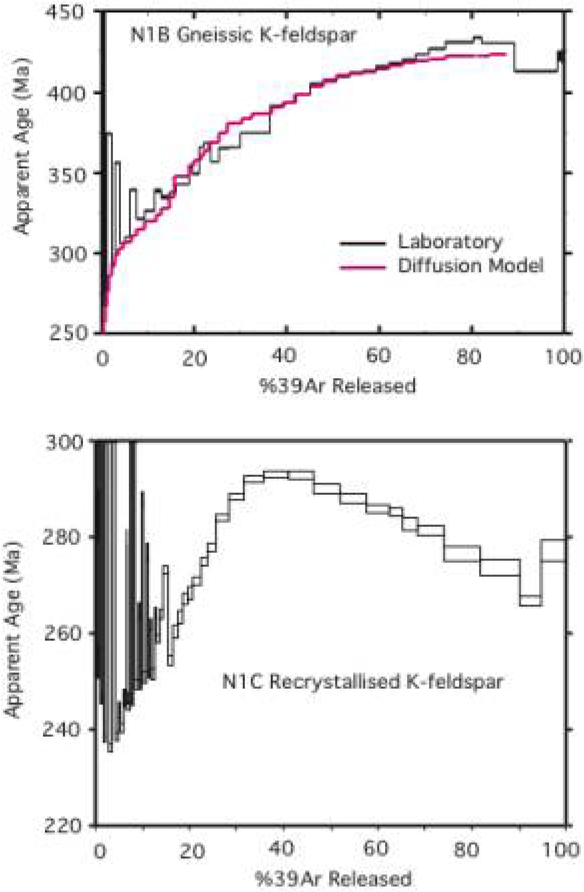

Figure xx*:* The recrystallized K-feldspar yields an age spectrum with ages between ~230-290 Ma, and a bulk age of 282 Ma

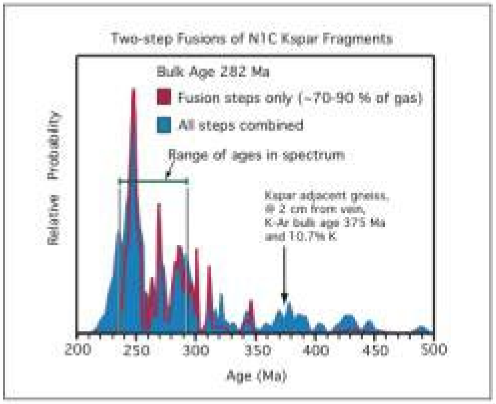

Figure xxx*:* the younger age limit of single fragment fusion ages for the recrystallised sample coincides with the suspected age of fracture initiation, during formation of the immediately adjacent Viking Graben and opening of the North Sea.

Precise dating of a palaeolandscape in the Koobi Fora Formation, Northern Kenya

I. McDougall, N.Stern[1] *and N. Porch*[2]

[1]Archaeology Program, La Trobe University, Bundoora, Victoria

[2]Department of Geography and Environmental Science, Monash University, Clayton, Victoria

This archaeological site in sediments of the Turkana Basin, northern Kenya, has been studied in great detail by N. Stern, and has included careful mapping and excavation, showing that the sediments are mainly levee and floodplain deposits. Stone tools and animal bones were found in a stratigraphic horizon immediately overlying a volcanic ash. The tuffaceous horizon has been dated by measurement of single crystals of alkali feldspar separated from three pumice clasts recovered from the tuff during excavations. The $^{40}Ar/^{39}Ar$ ages measured on a total of 27 different crystals are remarkably concordant and yield a mean age of 1.468 ± 0.016 Ma, where the error quoted is the standard deviation of the population rather than the mean. This age is interpreted as that of the explosive eruption that produced the tuffaceous deposit, with deposition in the Turkana Basin occurring very soon after. This precisely and accurately dated site is providing basic information on accumulation of archaeological material produced by hominids essentially at a point in time in the early Pleistocene, and the results contribute to the overall time scale for the evolution of the Turkana Basin and its wealth of hominid fossil finds.

Palaeozoic reworking in the western Arunta Inlier: clues from ^{40}Ar/^{39}Ar geochronology

Sandra McLaren, Jim Dunlap, Mike Sandiford[1], Ian Scrimgeour[2], Dorothy Close[2], Christine Edgoose[2]

[1] School of Earth Sciences, University of Melbourne

[2] Northern Territory Geological Survey

Continental reactivation and reworking, particularly in intraplate regions, is an intriguing problem of crustal dynamics. Central Australia is one of the best known examples of continental reworking, having recorded a complex polyphase deformation history from the Palaeoproterozoic through until the late Palaeozoic. Two Palaeozoic intraplate events are particularly intriguing: the Devono-Carboniferous Alice Springs Orogeny (400-300 Ma), and the recently recognized Orodovician Larapinta Orogeny (~440 Ma). Both events are associated with significant structural reorganization, metamorphism and magmatism, and occurred during intervals when the central Australian region was > 1000km from any active plate boundary. Although both orogens are reasonably well constrained in the eastern Arunta inlier, the timing and origin of Palaeozoic activity in the Western Arunta is still relatively poorly known.

Thermochronology is important in defining the timing and distribution of deformation within a terrane, and we use this technique to investigate the extent of Palaeozoic reworking in the Mount Liebig region of the south-west Arunta (Warumpi) province. The Mount Liebig region consists of basement Palaeo-Mesoproterozoic basement metasediments and metaigneous rocks, as well as Neoproterozoic Amadeus Basin sequences (the Heavitree Quartzite and Bitter Springs Formation). The basement units record a multiphase history including metamorphism during the Liebig Event (1640-1630 Ma), the Chewings Orogeny (1590 Ma) and the Teapot Event (1100 Ma).

Of the mineral thermochronometers analysed, the low closure temperature of K-feldspar (~150-350ϒC) allows documentation of cooling of the upper crust. In addition, analysis of several fine grained (~ 50 micron) muscovites, inferred to represent new crystallization, helps to constrain the last deformation episode.

Preliminary results suggest that reworking of the Mount Liebig region during the Palaeozoic was quite variable. The majority of samples indicate final cooling around 900-1000 Ma following the Teapot

Event. However, K-feldspar samples from some fault-bounded blocks indicate final cooling through 150-200ϒC between 400-300 Ma, during the Alice Springs Orogeny. Moreover, a single K-feldspar sample suggests monotonic cooling from > 350ϒC beginning at 440 Ma, implying that reactivation in some regions was associated with the Larapinta Event. This assertion is also supported by 440-410 Ma ages of recrystallized muscovite in another sub-region. If these ages can be corroborated, this is the first indication of Larapinta activity in the western Arunta.

The origins of the spatially and temporally variable reactivation are intriguing, and, given the potential controls on tectonic reworking, need to be fully evaluated in a thermo-mechanical framework. The spatial variability of tectonic reworking suggests that pre-existing faults provided the primary control on Palaeozoic reactivation. Ideally more detailed sampling would be undertaken in reworked regions to better characterize the extent of Alice Springs and Larapinta orogenic activity, and to understand the controls on tectonic reactivation.

Geoscience Australia: Research at RSES

Geoscience Australia: Research at RSES Summary Đ Dr J. ClaouŽ-Long

Research staff from Geoscience Australia (GA, formerly Australian Geological Survey Organisation) currently work within RSES, mostly on U-Pb SHRIMP geochronology, but now also including Ar-Ar geochronology. The geochronologists principally work in the Minerals Division within a variety of regional projects spread over several provinces across Australia (Yilgarn, Gawler, Tanami-Arunta, Broken Hill, Mt Isa, and Tasmania). GA research is based on the longstanding relationship with the Research School, in particular within the Geochronology and Isotope Geochemistry group. The scientific outcomes address GA's role in Minerals Promotions under the National Geoscience Agreement (NGA), Petroleum Promotions, and the Predictive Minerals Discovery Cooperative Research Centre (pmd*CRC). A selected range of research activities from these projects is described below.

Detrital zircon U-Pb SHRIMP geochronology as an aid to mapping in the Tanami Region

Andrew Cross

Introduction

The Tanami Region is located approximately 600 km northwest of Alice Springs and is a major Australian gold province. Straddling the Northern Territory-Western Australian border, the region is host to over 50 known gold occurrences in established gold fields at: Dead Bullock Soak; The Granites; and; Tanami and also significant prospects at: Groundrush; Crusade; Coyote and; Kookaburra. The Tanami region is characterised by an extensive regolith cover that is punctuated by sparse and variably weathered outcrop, rarely are the contacts between the various stratigraphic packages observed in the field. Because of this, the relationships between, and relative timing of the various packages have been constrained using a combination of: the known age of intrusive contacts; geophysical interpretations; structural and; metamorphic criteria. During 2001-2002 Geoscience Australia and the Northern Territory Geological Survey commenced a joint study to determine whether detrital U-Pb SHRIMP geochronology can be used as an aid to further understanding Tanami stratigraphy. The revised stratigraphy is presented in Figure 1.

Geology

Basement rocks of the Tanami Region are represented by two known late Archaean inliers, the Browns Range Metamorphics in the northwestern Tanami and the Billabong Complex southeast of The Granites mine. A banded granitic gneiss from the Billabong Complex has been assigned a magmatic age of 2514 ± 3 Ma (Page, 1995). The Palaeoproterozic MacFarlane Peak Group is interpreted as the oldest sequence in the Tanami region and generally consists of mafic volcanics and volcaniclastic sediments. Overlying the MacFarlane Peak Group is the Tanami Group which is a thick sequence of clastic sediments comprising the lowermost Dead Bullock Formation and the upper Killi Killi Formation. Vandenberg et al. (2001) have suggested that deposition of the Killi Killi Formation was halted by the onset of the Tanami Orogenic Event (TOE) between 1825 Ma and 1835 Ma. Following the TOE, Hendrickx et al. (2000) have suggested a period of extension resulting in felsic volcanism of the Winnecke Group and also the extrusion of basalt and deposition of volcaniclastic turbidites of the Mount Charles Formation. Intrusion of granites throughout the Tanami characterise the period between 1815-1790 Ma. Unconformably overlying the Killi Killi Formation are the shallow marine sediments of the Pargee Sandstone. This unit in turn underwent significant peneplanation before deposition of the overlying siliclastic sediments of the Birrindudu Group.

The reader is directed to Hendickx et al. (2000) for a more comprehensive review of Tanami geology.

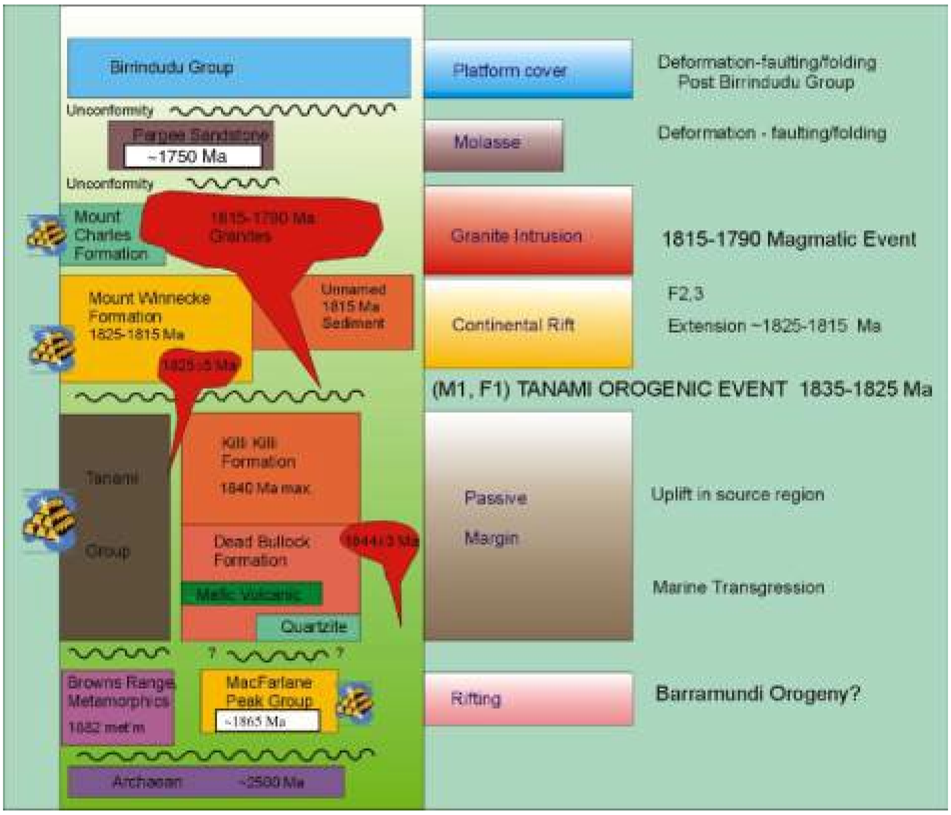

Figure 1. Time-event diagram for the Tanami region. Modified from (Crispe, 2002).

Results of recent Tanami detrital zircon U-Pb geochronology

Sediments from the MacFarlane Peak Group, Killi Killi Formation and Pargee Sandstone were sampled for detrital zircon SHRIMP geochronology. In order to maximise zircon yield, 25-35 kg of rock was sampled at each site. This approach was taken in an effort to compensate for the generally weathered condition of outcrop. Most samples contained high percentages of zircons with discordant compositions, presumably the result of an extended history of weathering.

MacFarlane Peak Group

Preliminary SHRIMP data suggest that this group was deposited after about 1865 Ma, slightly younger than the interpretation by Hendrickx et al. (2000), which suggests sedimentation of this group was between 1910-1880 Ma. The maximum depositional age of ~1865 Ma for this group supports the suggestion by Hendrickx et al. (2000) that it is the lowermost sequence in the Tanami, and also indicates that it may correlate with the ~1860 Ma Warramunga Formation in the Tennant Creek Inlier.

Killi Killi Formation

Zircons from six samples of Killi Killi Formation confirm this unitÕs widespread distribution, consistent provenance signature and maximum deposition age. Killi Killi Formation provenance is dominated by Barramundi-aged detritus (1880-1840 Ma), always contains a subordinate input of ~2500 Ma detritus and has a remarkably consistent maximum deposition age of about 1840 Ma. Also identified was a previously unrecognised phase of sedimentation in the Tanami with a maximum deposition age of about 1815 Ma. This currently unnamed unit, is non-magnetic in outcrop but overlies highly magnetic rocks, and therefore contrasts with the non-magnetic Killi Killi Formation (Crispe, 2002).

Pargee Sandstone

This unit was previously interpreted as a syn-orogenic molasse deposited during the TOE (1825-1835 Ma). SHRIMP U-Pb detrital zircon results for this sample prove the previous interpretation to be incorrect, because the youngest zircons define a maximum depositional age of about 1750 Ma. This result has significantly changed the interpretation for the Pargee Sandstone, and also strongly indicates that the unconformably overlying Birrindudu Group was deposited sometime after ~1750 Ma.

Conclusions

Detrital zircon U-Pb SHRIMP geochronology is a useful aid to mapping in regions typified by well-developed regolith cover and poor outcrop. Individual zircon ages potentially provide maximum depositional ages for units, and also a provenance signature that can be used to correlate sedimentary packages both within, and between different geological regions.

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Revealing the complex development of the Arunta region, central Australia

J.C. ClaouŽ-Long and A. Cross

The rocks exposed in the Arunta region of central Australia are renowned as a natural laboratory for studying the effects of complex polyphase metamorphic processes. Aspects of them have received study by the RSES Geochronology Group in previous years but the sum of available modern dating has been sparse and difficult to fit into an event framework.

Last year we reported the beginning of an ambitious partnership between geochronologists at Geoscience Australia and geologists at the Northern Territory Geological Survey who are remapping the fundamental geology of central Australia and using SHRIMP U-Pb geochronology intensively to identify and correlate major rock packages over very wide areas. The pattern of data now emerging shows why there has been great difficulty in comprehending this terrane until now. Zircons in rocks of the Arunta region record a repeated episodic progress of crustal events over a period of more than 2000 Ma, with more than ten distinct magmatic and metamorphic events overprinting one another. There can be few regions of the earthÕs crust which have experienced such prolonged and repeated reworking and which pose such a challenge to isotope geochronology.

The earliest preserved crust is late Archaean in age, and other basement rocks date from the ca. 1860 Ma ÔBarramundiÕ event for which there is evidence across northern Australia. Detrital zircon ages indicate that sediments were deposited on this basement after 1840 Ma and these were intruded by plutonic systems at ca. 1810 Ma and again at ca. 1780 Ma, following which zircons over widespread areas record metamorphism at ca. 1730 Ma while a more restricted region experienced earlier reworking at ca. 1750 Ma. A previously unrecognised event at ca. 1685 Ma is recorded by magmatic and metamorphic rocks in different areas, and by the magmatic age of a mafic dyke implying extensional tectonics at that time. A restricted region of the southern Arunta preserves previously unknown magmatic and metamorphic systems formed at ca. 1640 Ma in the newly recognised ÔLiebig eventÕ Ð which corresponds to a previously enigmatic deflection in the Australian Proterozoic Palaeomagnetic Polar Wander Path. The whole region then experienced widespread magmatism and metamorphic recrystallisation at ca. 1590 Ma in what is locally termed the ÔChewingsÕ event Ð which corresponds with a similar major event recorded in the Gawler and other Australian cratons. Another magmatic episode is locally expressed at ca. 1130 Ma Ð corresponding to the ÔGrenvillianÕ of north America. Finally, there is evidence that the already-complex Proterozoic basement was again reworked during the Phanerozoic, with both the Ordovician ÔLarapintaÕ event impacting in the eastern Arunta, and the later Alice Springs orogeny juxtaposing fault-bound basement units from different crustal levels later in the Palaeozoic.

Work is now proceeding to correlate this detailed event framework with the deposition systems operating in Proterozoic sedimentary basins, and to achieve wider correlations with other Proterozoic terrains in Australia and north America. The expectation is that these now-separate fragments of Proterozoic crust will be shown to have developed as linked crustal systems.

$^{40}Ar/^{39}Ar$ Geochronological Investigations in the Australian Proterozoic

Geoff Fraser

North Western Gawler Craton

The Gawler Craton comprises most of South Australia, and is highly prospective for new mineral discoveries, with major proven deposits of Cu-Au-U at Olympic Dam, Cu in the Moonta-Wallaroo district, and the newly mined Challenger Au deposit. The North Western part of the craton is particularly poorly understood geologically, and under-explored, largely due to its remote position and the extensive cover of deep regolith. A distinctive feature of the NW Gawler Craton is the presence of a large number of anastomosing NE-trending shear zones that stand out in aeromagnetic images, and define a region known as the Fowler Domain. The continuity of these structures suggests they formed late in the tectonic history of the region, but the absolute ages have until now been unknown. Several samples have been collected from rare outcrops within these shear zones, and also from the intervening crustal blocks, to help date the shearing and thermal history of the region.

Two of the most prominent magnetic features, the Coorabie and Tallacootra Shear Zones yield $^{40}Ar/^{39}Ar$ mica ages of ca. 1540 Ma and 1450 Ma respectively, indicating significant age variations between different structures within the Fowler Domain. Cooling ages from micas within the intervening blocks are older than mica ages from the shear zones, suggesting that the ages from the shear zones likely record the timing of at least some of the movement history on these structures. These ages are significantly younger than U-Pb ages from the craton, and extend the timing of tectonic activity to at least ~100 million years younger than previously suspected. The currently dated structures are cross-cut by the major Karari Fault as seen on magnetic images, thus suggesting this fault was active at least as late as ~1450 Ma. Timing of movement within the Fowler Domain and along the Karari Fault has major implications for the relationship of the NW Gawler Craton with adjacent cratonic regions to the north and west, specifically the Musgrave Block and Albany-Fraser province. Some of these faults also show evidence of significant fluid flow and represent possible targets for new mineral exploration. Work in progress includes samples from the Karari Fault, which will provide the first isotopic age constraints on this major bounding structure.

Tanami Region

The Tanami region of the Northern Territory is one of AustraliaÕs richest gold provinces, with potential for new discoveries. As with the Gawler Craton, geological understanding of the region is relatively poor, largely due to the lack of outcropping basement. Considerable uncertainty surrounds the timing of Au-mineralisation and its relationship with regional magmatic, deformational, and metamorphic events. A collaborative program between Geoscience Australia and the Northern Territory Geological Survey is addressing these issues. U-Pb zircon ages from regional granites yield intrusive ages between ~1820 and 1795 Ma. Ore-zone biotite samples at the Callie deposit in the Dead Bullock Soak goldfield produce $^{40}Ar/^{39}Ar$ ages of ~1735 Ð 1710 Ma. These results contrast with $^{40}Ar/^{39}Ar$ biotite ages from several regional granites which lie between ~ 1755 and 1810 Ma, suggesting that the ore-zone biotites record a distinct hydrothermal event that post-dates regional cooling. The timing of this late-stage hydrothermal event is coincident with significant magmatic and metamorphic events in the Arunta Block to the south, although causal links remain speculative. The data from the Callie deposit cast doubt on existing exploration models that assume a genetic relationship between regional granite intrusions and Au-mineralisation. The results also suggest that at least some of the deformation history in the Tanami region is almost 100 million years younger than previously thought.

Summary

The work described above, although conducted in the context of two distinct projects, is part of a larger effort within Geoscience Australia, as well as various university research groups, to understand the tectonics of Proterozoic Australia. Recent literature contains several contrasting Proterozoic tectonic scenarios, illustrating both an increasing interest in correlations between Proterozoic regions, as well as the need for more robust constraints on the event histories within individual crustal blocks. Many of these essential constraints are now emerging from Geoscience AustraliaÕs regional projects. Consequently, the next two to three years are likely to see rapid developments in both the documentation and understanding of Australian Proterozoic terranes.

Towards an understanding of the geological structure and evolution of the Gondwana supercontinent; evidence from SHRIMP zircon dating of Palaeozoic granites from Tasmania, northern Victoria Land and the South Tasman Rise

L.P. Black and A.M. Fioretti[1]

[1] CNR, Istituto di Geoscienze e Georisorse, c.so Garibaldi, 37, 35122 Padova, Italy

This is a collaborative study (known as TASMAP) between Geoscience Australia, Mineral Resources Tasmania, the University of Tasmania and the PNRA (the Italian National Antarctic Research Program). The aim of the study is to investigate the tectonic setting and preÐMesozoic geologic evolution of Tasmania and northern Victoria Land (NVL), and to test the possible correlation between their different tectonic elements. The South Tasman Rise (STR), a submerged continental fragment between Tasmania and Antarctica, has also been included, because it is also believed to have been part of the same Palaeo-Pacific margin of Gondwana, and represents a potential link between the other two terranes.

The study is mostly based on Palaeozoic igneous rocks (primarily granites of Cambrian and Devonian-Carboniferous age), in the expectation that these will provide information on different levels of the crust. The chemistry of those rocks will give a broad indication of source compositions. Their crystallisation ages will define the spatial evolution of the magmatism in these areas, and the inherited zircon will help constrain the age of source components. SHRIMP is an ideal instrument to address the geochronological issues, because its ~25 µm analytical resolution allows the dating of different generations of zircon from within individual crystals.

Current geochronology does not discriminate between the Devonian-Carboniferous emplacement ages of the six different (pre-Late Carboniferous) strato-tectonic elements of western Tasmania, though they do record a general younging towards the west. In contrast, the Devonian-Carboniferous granites of the Northeast Tasmania element are almost all older, extending back to ~400 Ma. Analogous age patterns have been found for the zircon inheritance. All six of the western Tasmanian elements have similar spectra, which are dominated by ~1600-1900 Ma zircon. However, inherited zircon from within the northeastern Tasmanian granites is characterised by ~500-600 Ma and ~1000-1200 Ma ages. The marked differences between the inheritance ages reflects source components of different ages in the two regions. The distinctiveness of those spectra makes it possible to distinguish the regional context of a granite even when the rocks it has intruded are not exposed. For example, an isolated granite outcrop off the southeast coat of Tasmania at Hippolyte Rocks can be shown to be part of the Northeast Tasmania element, thereby constraining the (unexposed) position of the boundary between these two regions in this part of Tasmania,

The comparison can be extended even further offshore, where a Devonian-Carboniferous granite sample dredged from the centre of the South Tasman Rise has an inheritance pattern that is typical of western Tasmania. Most of the granites from the South Tasman Rise that we have currently dated are of Cambrian age, but contain essentially no inherited zircon. The presence of granites of both of those ages in the STR would be expected if this region is indeed part of the east Gondwana margin.

Both Cambrian and Middle Palaeozoic igneous rocks also occur in NVL. Devonian-Carboniferous magmatic activity in NVL is represented by the I-type Admiralty Intrusives (AI) and the Gallipoli Volcanics (GV). Both units crop out in the Wilson, Bowers and Robertson Bay terranes. The new dating is showing that previously obtained ages from the oldest of the AI are about 20 million years too old, the oldest granites now appearing to have been emplaced at about 365 Ma, with granitic activity continuing for about 15 million years. Its south-westward progression is similar to that which occurred in Tasmania. The GV are of comparable age to the AI. Although both the AI and GV zircon contain very little inheritance, their age spectra are typical of that of northeast Tasmanian granites, which is in turn comparable to the spectra of granites within the Lachlan Fold Belt, on the Australian mainland.

The analytical phase of this project is due to be completed in mid 2003, when detailed interpretation of the results will begin.

Towards an understanding of the geological structure and evolution of the Gondwana supercontinent; evidence from SHRIMP zircon dating of Palaeozoic granites from Tasmania, northern Victoria Land and the South Tasman Rise

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The analytical phase of this project is due to be completed in mid 2003, when detailed interpretation of the results will begin.

Ore Genesis

Ore Genesis Summary Ð Dr I.H. Campbell

The highlight of the year was the completion of Mr RohrlachÕs PhD. He used a combination of district and deposit scale oxygen isotope mapping, fluid inclusion data, mapping of alteration patterns using a portable infra-red spectrometer and geochronology to study the volcano that hosts the mineralization at Tampakan in the southern Philippines. The result is a remarkably detailed study of the full lateral and vertical extent of the fossil hydrothermal system that gave rise to porphyry copper and high-sulphidation mineralization.

Mr Heath has completed the laboratory work for his PhD on the giant Golden Mile gold deposit in Western Australia. His study has covered stable isotopes, geochronology, trace element geochemistry and fluid inclusions. Highlights include a demonstration that the Golden Mile is surrounded an alkali enrichment halo that is one to two orders of magnitude larger than the visible alteration halo and recognition that Ar/Ar ages need to be corrected for the new value for the fluence monitor GA-1550, and a Cl correction. The first has important implications for gold exploration in Archaean greenstone belts and the second for absolute age of the Golden Mile.

Ms Stoltze has completed has completed a study of the trace element geochemistry of a suite of alkali, carbonatite, and lamprophyre dykes, and the associated magnetite alteration halo that hosts the ore at the Wallaby gold mine in Western Australia. The results show that all of the dykes and the alteration halo are strongly enriched light rare earth and other highly incompatible elements but that there is little evidence of alkali enrichment associated with the mineralisation, as observed by Mr Heath at the Golden Mile. Future work will concentrate on the use of radiogenic isotopes to trace the source of the ore fluids.

Drs Campbell and Davies have calculated the melting rate and melting efficiency of mantle plumes from the volume of volcanic material they produce, their geochronology and their volume flux. They have shown that melting rates are much higher for plume heads than for plume tails and that plumes that ascend below spreading centres have much higher eruption rates than intra-plate plumes. The melting efficiency of plume tails varies between 20% for spreading centre plumes and less than 1% for intra-plate plumes.

Reconstructed Palaeohydrology of a Volcano-centred Copper- and Gold-ore-forming Magmatic-Hydrothermal System

B.D. Rohrlach, R.R.Loucks and J.M.Palin

Reconstructions of the palaeohydrology of ore-forming magmatic-hydrothermal systems helps to understand the physico-chemical transport and deposition conditions for ore metals associated with porphyry Cu and high-sulphidation epithermal Cu-Au deposits in volcanic arcs. Hydrological systems associated with porphyry and epithermal ores commonly span depths of 4 to 8 kilometres in the upper crust and may extend laterally for 10 to 20 km. We have investigated the entire vertical and lateral extent of such a fossil hydrothermal system at Tampakan in the southern Philippines. The study looks at three hydrological regimes: 1) the physical properties and hydrological transport mechanics of supercritical fluids from the magmatic exsolution site, through the lithostatically-pressured rock column, to the meteoric- and magmatic-fluid mixing interface at the base of the deposit; 2) identification of the properties of the fluid end-members and the geometry of mixing and dispersion paths within the deposit in the deep hydrostatically-pressured domain; 3) the mixing proportions and geometry of hybrid magmatic and meteoric waters as they were entrained and radially dispersed by topographically forced flow down the western flank of the volcanic complex. The palaeohydrologic study utilised district-scale whole-rock oxygen isotope mapping; deposit-scale $\delta^{18}O$ and δD data obtained from hydrothermal alteration minerals; fluid inclusion data; detailed maps of regional- and deposit-scale alteration zonation patterns and assemblages constructed from PIMA II (portable infra-red spectrometer) data; the spatial variations of high-sulphidation-stage white mica chemical compositions which were calibrated with potassic white mica infra-red spectral signatures; isotopic constraints on the enthalpy of magmatic fluids; and geochronological constraints.

Pressure and enthalpy constraints calculated for the high-sulphidation-stage magmatic fluid at the end points of its ascent path from the intrusive stock to the deposit in pressure-enthalpy space (Figure 1) reveal that the magmatic fluid was a two-phase fluid. This fluid was dominated by a high-density vapor that ascended along a nearly isochoric decompression path through the lithostatic column, from the site of exsolution to the site of fluid mixing. The density of the vapor increased slightly from ~0.2 g/cc to ~0.3 g/cc over a vertical ascent distance of ~1.2 km. During transit, the vapor cooled conductively by ~350¡C. The slight volumetric contraction of the vapor during ascent sustained its metal carrying capacity to the fluid-mixing site in the deposit. The near-isochoric ascent of vapor through the lithostatically pressured, ductile rock column requires transport along fine-scale, transient hydrofractures, with intimate contact between the vapor and the ductile wall rocks during vapor ascent. This ensured substantial conductive cooling (~850¡C ♦ ~500¡C) along the ascent path and that thermal contraction of the vapor balanced the tendency to expand with decompression. Instantaneous isoenthalpic decompression of the magmatic-vapor-charged mobile hydrofractures at the lithostatic-hydrostatic interface (brittle/ductile transition) near the base of the deposit, was associated with ÒinstantaneousÓ cooling of the supercritical vapor from ~500¡C to ~370¡C. This pressure-temperature quenching efficiently condensed magmatic vapor to a modestly saline (5 wt.% NaCl) condensate that subsequently mixed with ambient meteoric water within a palaeo-aquifer along an erosional unconformity at ~2 km depth at the base of the hydrostatic regime. An important finding from a metal transport perspective is that, at the P-T conditions of two-phase vapor + brine exsolution from the melt, the mass fraction of high-pressure vapor was >99% and accounted for ~87% of the exsolved chlorine budget; hyper-saline brine was a minor component of the mixture. During ascent of the vapor component, the bulk of this chlorine (81-85 % of the original exsolved chlorine budget) remained within the high-pressure vapor until it was quenched at the hydrostatic interface. These hydrodynamic conditions of nearly isochoric vapor transport, vapor-dominated two-phase fluid flow and >4 wt.% chloride within the high-pressure vapor throughout its ascent path enabled efficient transport of copper-chloride complexes from the magmatic interface to the lithostatic-hydrostatic interface. The low degree of condensation during ascent through the lithostatic rock column allowed maximum transfer of enthalpy to the base of the hydrostatic zone that promoted vigorous meteoric-hydrothermal circulation in the overlying hydrostatic domain.

Oxygen-isotopic material balance and enthalpy balance indicates that sericite in the deep portions of the deposit and pyrophyllite at higher and peripheral regions precipitated from a hybrid fluid comprised of magmatic condensate and meteoric water. The hot, hybrid fluids formed a thermally buoyant plume that ascended and were entrained into a stratabound aquifer system on the west slope of the volcano. A substantial hydraulic head in the aquifer is implied by down-stratigraphic-slope deflections in the time-integrated proxy fluid isotherms identified and calculated from calibrations of PIMA II™ infrared spectral parameters with the chemical composition of potassic white mica. These calibrations reveal chemical trends in the composition of potassic white micas that comprise a central, and deep-seated, high-temperature zone of nearly stoichiometric muscovite coincident with the locus of the inferred magmatic vapour plume. This zone is transitional to shallow peripheral regions where there is an increasing expression of a hydropyrophyllite molecular component in the potassic white mica crystal structure, and decreasing Cu and Au grades. These trends reflect a central, deep-level zone of high fluid temperatures, with cooling paths deflected down-palaeo-slope at shallower levels in the volcanic edifice. The calibration of infra-red spectral data from the Tampakan hydrothermal system reveal that the deposit is a superb example of hydrothermal plume-groundwater interaction and downslope dispersion. Infrared spectral parameters of white mica are shown to reflect both time-integrated palaeo-temperature gradients and relative element activity gradients for Si, Na, K, ferric Fe and Ti.

At the district-scale, isotopic modelling of the fluid mixing proportions and mixing geometry was undertaken using whole-rock $\delta^{18}O$ values and accounting for the effects of rock chemical variations on the bulk rock isotope fractionation factors along the fluid outflow path. The model reveals that the plume of thermally heated meteoric water and admixed magmatic condensate in the hydrostatic environment was centred within the Tampakan deposit. Substantial magmatic fluid also ascended into the hydrostatic regime along a 5 km by 1.5 km wide NNE-trending fault zone that partly controlled mineralisation. The deposit is located where gradients in the hybrid fluid temperature, and in the proportion of magmatic fluid, were greatest. Lateral outflow of the hybrid magmatic-meteoric fluids was strongly controlled by regional dilational faults that transect the volcanic centre. A two-tiered plume model is applicable to the Tampakan high-sulphidation epithermal system. Mineralisation was localised in the zone of steep temperature and pressure gradients associated with the interface between a deep lithostatic-pressured plume and a shallow hydrostatic-pressured plume.

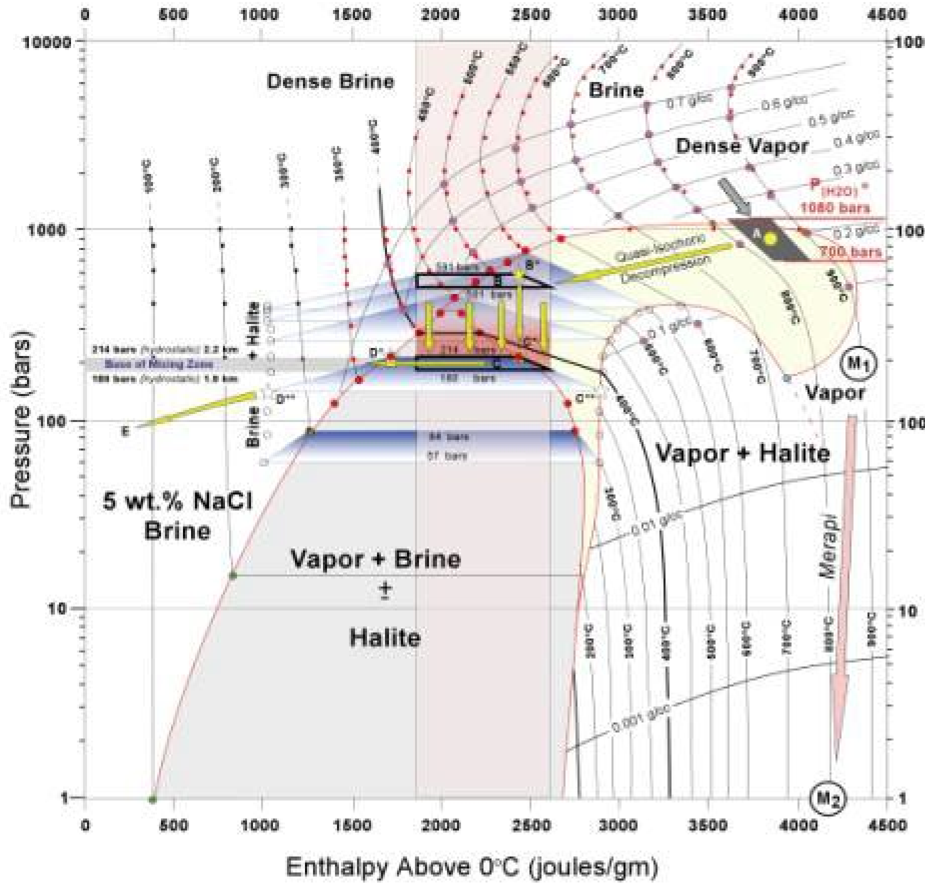


Figure 1: Pressure versus enthalpy plot showing the one-, two- and three-phase fields for the H_2O-NaCl system with 5 wt.% NaCl, and showing vapor and liquid isotherms and isochores. The trajectory of the Tampakan high-sulphidation magmatic fluids (yellow arrows and black boxes) are shown from the point of exsolution (A) from the parental melt to the site of isoenthalpic decompression (B-C) at the brittle-ductile transition, and for the path of subsequent condensation and mixing in the deposit (D*-D**-E). The brittle-ductile transition is assigned to the 400¡C isotherm. The diagram was constructed from tabulated and derived fluid physical properties.

Origin and composition of ore-forming fluids in the giant Golden Mile gold deposit, Kalgoorlie Western Australia

This report is no longer available.

A carbonatite source for alteration fluids at the Wallaby Gold Deposit, Laverton, Western Australia

A. Stoltze and I.H. Campbell

The Wallaby gold deposit of the Archaean Yilgarn Craton is a mesothermal deposit of Archaean age located within the Northeastern Goldfields Province of Western Australia. The country rock of polymictic, dominantly metabasaltic, conglomerate (Wallaby conglomerate) is intruded by a suit of monzonite-syenite-carbonatite dykes that are concentrated in the center of a pipe of magnetite-actinolite alteration that plunges south-south-west at 50ϒ. The pipe is broadly rectangular with a mantle of weak magnetite and a low magnetic center. This pipe hosts the majority of the sub-horizontal and shallow NE dipping mineralisation loads, which are associated with an alteration assemblage of albite + dolomite + pyrite. The relationship among the intrusion suite, the magnetite-actinolite alteration pipe, and the overprinting ore alteration has initially been investigated using trace element geochemistry.

A single drill hole, that extends from the regional greenschist chlorite-calcite metamorphosed conglomerate, through an ore zone that is external to the magnetite-actinolite pipe, then into the edge of the pipe and the associated ore zones, was chosen for geochemical investigation as the majority of alteration types observed at Wallaby are present within this hole. A selection of least-altered intrusion samples, covering the full range of rock compositions seen in the intrusions, was also analysed. Whole rock analyses were preformed, on glasses made from crushed samples, by laser ablation ICP-MS, with Ca as the internal standard. Major elements were analysed for samples from the drill hole and intrusion by EDS and XRF respectively.

The trace element geochemistry of the alkali, carbonatite, and lamprophyre dykes (Figure 1) show a low abundance of some high-field strength elements (Nb, Ta, Zr, Hf and Ti) in comparison to the lithophile incompatible elements (eg. Rb, Ba, K). This trace element abundance is characteristic of the shoshonitic series and has previously been observed in lamprophyre dykes associated with gold mineralisation in Archaean cratons. The only exception is a post-ore lamprophyre, with normal high-field strength element abundance, that cross-cuts all alteration and deformation observed within the deposit.

There is a strong enrichment of LREE in all intrusion types with the most extreme concentrations found in the carbonatite, which is typical of carbonatites globally. Only minor enrichment of HREE is observed. LREE enrichment is also noted associated with magnetite-actinolite altered Wallaby conglomerate. The magnetite-actinolite alteration is easily identified by magnetic susceptibility readings taken during core logging. It is possible therefore to compare variations in element abundance to the magnetic susceptibility to interpret a link between the magnetite-actinolite alteration and analysed elements. This relationship is particularly well illustrated by La against magnetic response shown in Figure 2.

A good correlation is also observed between all other elements that are enriched within the alkali intrusion suite such as Th, U, Ba, Sr, and Y, and magnetite-actinolite alteration. This relationship suggests a strong genetic link between the alkali intrusions

and the magnetite-actinolite alteration. The magnetite-actinolite pipe has not been formed directly by contact metamorphism from the dykes, as the contact metamorphism is very narrow, only centimeters wide, but by a fluid derived from the same magmatic source, and localised along structural channels.

Any link between the fluid derived from the alkali intrusion suite and the gold mineralisation can not be distinguished with the current trace element information therefore further investigation will be undertaken. Whole rock Sm-Nd and Rb-Sr isotopes will be analysed for the alkali suite and gold mineralisation in an attempt to identify the source of the mineralising fluid.

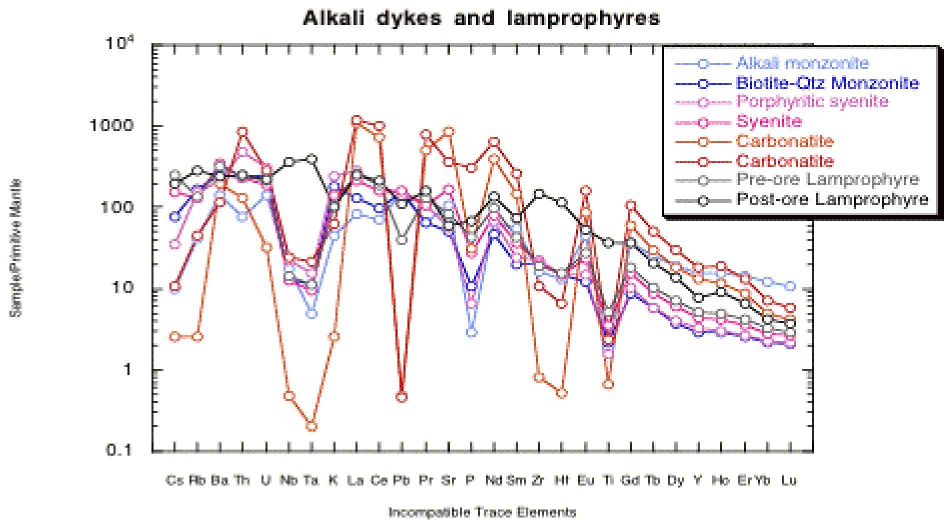


Figure 1. Primitive mantle normalised incompatible trace element concentrations for Wallaby alkali dykes and lamprophyres. A low abundance of Nb, Ta, Zr, Hf and Ti is evident in all intrusions but the post-ore lamprophyre. Note the very high LREE levels (~1000↔ primitive mantle) of all units particularly the carbonatite.

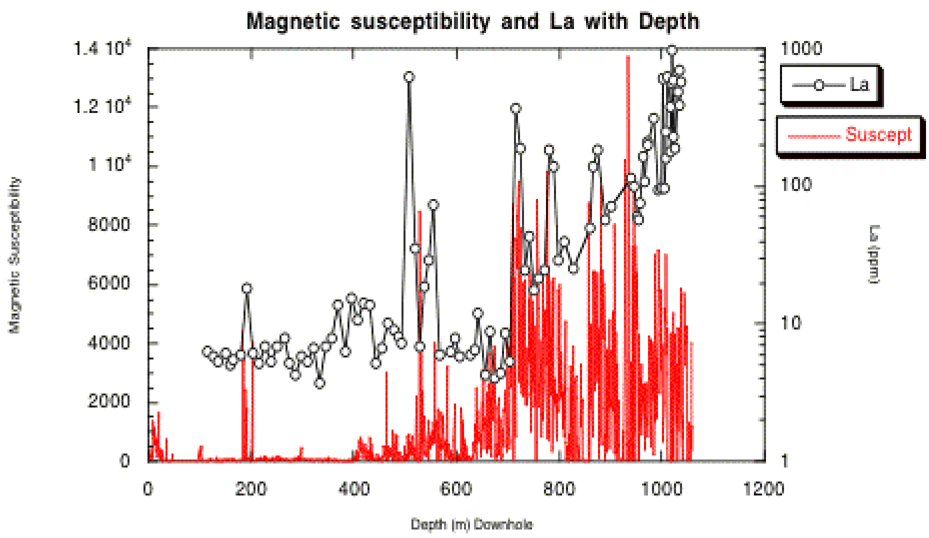


Figure 2. The magnetic susceptibility of the Wallaby conglomerate and the concentration of La (ppm) with depth in a drill hole through the Wallaby Gold Deposit. A sharp increase in the La concentration is observed at approximately 720m depth along with an overall increase in the magnetic response.

Melting rates and melting efficiencies in mantle plumes

I.H. Campbell and G.F. Davies

The volumes of three oceanic plateaux, the Kerguelen, Ontong Java and Iceland Plateaux and four aseismic ridges, the Walvis-Rio Grande, Hawaiian-Emperor, Ninetyeast and Chagos-Laccadive Ridges, have been calculated from digital images of sea floor. These data, combined with seismic data and geochronology, have been used to calculate melt production rates for the Kerguelen, Ontong Java, Iceland, Reunion, Tristan da Cunha, and Hawaiian plumes. The results show that the principal factors controlling melt production rates for the plumes are whether the material melting is a plume head or a plume tail and the tectonic setting of the plume. The melt production rates of the plume heads that produced the Kerguelen and Ontong Java Plateaux are 4.7 and 16.5 km^3a^{-1}, which are 15 and 50 times respectively greater than Iceland, the most efficient of the modern plume tails, and 80 and 250 times respectively greater than Hawaii. The principal factor controlling the melting efficiency of plume tails is whether they melt in aalteran intra-plate setting or at a spreading centre, with the strength of the plume being of secondary importance. The Iceland plume, which melts at a spreading centre, has an eruption rate that is five times that of the intra-plate Hawaiian plume, in spite of the buoyancy flux of the Hawaiian plume being six times that of the Iceland plume. The tectonic setting of two of the plumes, Reunion and Tristan da Cunha, changes with time from spreading centre to intra-plate, which leads to a decrease in the melt production rate of a factor 20 to 50 respectively.

The melting efficiency of four of the plumes, Iceland, Reunion, Tristan da Cunha, and Hawaiian has been calculated by dividing their melt production rate by their volume flux. The results show that the melting efficiency of the Iceland plume, which melts at a spreading centre, is about 20%, which compares with less than 1% for the intra-plate Hawaiian, Reunion and Tristan da Cunha plumes. The low efficiency of melt production in the intra-plate plumes means that melting will be dominated by low melting temperature components in the plume source such as basalt and sediment. This may explain why geochemical end-members in the mantle can be recognised in intra-plate plume but not in MORBs where the efficiency of melting is higher. The high efficiency of melting in the Iceland plume may also explain why its source appears to be more primitive than that of other plumes. Note however that Iceland basalts are not as primitive as MORB showing that there is a fundamental difference between the OIB and MORB source and that differences in their basalt geochemistry cannot be explained solely by differences in melting efficiency.

B. Ayling

The ocean's strontium isotope composition has been changing through geologic time, with intervals of both decreasing and increasing 87Sr /86Sr ratio indicated by analysis of deep sea sediment cores. Since the mid-Cretaceous (~100Ma), the general trend has been a gradual increase in the 87Sr /86Sr ratio from 0.70740 to its present day value of 0.70917. The three main sources of strontium input into the oceans are hydrothermal exchange at mid oceanic ridges, river runoff from continental weathering, and release of strontium from the skeletons of marine carbonates due to lowering of sea level and subsequent carbonate exposure and recrystallisation. Mid oceanic ridge-derived strontium typically displays a lower 87Sr /86Sr ratios of 0.703, while river runoff is usually higher (around 0.711) due to weathering of basement rocks which are relatively enriched in radiogenic strontium. Carbonate weathering acts as a buffer to the ocean's changing strontium isotope composition, as it negates the increasing 87Sr /86Sr ratio by contributing 87Sr /86Sr ratios from carbonates formed when the ocean's 87Sr /86Sr was lower.

Because of these changes in marine 87Sr /86Sr, strontium isotopes in fossil material have the potential to date and/or correlate marine sequences. In addition, there has been work into the utilisation of strontium isotopes as paleosalinity indicators where d18O or d13C paleosalinity interpretations are questionable. Strontium isotope ratios appear unaffected by biological processes or evaporation, and are therefore more likely to remain conservative in the seawater-freshwater mixing zone than d13C or d18O.

Part of my work will entail measurement of strontium isotopes from Pliocene and Pleistocene marine molluscs collected from the Wanganui Basin, New Zealand. The Wanganui Basin contains a ca. 2km thick cyclothemic sedimentary sequence which represents a near continuous record of predominantly marine sediment deposition from the late Pliocene (ca.2.5 Ma) to late Pleistocene. Mollusc samples were collected from 5 units which are chronologically dispersed throughout the section. These are the:

Landguard Formation (~0.25 Ma)
Tainui Shellbed (~0.5 Ma)
Kupe Formation (~0.68 Ma)
Omapu Shellbed (~0.85 Ma)
Hautawa Shellbed. (~2.5 Ma)

The ages of these deposits are already fairly well constrained by the combination of cyclostratigraphy, tephrochronology, biostratigraphy and paleomagnetic studies. It will therefore be interesting to analyse strontium isotopes from these deposits to provide additional age constraints/dating comparisons, and potentially add more data to the Pleistocene section of the ocean's strontium isotope evolution curve which is somewhat lacking in detail.

Macrofossils from these units generally show excellent preservation for the 4 youngest samples, particularly the Tainui Shellbed (see Figure 3).

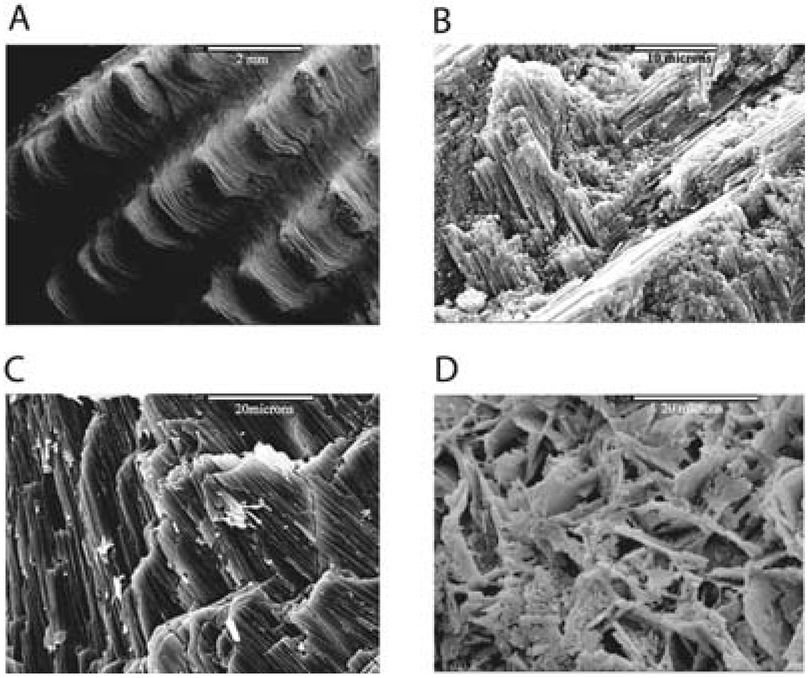


Figure 3: Tainui shellbed fossil assemblage:

A = Ostrea chilensis, B = Talochlamys gemmulata,

C = Purpocardia purpurata, D = Tawera spissa, E = Amalda mucronata,

F = Austrofusus glans, G = Notocallista multistriata.

XRD was performed on selected species from the Tainui shellbed, and it was found that the molluscs are 99% or greater calcite or aragonite, indicating excellent preservation. In addition, molluscs were examined under a SEM to investigate the appearance of primary aragonite or calcite crystals. It appears that the exterior portions of the molluscs are the most likely to experience diagenetic recrystallisation whereas nacreous surfaces are commonly pristine (see Figure 4).

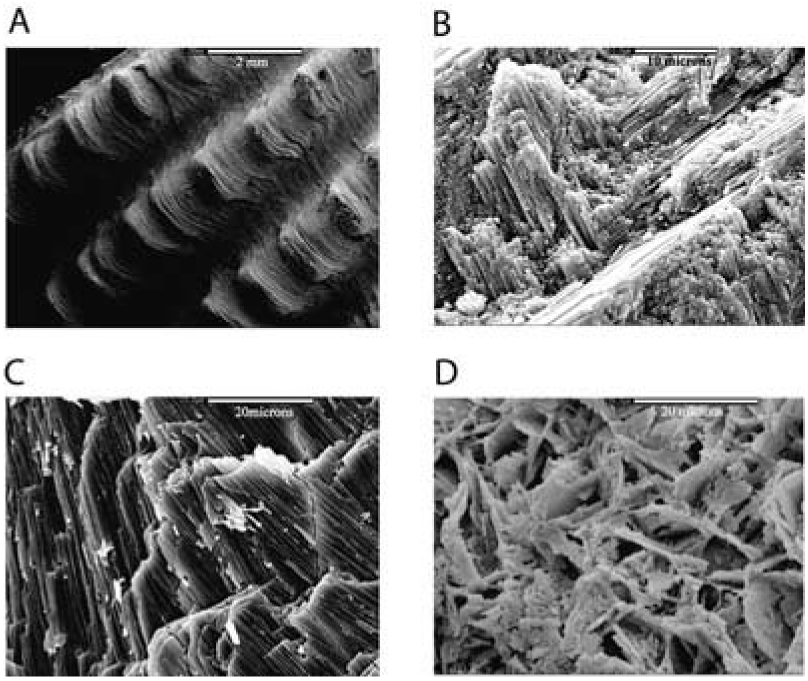


Figure 4: SEM images of selected fossils from the Tainui Shellbed. A = exterior of Purpocardia purpurata, B = pristine primary aragonite in Purpocardia purpurata, C = pristine primary calcite in Talochlamys gemmulata, D = diagenetic randomly oriented calcite crystals in Ostrea chilensis.

Shell sampling for strontium isotope analysis was undertaken using a handheld dental drill. Several sub-samples were collected from each mollusc, both to examine intra-mollusc variation in 87Sr /86Sr (there should be no detectable variation in this ratio over the lifetime of a mollusc), and to attempt to identify areas of a mollusc which preferentially experience dissolution (for example anterior Vs posterior, nacreous interior Vs exterior).

The samples were dissolved in weak acetic acid (1N), centrifuged to remove organics and clay material, and the resulting leachate was passed through a strontium specific cation exchange resin. Currently they are being analysed by TIMS (thermal ionisation mass spectrometry) for their strontium isotope composition.

High resolution LA-ICP-MS analysis of 238U-234U-230Th in ferruginous concretions: In search for a geochronological proxy for weathering processes

J.P.Bernal, S.E. Eggins, M.T. McCulloch,
R.A. Eggleton1
1CRC-LEME. Department of Geology, ANU

Understanding rates of weathering and pedogenic processes requires a geochronological framework to establish the origin and environmental conditions under which these processes take place. The lack of reliable geochronological information has proved to be the limiting factor in linking weathering and pedogenic processes with changing climatic regimes. Difficulties arise due to the texture and small size of weathering minerals, which makes them difficult to separate by standard physical methods for further analysis.

Pisoliths are concentric concretions of approximately 1 cm in diameter formed during the latter stages of weathering. Ferruginous pisoliths show layering of hematite and goethite (Figure 5) suggesting that these materials have been subjected to different cycles of aridity/humidity, controlled by the local climatic conditions.

Figure 5: Ferruginous pisolith from Ranger Uranium Mine, Northern Territory, Australia. Dark bands are hematite rich layers, light bands are goethite rich layers

To obtain geochronological information from these minerals we have developed a methodology to measure 238U-decay series isotopes (238U-234U-230Th) in-situ using Laser Ablation Multi Collector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICP-MS). We have developed two differentstandards with constrained U-Th composition which allows to assess the precision and accuracy of the methodology. Furthermore, the use of matrix-matched standards have allowed us to account for matrix effects. Our method enable us to measure 238U decay series with a spatial resolution of 80µm and a precision of (6 kyr for samples 100 kyr old and ~300 ppm of U.

Analysis of the pisoliths show (see Figure 6) that the outermost layers are younger (60-140 kyr) than the interior layers (160-200 kyr). The outer layers are systematically lower in 234U/238U activity ratios and two scenarios for this are contemplated:
1) Co-precipitation of the goethite and uranium with different 234U/238U and subsequent closed system behaviour.
2) Leaching of U (with preferential dissolution of 234U) at the margins of the pisolith which would give older apparent ages.
Nevertheless, constrains on the rates of grow can still be calculated using appropriate open-system considerations. Our results indicate that a growth rate of 0.010 to 0.020 µm /y for each analysed pisolith.

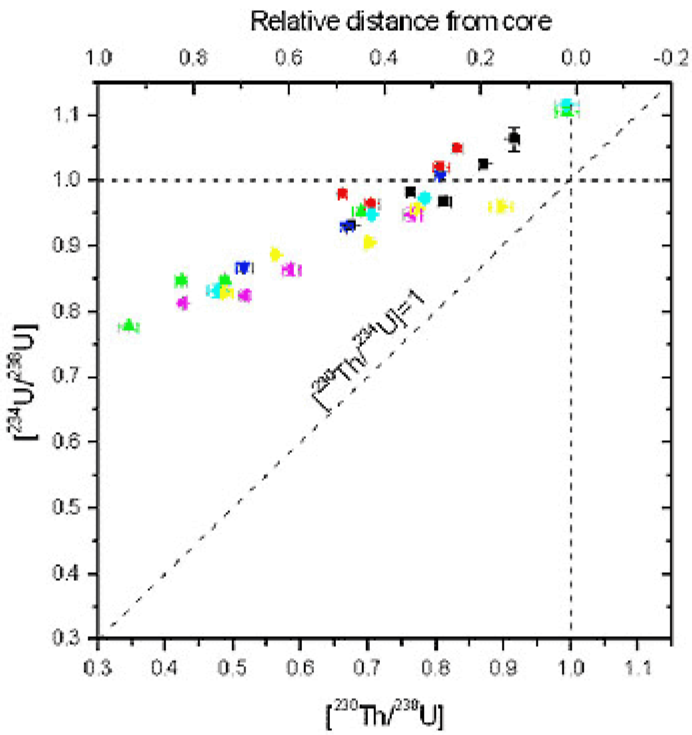
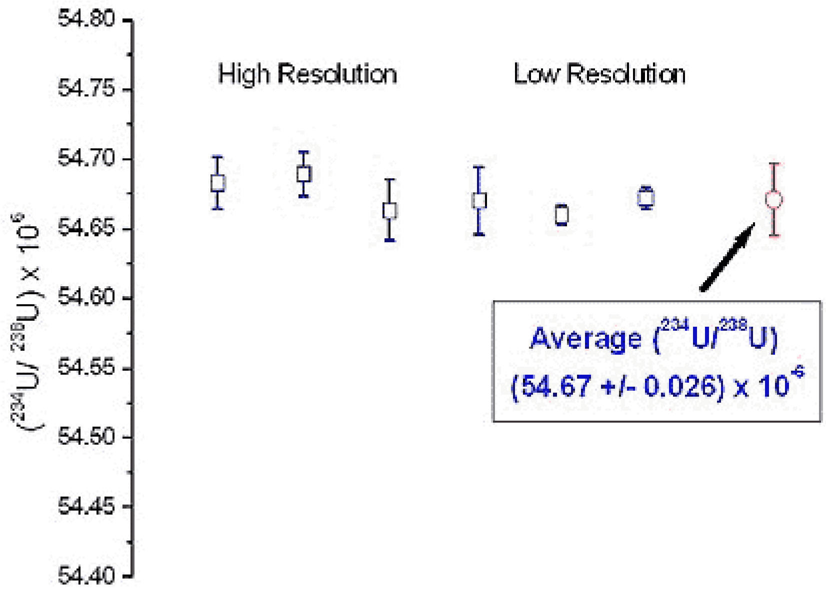


Figure 6: Activity ratios for core, inner and outer layers for the different pisoliths analysed

The decay constant of 234U revisited

J.P. Bernal, M.T. McCulloch, G.E.Mortimer and T.Esat

A new approach has been used to measure the abundance of 234U in samples in secular equilibrium with improved precision and accuracy. Taking advantage of the several features of the new NEPTUNE MC-ICP-MS, we have been able to measure concentrated solutions of previously well characterized uranium standards (HU-1 and ALH). As a result, an 234U ion beam was created with sufficient intensity to be measured on a Faraday cup. Using a calibrated 233U-236U calibrated double-spike, themulticollection, combined with high and low mass-resolution modes a 234U/238U isotope ratio for samples in secular equilibrium of (54.67 (0.026 (10-6) has been obtained (Figure 7), in excellent agreement with measurements from other laboratories, but with a three-fold improvement in precision. Hence, a revised, and more precise, decay constant (2.837(10-6 (1.3(10-9) and half-life (244,290 (120 y) of 234U has been obtained (Figure 8).



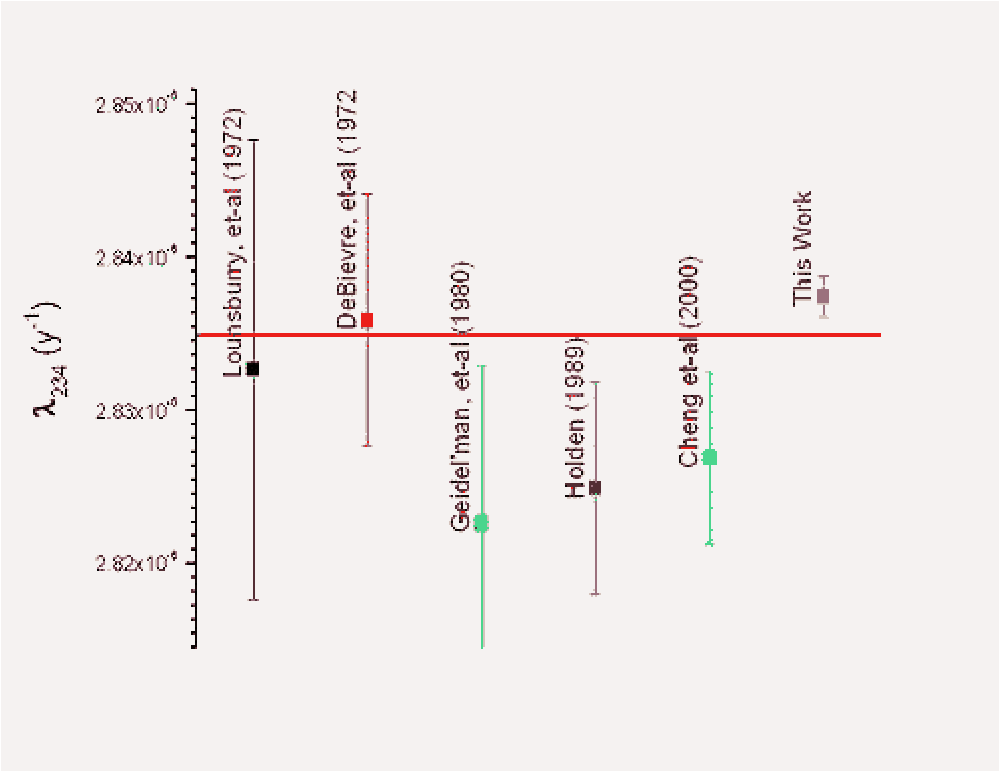


Figure 7: Repeat measurements of 234U/238U in secular equilibrium standards using high and low- resolution. Low-resolution data has better precision due to higher ion-beam intensity.

Figure 8: The half-life of 234U calculated in this work compared to previously accepted values.

Slowly down the Yangtse: landscape denudation and sediment flow in China

J. Chappell

Erosion, loss of soil and river degradation through the impacts of human activities are familiar problems. Although methods for improving the situation sometimes seem obvious, the real characteristics of many such problems are not accurately known because processes in natural landscapes were not assessed before human populations became large. Such processes are difficult to assess from short-term observations, because high-impact events such as very large floods occur rarely. However, much of the essential information is preserved in modern and ancient riverine floodplain deposits.

The Yangtse is one of the world's largest river systems. Rising in very high plateaus and mountains of north Tibet and western Sechuan, it passes through the lowlands of eastern China and delivers a large quantity of sediment to the East China Sea. Contrasting climates and sea levels between Quaternary glacials and interglacials doubtless induced major changes of regional erosion and sedimentation. In collaboration with colleagues at Tongji University in Shanghai, the project aims to evaluate long-term rates of erosion and soil loss by measuring rare isotopes producedby cosmic rays entering surface rocks. Average erosion rates and the transport history of sediments can be gauged by measuring the concentration of these isotopes in hillslope deposits and river sand. The measurements are made by Dr Keith Fifield and his accelerator mass spectrometry (AMS) team in the Research School of Physical Sciences and Engineering here at ANU.

Our previous studies in various terrains have proven the method in small catchments (Annual Reports 2000; 2001) and provide the basis for using similar methods at the much larger scale of the Yangtse River system. In the first phase of the project, sand samples were collected throughout the Yangtse river and its major tributaries: results are used to test regional models of slope erosion and sediment transport that explore the effects of tectonic uplift, climate change and human impacts. Initial results based on cosmogenic 10Be in quartz grains from the sand samples (illustrated in Figure 9) indicate higher than expected erosion rates in mountain catchments in eastern China, pointing to high human impact in historical times.

Compositional variation in planktonic Foraminifera shells:
Implications for reconstruction of paleoseawater temperature and salinity, and habitat migration

S. Eggins, P. De Deckker* and J. Marshall
*Department of Geology, ANU

The incorporation of Mg into the tiny calcitic shells (tests) that are secreted by planktonic foraminifera is extraordinarily sensitive to temperature, with large exponential increases of about 10% per °C occurring in shell Mg/Ca ratio. Thermometers calibrations have now been made for a small but expanding number of planktonic foraminifera species and form the basis of a rapidly emerging tool for reconstructing paleoseawater temperature from fossil shell material. Precise seawater temperature estimates are now routinely derived by bulk analysis of between 10 and 50 whole fossil foraminifera shells using modern instrumental techniques. Unfortunately, the reliability of these estimates is compromised by the compositional variation that occurs within a population of foraminifera shells (due to seasonal and interannual seawater variability), subsequent modification of preserved bulk shell compositions due to preferential dissolution on the seafloor of more Mg-rich shells and shell parts and, the effects of cleaning to remove contamination by diagenetic/detrital phases.

To illuminate the extent of these problems we have investigated the extent of compositional variation within several planktonic foraminifera species that are commonly used in paleocean reconstruction. Using in-house developed laser ablation ICP-MS technology, we are able to analyse individual chambers and to profile chamber walls with sub-micron depth resolution (Figures 10 & 11). We have found correlated Mg/Ca, Mn/Ca, Ba/Ca and Zn/Ca variations but relatively unfirm Sr/Ca compositions through the shell walls of Globigerinoides sacculifer, Globigerinoides ruber, Globigerina bulloides, Neogloboquadrina pachyderma and Neogloboquadrina dutertrei. Distinct chamber and chamber-wall layer compositions occur within individual shells, particularly in species that migrate within/through the thermocline. This compositional heterogeneity appears to be consistent in detail with seawater temperature changes that accompany habitat migration during the adult life-cycle stages of the investigated species. However, an anomalous, Mg-rich (<1-6 mol% Mg) surface veneer occurs on each of the analysed species and is found on both fossil and modern shells. These shell surface coatings are of primary biogenic origin and bias the analysed bulk shell compositions toward higher Mg/Ca values by between 5 and 35%. Subject to the ability to exclude the surface veneer during analysis as possible with laser ablation ICPMS anlaysis, bulk shell Mg/Ca compositions may provide reliable mean seawater temperature estimates only for species that calcify under uniform (near-surface?) conditions. Laser ablation ICPMS shows considerable promise as a means for reconstructing paleoseawater temperatures and has the potential to add considerable value to deep-sea core paleocean and climate records by yielding: (1) the range and variability of past seawater temperature from a population of shells, (2) the thermocline and compositional structure of the water column through analysis of specific shell parts in species that migrate over large vertical ranges; and (3) integration with _18O analysis of the remaining shell material to constrain past seawater _18O from the temperature dependent variation of _18O and therefrom estimate past seawater salinity and density. The technique may also be used to track habitat changes occurring during the adult life-cycle stages of planktonic foraminifera.

Figure 10: SEM image of a N. dutertrei shell in which multiple (14 separate), 29µm diameter, laser ablation ICPMS analyses have been made with a pulsed ArF Excimer laser (_=193nm). Each analysis requires <60 seconds and consumes only 10-20 ng of shell material, or about 0.1% of the total shell mass, leaving the remainder available for (18O or other analysis.

Figure 11: High-resolution compositional depth profile obtained through the lower large chamber wall of the N. dutertrei specimen shown in Figure 1. Note the distinct compositions of the inner and outer wall layers, the highly Mg-rich surface veneers, and the sub-micron scale compositional resolution achieved. Total analysis time was 60 seconds.

Skeletal Sr/Ca and _18O profiles in a giant long-lived Tridacna maxima

M. Elliot, M.T. McCulloch, M.K. Gagan, G. Cabioch* and J. Chappell
*Institut de Recherche pour le Developpement, Nouméa, New Caledonia

We measured the trace element composition (Sr/Ca) and oxygen isotope ratio (δ18O) of a modern Tridacna maxima shell collected live in December 2001 from New Caledonia. Bivalves secrete daily layers of carbonate which can be sub-sampled to obtain information with seasonal resolution. T. maxima are found in tropical reef environments and can live for over one-hundred years. In contrast with corals, they precipitate their shell in isotopic equilibrium with the water in which they grow and thus have the potential to be valuable tools in paleo-environmental studies. Sr/Ca and Mg/Ca of marine carbonates are commonly used to reconstruct past temperatures. However previous studies have not succeeded in establishing a clear relationship between water temperature and the Sr/Ca of T. maxima bivalves. Our approach was to measure skeletal Sr/Ca using high resolution by laser ICP-MS and the δ18O of a modern specimen which has grown in a controlled environment.

A section of the giant T. maxima shell reveals 3 distinct zones. The hinge and the outer zones present well-defined successive dark and light yearly increments, whereas the inner layer is homogenous and reveals no obvious annual banding. The Sr/Ca of different zones was analysed in order to assess any differences in the distribution throughout the shell. We obtained high-resolution profiles of Sr/Ca from the hinge and inner zones, The profiles of Sr/Ca in each zone all exhibit seasonal variations but with different amplitude (Figure 12). The δ18O profile along the hinge area also shows seasonal variations which have been used to develop an annual chronology. High Sr/Ca and δ18O values are associated with the dark-winter increments in the hinge zone which is similar to what has been observed in corals. We have thus been able to obtain seasonal variability of trace elements which covary with the δ18O record. This observation supports the possibility of a temperature-controlled uptake of trace elements. However, our results show that the distribution of the trace elements throughout the shell varies significantly. The biological and physical processes controlling the uptake of trace elements from the surrounding water and their distribution within the shell of T. maxima will have to be better understood before obtaining a reliable palaeothermometer.

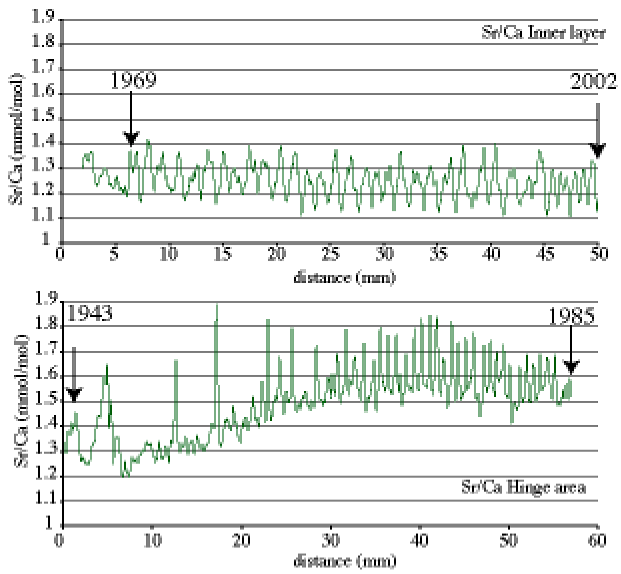


Figure 12: Sr/Ca variations measured by laser ICP-MS along the inner layer (top) and along the hinge area (bottom) of a modern T. maxima collected live in December 2002, in New Caledonia. The estimated age of this specimen is approximately 49 years. The transect of the inner layer covers the last ~33 years, whereas the transect along the hinge area covers the period 1943-1985.

which were unaltered relative to the outer zone. Two parallel scans perpendicular to the growth layers were performed in order to check the reproducibility of the laser ICP-MS Sr/Ca measurements which were obtained every 50 microns. δ18O was measured on samples of carbonate powder extracted from the hinge area with an average resolution of 300-400 microns using a high precision microdrill.

Stable isotope analysis of bone collagen and tooth enamel of modern Australian faunas to investigate dietary inputs: implications for palaeo-diet and palaeo-environmental reconstructions.

R. Fraser, T. O'Connell* and R. Grün

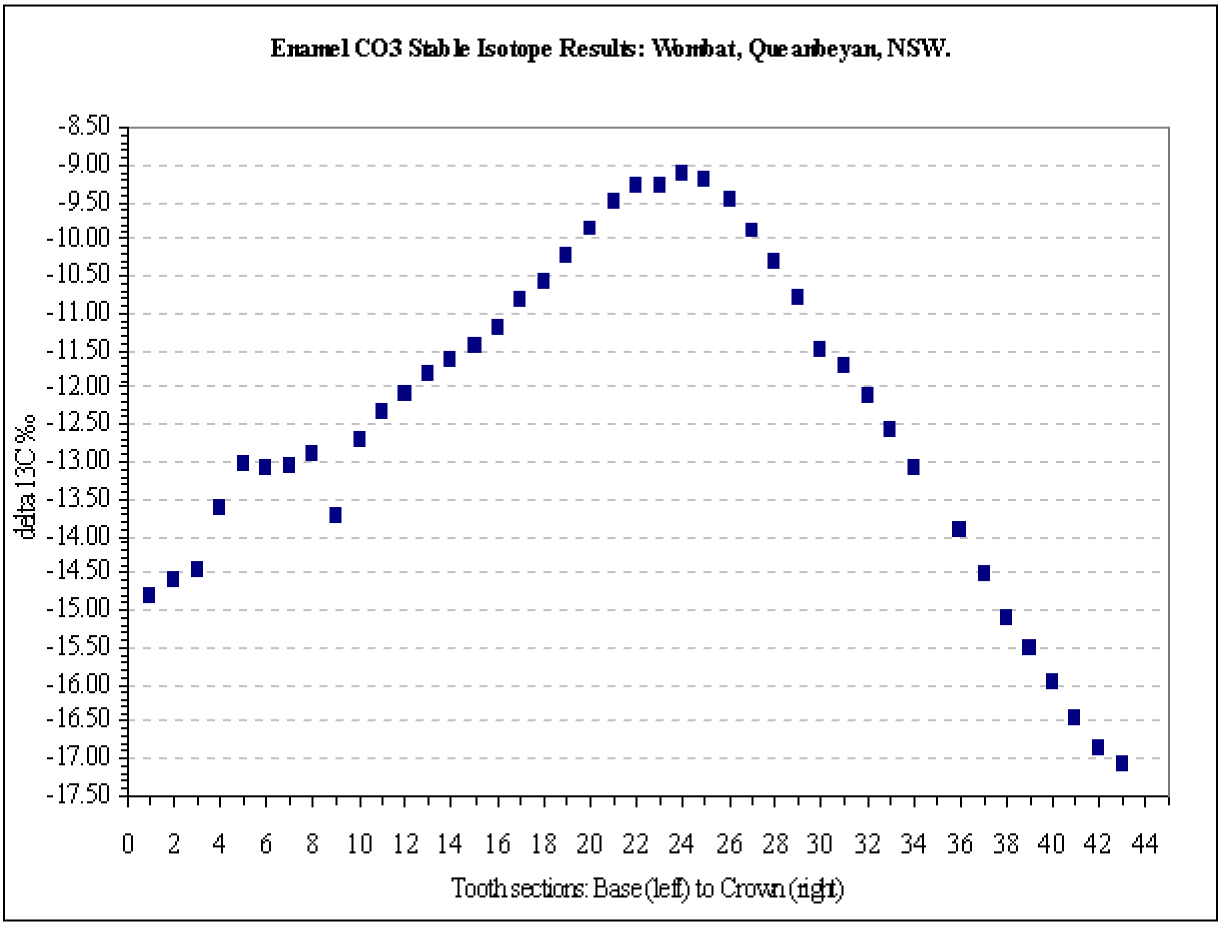
*University of Oxford

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 isotopes of carbon, nitrogen and oxygen within fossil bones and teeth, are an additional source of diet and climate information. Whilst the use of stable isotopes in palaeodiet research is used extensively overseas in the archaeological and ecological fields, it remains vastly under utilised when considering Australia's fossil faunas.

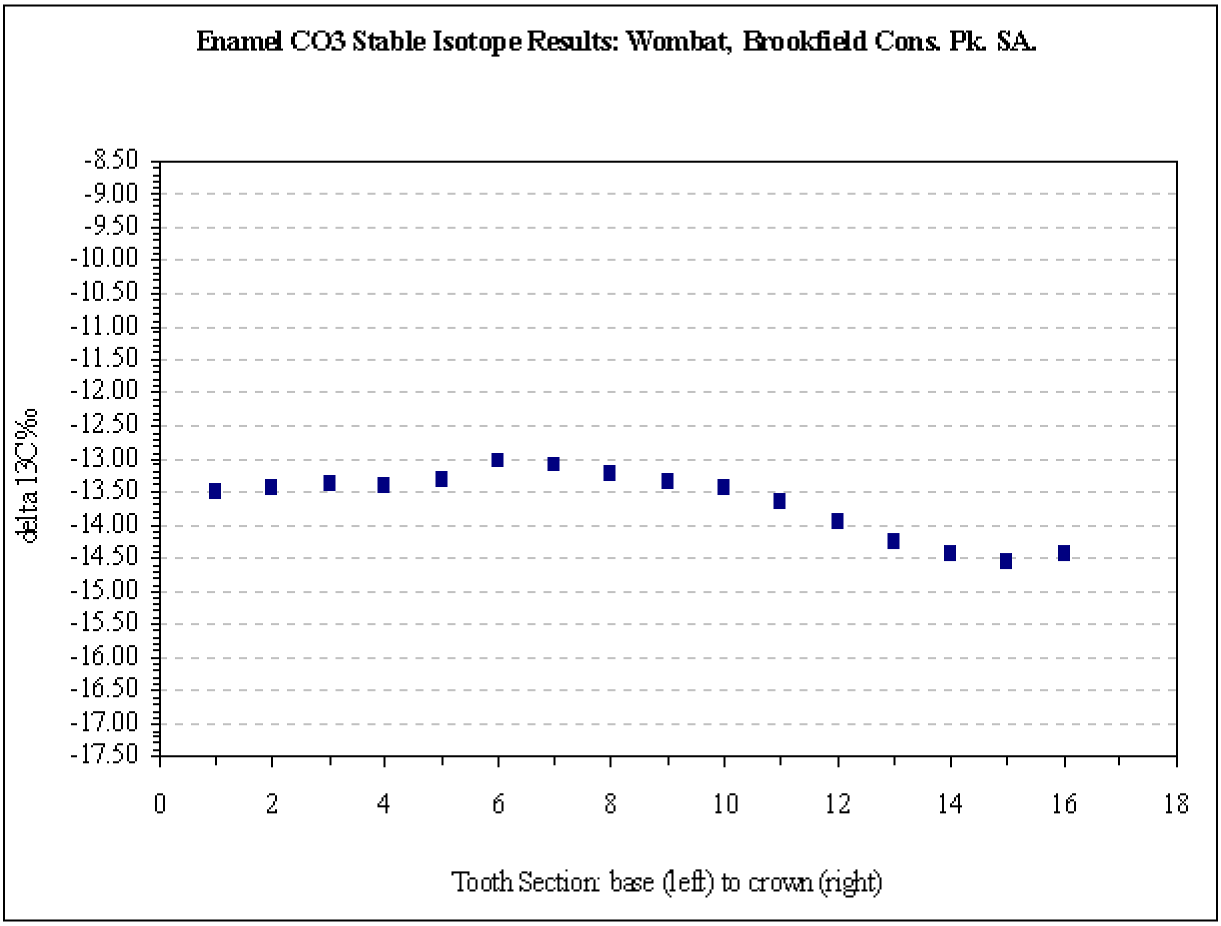
There is uncertainty about how stable isotopes reflect diet and climate in the Australian context, therefore this project has begun by measuring the δ13C and δ15N of bone collagen and the δ13C and δ 18O of tooth enamel from modern marsupial herbivores; kangaroos, wombats and koalas. By analysing these 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.

δ13C in tooth enamel

.Isotopic analysis of enamel CO3 within the hypsodont (continuously growing) teeth of grazing wombats has revealed variations in δ13C over the growth of the tooth, as shown in Figure 15. These incremental changes along the time series represented display what is likely to be seasonal changes in δ13C plant values of the animal's plant diet. The range of δ13C values within a tooth series varies between geographic areas. The large ~8 range of the wombat shown in Figure 15 may be due to the greater seasonal variation in C3 and C4 grass types in this area. Figure 16 shows a tooth series with less delta13C change (only 1.5), this wombat lives in a predominantly C3 grass area with little seasonal variation. As the distribution of C3 and C4 grasses is predominantly determined by temperature and season of rainfall, the isotopic series provided by wombats' teeth might indicate the magnitude and type of climatic or plant seasonality at that location.



Enamel CO3 Stable Isotope Results: Wombat, Queanbeyan, NSW.
delta 13C ‰
-8.50
-9.00
-9.50
-10.00
-10.50
-11.00
-11.50
-12.00
-12.50
-13.00
-13.50
-14.00
-14.50
-15.00
-15.50
-16.00
-16.50
-17.00
-17.50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
Tooth sections: Base (left) to Crown (right)



δ13C of kangaroo and koala tooth enamel CO3 has also been measured. The sampling of separate teeth within an individuals' tooth row revealed significant differences in δ13C between teeth; up to a 5 variation was observed in modern kangaroos.

Ultimately, this 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 diets of extant fauna, such as the kangaroos, over time in response to changing climate and vegetation regimes will increase our understanding of ecological change.

Holocene ocean-atmosphere interactions and seasonal expression of the El Niño-Southern Oscillation

M. K. Gagan, L. K. Ayliffe(1), W. S. Hantoro(2), D. Hopley(3), H. Scott-Gagan, C. D. Woodroffe(4), M. T. McCulloch

1) Laboratoire des Sciences du Climat et de l'Environnment, Gif-sur-Yvette cedex, France.
2) Research and Development Center for Geotechnology, Indonesian Institute of Sciences.
3) Coastal and Marine Consultancies Pty. Ltd., Townsville, Qld.
4) School of Geosciences, University of Wollongong, NSW.

Changes in the magnitude and frequency of El Niño-Southern Oscillation (ENSO) events observed in instrumental records since the 1970s have generated considerable debate about recent ENSO behaviour, and the possibility that it may be responding to global warming. Ocean-atmosphere dynamics and atmospheric circulation are known to be particularly sensitive to large-scale changes in latitudinal temperature gradients. Thus there is intense interest in documenting ENSO variability since the mid-Holocene (~6,000 years ago), when climate boundary conditions were comparable to today, yet the seasonal distribution of insolation across Earth's surface was different because of precession of the equinoxes.

A central issue limiting our understanding of the palaeo-ENSO is that it is not known if the precipitation anomalies in palaeorecords are directly related to changes in El Niño temperature anomalies in the tropical Pacific. Resolving the debate requires seasonal palaeoclimate data that are capable of revealing the relative magnitude of the oceanic and atmospheric signals diagnostic of the ENSO phenomenon. Coupled measurements of Sr/Ca and 18O/16O in

We investigated the relationship between mean climate and ENSO using Holocene Porites coral colonies preserved in growth position on palaeo-reefs at Sumba (southern Indonesia) and Orpheus Island (central Great Barrier Reef). Bi-monthly resolution measurements of Sr/Ca and 18O/16O for these corals provide a history of off-equator warming of the surface ocean, enhanced evaporation in the austral spring, and reduced interannual variability of monsoon rainfall from 4,800 to 6,200 calendar years before present. Despite this different climate state, the ocean-atmosphere feedbacks diagnostic of the ENSO remain predictably phase-locked to the annual cycle. Yet, compared to ENSO behaviour of recent decades, the response of Australian monsoon precipitation to El Niño temperature anomalies is subdued in the mid-Holocene.

Records of skeletal 18O/16O for massive Porites microatolls from Christmas Island (Kiritimati) in the central equatorial Pacific provide high-resolution proxy records of ENSO variability since 3,800 years ago. The comparative histories indicate that ENSO anomalies were less intense between 3,800 and 2,800 years ago, and more pronounced 1,700 years ago.

Suppression of the ENSO during the mid-Holocene and amplification ~2,000 years ago are consistent with model predictions based on precessional changes in insolation seasonality. However, the abrupt onset of ENSO variability in the Late Holocene is unexpected, and appears to reflect stronger rainfall teleconnections. We propose that this shift in Late Holocene ENSO behaviour reflects enhanced interaction between the Southern Oscillation and the Intertropical Convergence Zone during. The suppressed ENSO-monsoon interaction observed during the mid-Holocene is best explained by enhanced south-easterly wind-driven coral skeletons provide a means for reconstructing 18O/16O in seawater, as well as temperature, by removal of the temperature component of the coral 18O/16O signal. In this study, we expand the coupled Sr/Ca-18O/16O technique to generate records of the seasonal cycle of seawater 18O/16O to examine the interaction of temperature, precipitation and evaporation during individual palaeo-ENSO events.

divergence in the tropical Pacific, and northward displacement of the Intertropical Convergence Zone. Tighter coupling between the Southern Oscillation and a more southerly Intertropical Convergence Zone during the Late Holocene could serve to amplify ENSO precipitation variability.

The results suggest that large-scale changes in tropical atmospheric circulation can play an active role in modulating ENSO-monsoon interactions and the precipitation response to El Niño temperature anomalies. Transient greenhouse warming simulations suggest that the distribution of global warming will not be homogeneous in the 21st century, and that large-scale changes in surface temperature gradients and atmospheric circulation may result. Our findings predict that the impact of El Niño temperature anomalies on precipitation will evolve along with global climate change, even if El Niño temperature perturbations remain relatively stable.

Dating of the Border Cave 5 mandible

R. Grün, P. Beaumont1, P.V. Tobias1 and S. Eggins
1 McGregor Museum, South Africa
2 Sterkfontein Research Unit, School of Anatomical Sciences, University of the Witwatersrand Medical School, South Africa

The archaeological site of Border Cave, Kwazulu Natal, South Africa, has yielded a number of modern hominid remains, labelled BC1 to BC8. BC5 is a fairly complete lower jaw (Figure 1) which was recovered by C. Powell in 1974 from the northwest edge of square T20, while she and one of us (PBB) were collecting sediment samples, at the request of K.W. Butzer, from the south face of Excavation Area 3A. It came from the 3 WA (the site shows an succession of white and brown sediments which have been termed "white ashes" (WA) and "brown soils" (BS), numbered from top to bottom), about 0.25 m below its intact surface, and immediately adjacent to a previously mapped and photographed depression, the base of which cut by up to 0.15 m into the upper part of the underlying 4BS.

Border Cave has been the subject of several dating studies, by radiocarbon on charcoal, ESR on faunal teeth, amino acid racemisation of ostrich eggshells and thermoluminescence on burnt flint. Comparison of the dating results found slightly younger mean ESR dates (in the range of 5 to 10%) than those of the other dating techniques. This has been attributed to a small fading component (see Grün and Ward 2002). There are unfortunately no definite amino acid and TL results available on layers 3WA and 4BS. If BC5 was contemporaneous with the faunal teeth found in 3WA its age would be about 66±2 ka (average ESR age of layer 3WA) and younger than 82±2 ka (average ESR age of Layer 4BS).

However, all arguments above are circumstantial and conclusive proof for the age of BC5 can come only from the direct dating of this specimen (see also Grün and Beaumont 2001). In 2002, we obtained permission to sample a small tooth fragment of BC5 for ESR dating. Using a small screwdriver, a 4.6 mg fragment was detached from the loose, partial crown of the mandibular right third molar and can be fitted back on to the stump of that tooth which is still in the alveolar part of the mandible. The tooth from which the chip was detached by Dr. R.J. Clarke is moderately worn with only a small island of dentine exposure, in contrast with the more heavily attrited second molar of the same side, which is in position in the jaw. The degree of wear of the second and third molars is compatible with this jaw having belonged to an adult individual. The average thickness of the fragment was 600±100 µm. First, we used laser ablation ICP-MS on the mirror surface of the remaining tooth to obtain U-profiles of the enamel and dentine (for details of this technique, see Eggins et al. in press). The uranium concentration in the enamel, 1 to 10 ppb, is close to modern values, whereas the uranium concentration in the dentine, 220±20 ppb, is slightly elevated and very uniformly distributed. For measurement of the dose value we used the non-destructive procedures developed at ANU and have been reported in earlier annual reports. A 4.6 mg tooth fragment yielded an average dose value of 150±5 Gy. Using the gamma dose rate values of an earlier detailed survey as well as neutron activation results of a representative sediment sample, we obtain an age of 76±5 ka. Because of the low U-concentrations in enamel and dentine, the age estimate is not sensitive to the mode of U-uptake. When compared to the results of the previous ESR dating study on faunal material, the age of BC5 fits exactly into the sequence of previously obtained age estimates (Figure 2).

Sillen and Morris (1996) have published and provided one of us (PBB) with splitting factor (SF) and nitrogen (N) assays on BC1 to BC7 and on faunal cortical fragments from the Excavations 3A and 4A sequence that were submitted to Sillen between 1990 and 1993. The interpretation by Sillen and Morris (1996) of the Border Cave data (Figure 3) was based on Elands Bay Cave (EBC) results where SF increases with depth to a limit at about 20 ka BP. However, no comparable trend is evident at Border Cave, except for increases from about 2.9 to 3.7 in the 1BS.UP (Iron Age) spits and from about 3.4 to 5.3 in the basal 6BS (arrows in Figure 3). Sillen and Morris (1996) concluded that "until the differences [of SF factors] between BC3 and BC5 on the one hand, and the MSA fauna on the other can be explained, these hominids cannot be connected to the MSA period with confidence".

The following questions arise from the study of Sillen and Morris (1996):
* Are BC3 and BC5 significantly younger than the layers in which they were found?
* Is the measurement of lower SF factors in hominid material proof of their claimed Holocene provenance?

Our dating result demonstrates conclusively that BC5 was buried at the beginning of the deposition of layer 3 WA. Its best age estimate is 76±5 ka. We conclude from our dating result on BC5 and the above discussion that measurements of SF and N assays are not particularly well suited to derive age assignments for the fossil hominids at Border Cave. The age of the other specimens are also best obtained by chronometric studies. At present, it seems, ESR cannot provide any further age information for the Border Cave hominids, as the only other specimen with teeth, BC3, has vanished. It may, however, be possible to date enigmatic fossils BC1 and BC2 by U-series dating. On the other hand, non destructive ESR dating may help to establish the ages of other important fossils whose age is debatable, e.g. the mandible of Banyoles.

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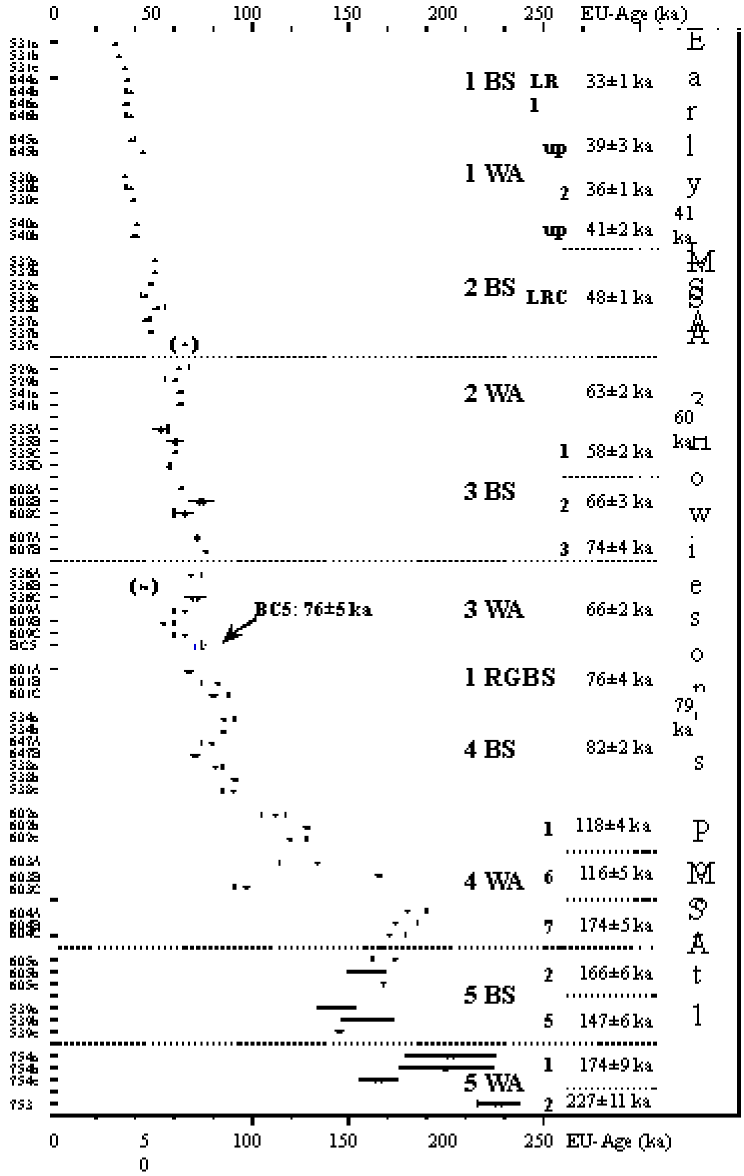


Figure 2: The age of BC5 in context with the revised ESR chronology for Border Cave (Grün and Beaumont 2001). Lowercase letters following the sample number denote sub-samples of a single tooth, capital letters separate enamel fragments. The two bracketed results were not used for the calculation of the average ages of the units.

Uranium Isotopes in the Oceans

L. Kinsley, G. Mortimer, T. Esat and M.T. McCulloch

and lasted for 1_ hours. The 235U/238U ratio with 235U measured in a Faraday cup and in the electron multiplier (SEM) provided a direct calibration for the SEM gain, including any non-linearities, except

We have determined the operating characteristics and the precision obtainable from the newly acquired Finnigan multi-collector inductively-coupled mass spectrometer 'NEPTUNE' in measuring uranium isotopes. Such a measurement places high demands on instrument performance as the isotope ratio of interest is small ~5x10-5 and susceptible to small amounts of interfering molecular beams. It involves combined use of Faraday-cups and an 'electron-multiplier' and the accounting for, or elimination of tailing from intense 238U beams. In addition, there appears to be a discrepancy in the U isotopic composition between modern corals and sea-water. We have determined the U isotopic composition of sea-water to help resolve the difference.

Data collection consisted of 30 2-second simultaneous integrations of 234U, 235U 238U, a peak jump, and 10 2-second integrations of 235U and 238U. Each experiment included 10 cycles of 6 blocks for a correction in dead-time between different count-rates of 234U and 235U. The use of 235U for SEM calibration restricts the usable signal intensity to about 2 volts 238U (1011 Ohm) so as not to overload the SEM.

The present results show that the isotopic composition of uranium can be measured to a precision better than 1 with Neptune SEM and retardation lense in a reproducible fashion. The instrument, and the particular measurement technique used, can achieve this independent of beam intensity. The measured 234U/238U ratio for the standard is identical to the secular equilibrium value (5.467x10-5). Indicating that standard 'ALH' is in secular equilibrium and also that the instrument can provide absolute values of this ratio when appropriately calibrated. Uranium isotopic composition of 'modern' sea-water is indistinguishable from uranium isotopic composition of 'modern' corals within the analytical precision.

The previously determined mean sea-water value of 144±2 (Chen et al., *EPSL* ***80***(1986)241) should be revised to ~148.4±0.5 in close agreement with the modern coral value of ~148-149 .

References

Chen, J.H., Edwards, R.L. and Wasserburg, G.J., 238U, 234U and 232Th in seawater, *Earth and Planetary Science Letters*, 80, 241-252

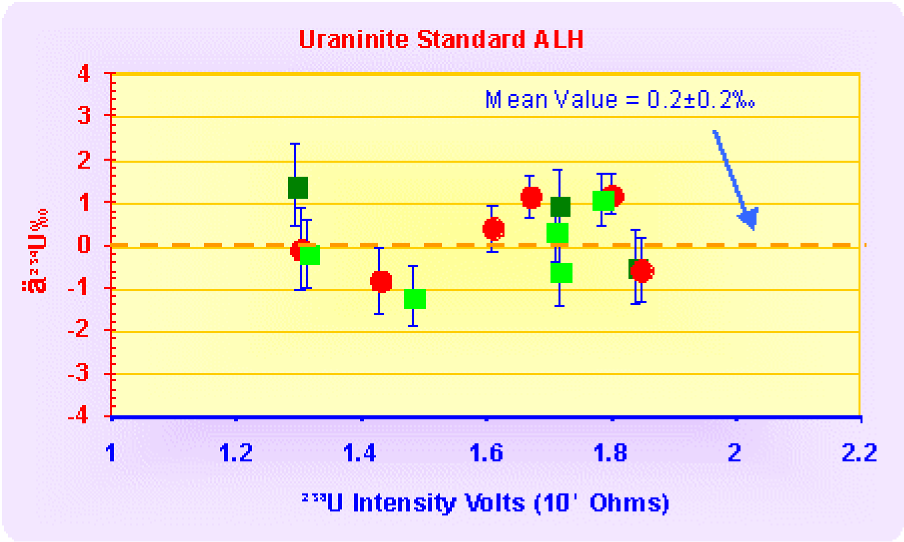


Figure 13: **Results for the isotopic composition of uraninite standard 'ALH', assumed to be in secular equilibrium, are shown here. The 14 determinations over a period of two months yield a mean close to zero, relative to the secular equilibrium value of 5.467x10-5. This is a direct determination with Neptune without reference to any other standard.**

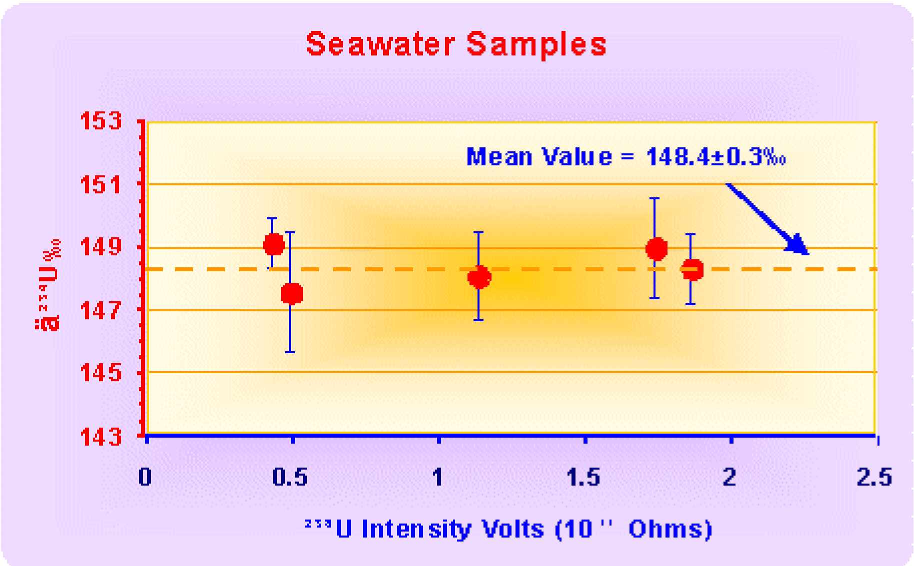


Figure 14: **Uranium from 50 to 100 ml seawater samples was extracted by co-precipitation with iron chloride and the Fe removed by ion-exchange. The results**

shown here (relative to 5.4709x10-5) are internally consistent and very similar to those measured in modern corals

Impact of drought on sediment fluxes entering the Inner Great Barrier Reef

M.T. McCulloch and T. Wyndham

Australia is in the midst of a major drought with many areas having less than 10% to 30% of normal seasonal rainfall (Bureau of Meteorology rainfall data to August 2002). Although the main focus of public attention has been on the loss of agricultural related GNP, equally devastating impacts may soon occur in the Great Barrier Reef (GBR). Depending on the character of drought-breaking floods, major increases in suspended sediment loads can be anticipated in river runoff from the two largest river systems that drain into the GBR, the Fitzroy and Burdekin Rivers. These rivers have large semi-arid catchments and hence are particularly susceptible to large-scale erosion due to loss of groundcovers and chronic overstocking that inevitably occurs during periods of drought. What is the likely impact of drought-breaking floods on the GBR?

High-resolution Ba/Ca studies of inshore corals now provide insights into this question. Barium is desorbed from fine grained particles in the estuarine mixing zone, and then advected in river flood plumes and finally partitioned into the coral skeleton. Coral records from Havannah Island reef study site thus show that suspended sediment loads in drought-breaking floods can be 2 to 3 times greater than in floods that occur during non-drought periods. Prominent recent examples include the drought-breaking floods of 1927, 1936, 1968, 1970 and 1988. In contrast, prior to European settlement, the coral record indicates that floods generally carry 0.1 to 0.2 lower concentrations of suspended sediment. The only significant events which are registered in the coral are the drought breaking floods of 1761, 1765, and smaller events in 1795 and 1801.

The five to tenfold increase in suspended sediment entering the inner GBR since European settlement is likely to have major ecological consequences. The Burdekin River typically carries ~107 tonnes of sediment of which ~106 tonnes of fine grained clays will remain entrained in the flood plume and be dispersed to the inner/mid shelfs. A portion of this is likely to be carried directly to mid-reef sites such as Rib and Britomart.. In the inner shelf, supply of sediment available for later resuspension by wind/wave action will also be replenished. Fluxes of total P (90% particle bound) and to a lesser extend N (~40% particle bound) will increase, although particulate P is not released directly into solution, requiring a more protracted cycle of anoxic reduction. Terrestrial runoff into coral reefs needs to be reduced, especially following droughts, if corals are to survive the dual impacts of direct anthropogenic disturbance and coral bleaching due to unusually warm ocean temperatures.

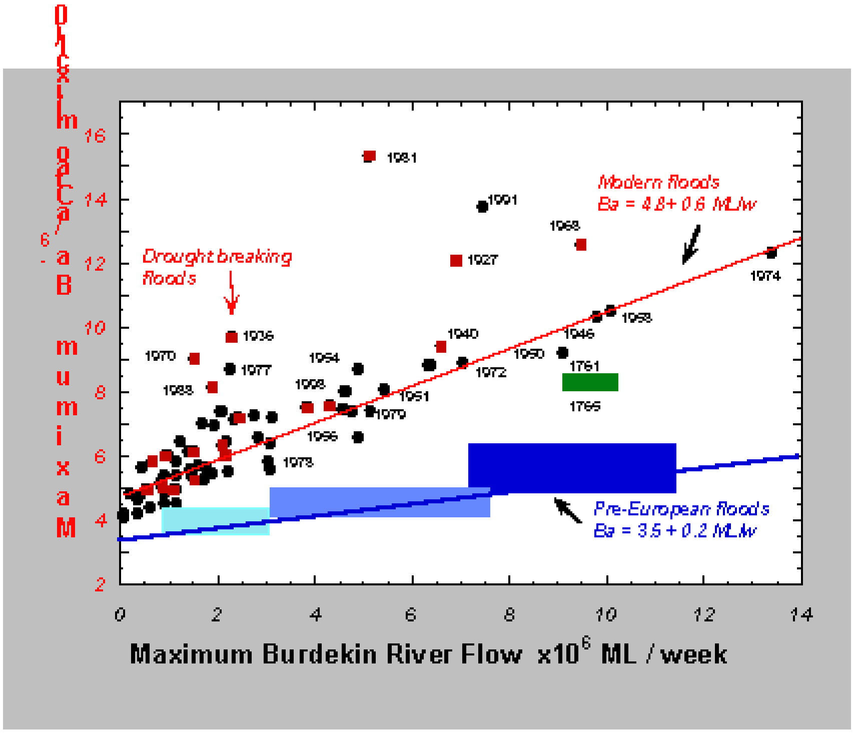


Figure 17: Plot Showing the Ba/Ca ratios (ie suspended sediment loads) versus Burdekin River flow. Floods that follow droughts generally have much higher Ba/Ca ratios consistent with greater erosion for larger magnitude drought breaking floods.

High resolution coral proxy records of an abrupt shift in mid-Holocene climate in the Western Pacific Warm Pool

H.V. McGregor, M.K. Gagan, M.T. McCulloch and J. Chappell

This study uses coral climate reconstructions from the Western Pacific Warm Pool (WPWP), a key player in the El Niño-Southern Oscillation (ENSO) system, to investigate WPWP-ENSO-monsoon interactions during the mid-Holocene. Modern and fossil Porites sp. corals were drilled from Koil and Muschu Islands, Papua New Guinea (PNG), in the WPWP core region. Here reductions in sea surface temperature (SST) and rainfall characterise El Niño events. Changes in salinity and SST are reflected in coral skeletal oxygen isotope residuals δ18O) and Sr/Ca respectively, allowing reconstruction of mean climate conditions.

Bulk samples were analysed to examine mean climate conditions (Figure 18a,b). Fossil coral δ18O from 7.6 to 6.1 ka show drier conditions compared to present, and coral Sr/Ca-SST indicate warming from 2.5(C below present to a SST peak similar to today. Between 6.1 and 5.4 ka Sr/Ca-SSTs and δ18O values suggest an abrupt shift to cooler and less saline conditions. By 2ka, salinity is similar to present, though SSTs are slightly cooler. The PNG coral records show a similar abrupt shift to that at the end of the African Humid Period. This suggests a climate link between these regions, perhaps via monsoons. The abrupt shift may represent the rapid establishment of a modern-like warm pool.

Bimonthly analyses were used to "zoom-in" on periods of interest in the mean records, before and after the abrupt shift (Figure 18c). Prior to the shift the ((18O records show:

- Reduced rainfall
- Increased dry season salinity and evaporation, therefore stronger winds across the western Pacific
- δ18O minimums do not fall on the Sr/Ca SST minimum line, suggesting a change in timing of salinity and SST minima.

Sediment core records from the east and west tropical Pacific suggest an increased mid-Holocene SST gradient, with stronger winds, Walker circulation and western Pacific SSTs. PNG coral records also suggest stronger winds, though in contrast PNG SSTs indicate cooler conditions.

One possible scenario to reconcile conflicting SSTs would be an enhanced La Niña state. For example, the La Niña of 1999 saw strong winds send a cold tongue of water across the equatorial Pacific. With stronger mid-Holocene Pacific winds, this cold tongue could extend to PNG giving cooler SSTs but warming the surrounding region.

Effect of early marine diagenesis on coral reconstructions of 20th century changes in surface-ocean carbonate saturation state

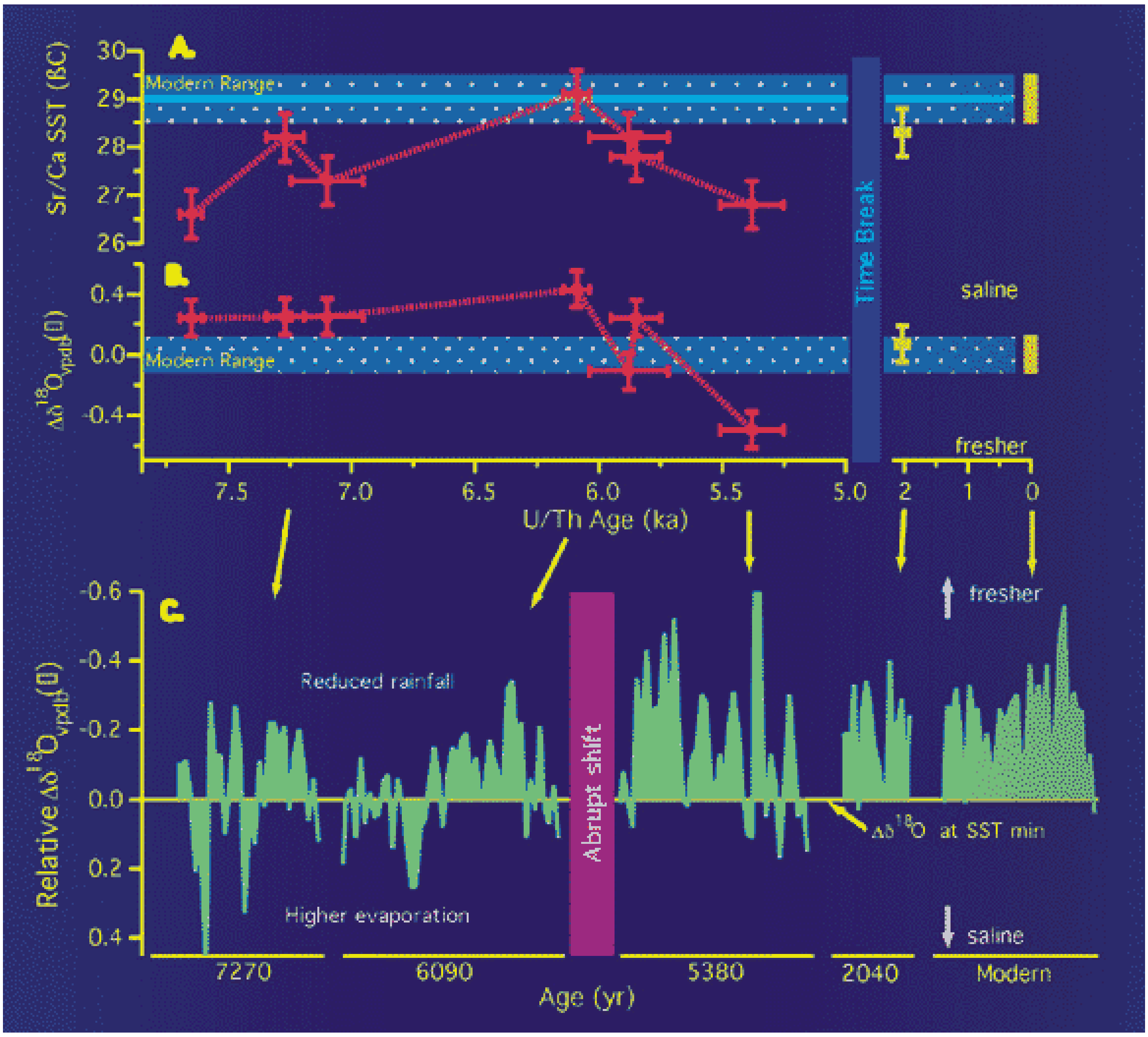


Figure 18: Relative changes in ((18O and Sr/Ca-SST between fossil and modern corals. (a) Changes in mean Sr/Ca-SST. (b) Changes in mean ((18O. (c) Changes in seasonal ((18O for selected fossil and modern corals.

Ice sheets: landscape preservers or destroyers.

D. Fabel, J. Harbor1, A. Stroeven2, J. Kleman2, C. Hättestrand2, D. Elmore3 and D. Fink4

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

Over the past three years we have worked collaboratively to examine deglaciation chronology and patterns of erosion and landscape preservation in the northern Swedish mountains, the core area of the Fennoscandian ice sheet using in situ produced cosmogenic 10Be and 26Al. The accumulation of in situ produced cosmogenic 10Be (half-life = 1.51 ± 0.05 x 106 yr) and 26Al (half-life = 7.1 ± 0.2 x

3 PRIME Lab, Purdue University, U.S.A.
4 Australian Nuclear Science and Technology Organisation.

Critical tests of global climate models include their ability to reconstruct environmental conditions during former periods of distinctly different or rapidly changing climate, such as glacial maxima and periods of large-scale ice-sheet growth and decay. Global climate signals and ice volume estimates have been extracted from deep-sea, coral reef, and ice sheet proxies. Over the past 20 years, since the CLIMAP reconstruction of the Last Glacial Maximum (LGM), including LGM ice volumes, there has been growing concern that ice sheet thicknesses and volumes suggested by CLIMAP may have been overestimated, and that new reconstructions are needed. However, CLIMAP estimate of LGM ice volumes are broadly consistent with some recent new evidence: (*i*) far-field evidence of sea level low-stands imply more ice on earth than formerly thought, (*ii*) relative sea level curves from glaciated regions do not normally cover the late glacial period, and, hence, potentially underestimate the volume of ice at LGM, (*iii*) the Arctic ocean *may* have been covered by an ice shelf, and (*iv*) direct glacial-geological observations of ice sheet extent have modified prevailing perceptions of ice sheet volume (*e.g.* the Innuitian Ice Sheet is now commonly accepted). However, key aspects such as the height and evolution of individual paleo-ice sheets cannot be traced in proxy sea level data, yet have a significant impact on climate models. Potential records of the paleotopography of Northern Hemisphere ice sheets are found in formerly glaciated areas in northern Sweden, western Norway, Scotland, and eastern Canada. In these locations, features such as the upper limit of glacially eroded bedrock surfaces (trimlines) and differences in rock 105 yr) in quartz exposed to cosmic radiation provides a means of determining the amount of time the rock has been at or near the ground surface. Because nuclide production decreases with depth, removal of two or more meters of irradiated rock during one glacial event will create a zero age surface. In this context, areas known to have been ice covered should have exposure ages equivalent to deglaciation if they were significantly eroded by ice and older exposure ages if they suffered limited erosion or were completely protected. Ice cover of 10m or more shields the underlying rock surface from most cosmic radiation, so areas that undergo multiple cycles of ice sheet overriding but no erosion should accumulate 10Be and 26Al cosmogenic nuclide concentrations equivalent to the sum of the ice free periods, minus decay during periods of ice shielding.

Patches of relict landform assemblages were identified in the northern Swedish mountains through extensive field and air photo mapping. Quartz-rich samples for cosmogenic radionuclide analysis were collected from bedrock outcrops and erratics in mapped relict patches. Erratics confirm that the sites were overridden by ice and were dated to determine whether they were deposited during the last glaciation. Bedrock in relict patches was sampled to determine whether these sites were in fact eroded during the last glaciation (to give a deglacial exposure age) or whether they are relict (exposure ages reflect both post-glacial time and inheritance from one or more previous ice-free period).

Our results from erratics provide deglaciation ages and indicate that relict patches have been covered by ice during the last glaciation. Bedrock samples from the same relict patches provide much older cosmogenic ages suggesting insufficient glacial erosion and hence preservation of weathering (weathering zones) have been interpreted as indicators of former ice sheet height. This interpretation has been questioned by others who have argued that such features may reflect internal thermal boundaries between wet (warm-) based erosive ice and dry (cold-) based ice that is effectively non-erosive. Resolving this issue is critical because of differences in predicted ice sheet configurations. For example, a large and thick late Weichselian Fennoscandian ice sheet (FIS), as opposed to a much thinner, and possibly multidomed, late Weichselian ice sheet.

these patches during multiple ice overriding events. Relict patches therefore appear to represent areas of frozen bed conditions at the base of the FIS supporting the current swing in opinion toward the idea that, under given boundary conditions, ice sheets are landscape *'preservers'* rather than *'destroyers'*.

Origin of the Neolithic Alpine Iceman: constraints from isotope geochemistry

W. Müller, H. Fricke1, A.N. Halliday2, M.T. McCulloch and Jo-Anne Wartho 3

1Department of Geology, Colorado College, Colorado Springs, CO 80903, U.S.A.

2Department of Earth Sciences, ETH Zürich, CH-8092 Zürich, Switzerland

3Department of Applied Geology, Curtin University of Technology, Perth, Australia

The discovery of a perfectly preserved late Neolithic human mummy in a glacier at the main Alpine ridge in northern Italy during autumn of 1991 was a truly unexpected finding. The 'Iceman' turned out to be ~5200 year old, and was found in-situ, i.e. outside an arranged burial site, together with his entire equipment. This finding thus provided the unique opportunity to investigate circumstances of 'real' life during the late Neolithic. One of the remaining open questions concerns the Iceman's origin, particularly regarding his early life. Did he grow up in the vicinity of the finding site or did he migrate to the area during his adulthood, i.e. was he a local or migrant? Because of the lack of pottery amongst the Iceman's equipment (substituted by more appropriate lightweight equipment such as birch-bark containers), his assignment to a contemporaneous culture either north or south of the Alps based on pottery typology was impossible. Here we utilize isotope geochemistry to answer the questions of origin and migration of the Iceman.

Combined radiogenic (Sr, Pb) and stable isotopic (O) analysis of a comprehensive suite of samples formed at different ontogenetic stages during the Iceman's life was conducted in order to unravel his origin and migration, both regarding his child- and adulthood. Investigated samples included enamel of three teeth, dentine, cortical and trabecular bone and intestine content. Soils from contemporaneous archaeological sites, river waters and modern human teeth were used for comparison. The oxygen isotope record of the Iceman's biominerals is consistent only with his southern origin, both valid for his childhood (enamel) and adulthood (bone). Areas north of the finding site (e.g. Ötztal) can be excluded. Based on Sr and Pb isotopes, the Iceman grew up on soils above gneisses and phyllites ('crystalline basement'), whereas carbonate or volcanic soils can be excluded (Fig. 1). This makes him a member of the local population from childhood onwards, as the former lithologies mainly occur close to the finding site. The isotopic compositions of bones suggest a different food source during his last ~10 - 20 years of life, and indicate the Iceman's migration during later life. This is currently investigated further, also using single grain 40Ar/39Ar ages of white micas recovered from the Iceman's intestine, as K/Ar and 40Ar/39Ar white mica ages vary considerably in the area under investigation, mainly as a result of strongly variable metamorphic overprint following the Alpine orogeny. The small difference in _18O between enamel and bone indicates that the Iceman did not spend protracted periods of his later life at elevated altitudes, for example in the southern Ötztal area, as in this case his bone oxygen should be isotopically significantly lighter.

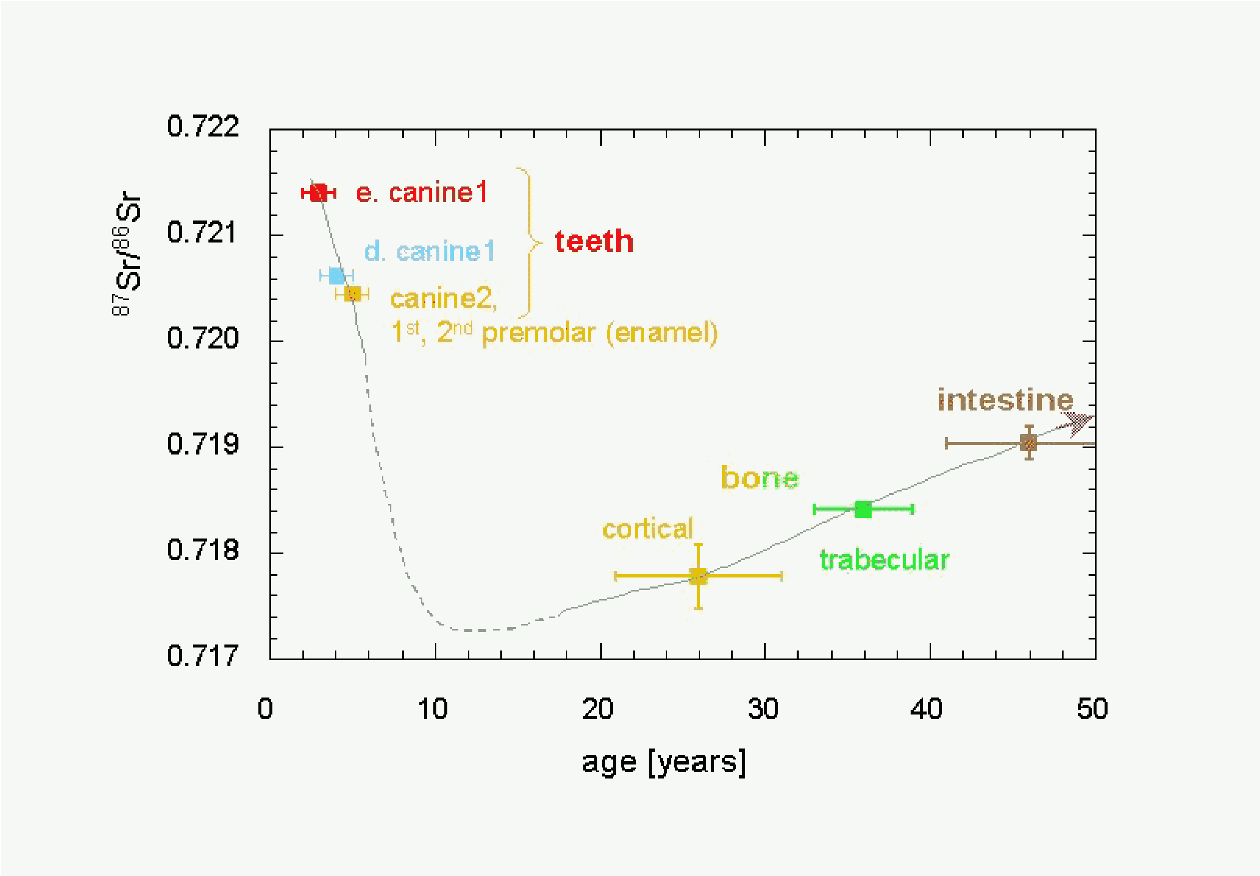


Fig. 21: Diagram of Sr isotopic ratio vs. biological age of the Iceman. The different biominerals and the intestine content clearly record different Sr isotopic compositions for the various ontogenetic stages of the Iceman. The contrasting Sr isotope values for childhood and adulthood suggest migration of the Iceman during later life. e. ... enamel, d. ... dentine.

Reconstruction of past ocean temperatures and seawater chemistry by means of molecular biomarkers and isotope studies.

C. Pelejero, E. Calvo, S. Eggins and M.T. McCulloch

Since the beginning of the Industrial Revolution, burning of fossil fuels has increased the atmospheric CO2 content from ~280 to almost 370 ppmv, a level unprecedented in the last 420,000 years. This excess atmospheric CO2 is largely absorbed by the oceans, which are one of the main carbon reservoirs of our planet, basically due to the high solubility of CO2 in seawater and biological processes that transfer carbon from surface into deep waters. However, the capacity of the oceans to respond to this large amount of anthropogenic CO2 is still not known.

A multi-proxy approach to evaluate the role of the oceans in absorbing CO2 is being carried out by means of molecular biomarkers and isotope studies of marine sediments south of Australia, namely C37 long chain alkenones and boron isotopes ((11B). Alkenones are compounds specifically synthesized by phytoplanktonic Haptophyta algae and are characteristic biomarkers in sediments from all oceans. Their relative abundances, expressed as the UK37 index, show a close relationship with the temperature of the waters where these compounds were biosynthesized, forming the basis of a well established paleothermometer for marine waters (Figure 1). So far, the UK37 method has been set up at Geoscience Australia where a recently acquired Dionex Accelerated Solvent Extraction device (ASE 2000) has been optimised for this purpose, allowing a more rapid sample extraction, increased automation and lower solvent consumption and exposure. Apart from estimating paleo-sea surface temperatures (SST), these compounds are also taken as qualitative indicators of paleo-marine productivity as well as paleo-pCO2 (through the analysis of the carbon isotopic composition, (13C, of these alkenones).

On the other hand, the response of seawater pH to past changes in atmospheric CO2 will also be addressed by means of the analysis of boron isotopes on foraminifera and corals, given that seawater B isotopic composition changes with pH. Data on (11B will be obtained by means of multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS). In this sense, the new Finnigan Neptune MC-ICP-MS set up at RSES, which provides near constant mass fractionation and high precision, is being optimized to obtain a robust method to routinely analyse boron isotopes.

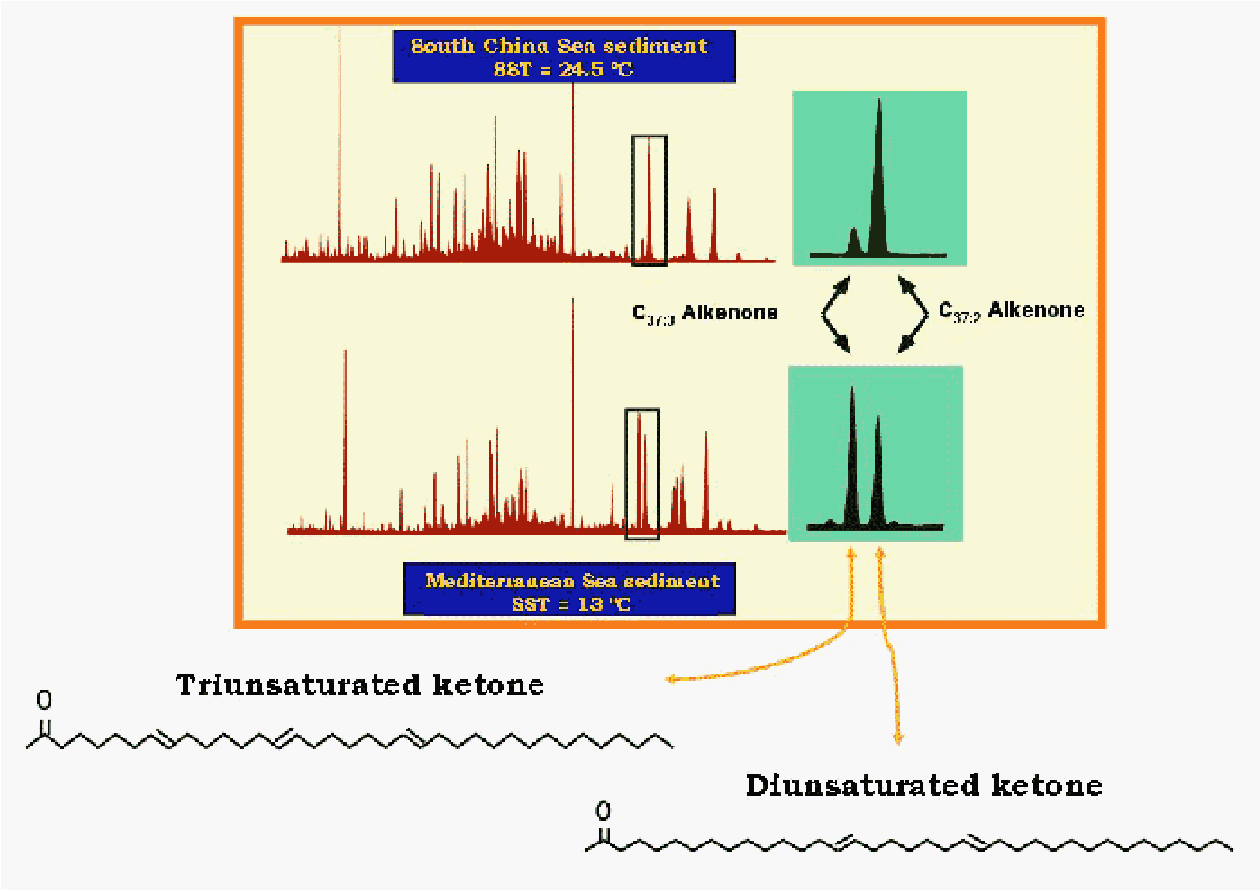


Figure 22: Representative Gas Chromatography chromatograms of two deep sea sediments from the South China Sea and the Mediterranean Sea depicting the different alkenone pattern.

Subdividing the Pleistocene using the Matuyama-Brunhes boundary (MBB): An Australasian Perspective

Brad Pillans

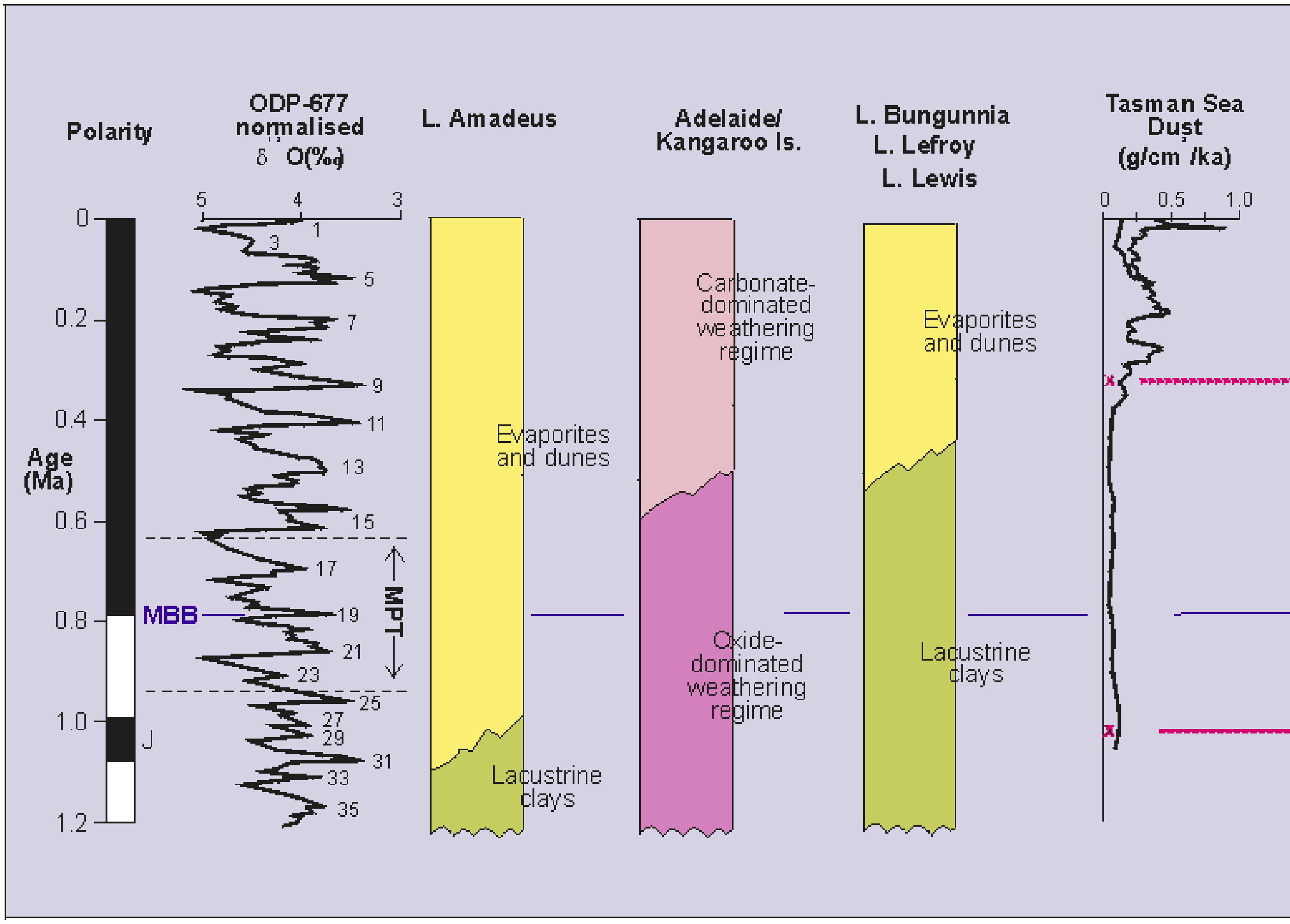
The last major polarity reversal of the Earth's magnetic field, known as the Matuyama-Brunhes polarity transition or reversal, has long been used as a chronostratigraphic marker in Pleistocene studies. The Matuyama-Brunhes boundary (MBB), dated at 0.78 Ma, has been identified globally in both marine and continental sequences and is also a key

In Australia, the MBB is identified in many continental sequences, particularly saline lake basins. A major arid shift in paleoclimate is interpreted to have succeeded the MBB at sites including Lakes Lewis (NT), Lefroy (WA) and Bungunnia (NSW), as well as in southern South Australia (Adelaide and Kangaroo Is.), and is also evidenced by increased aeolian dust concentrations in Tasman Sea cores (Fig. 1). At Lake Amadeus the arid shift predates the MBB, perhaps as a result time marker for the chronology of human evolution and migration. It has gained wide acceptance as the boundary between the Lower and Middle Pleistocene, although it has never been formally defined as such. A working group of the international Subcommission on Quaternary Stratigraphy is currently considering the status of the boundary.

In New Zealand, the MBB is precisely located in shallow marine sediments of Wanganui Basin, where it corresponds with the base of the New Zealand Putikian Substage. A combination of marine biostratigraphy, sequence stratigraphy and tephrostratigraphy permit correlation from Wanganui Basin to other on-land sections and deep-sea cores (Fig. 1). Major loess/paleosol sequences, in both islands of New Zealand, post-date the MBB.

of differing responses to regional and local hydrologic thresholds.

During the period from about 1 to 0.6 Ma there is a marked change from 40 ka to 100 ka cyclicity in oxygen isotope records from deep-sea cores, often called the Mid-Pleistocene Transition (MPT) Fig. 1. Placement of the Lower-Middle Pleistocene boundary at the MBB, which occurs in the middle of the MPT, would constitute a widely recognisable chronostratigraphic marker in both marine and continental deposits.



Stratigraphic and correlation diagram showing Geomagnetic Polarity Time Scale, deep-sea oxygen isotope record and summary paleoenvirnmental records from Australia and New Zealand. MBB = Matuyama-Brunhes boundary. MPT = Mid-Pleistocene transition

Barbados 80,000 and 100,000 year interstadials

E-K. Potter, T. Esat, K. Lambeck and M.T. McCulloch

Dating of coral outcrops at Barbados was carried out on the two major sea-level high stands immediately following the Last Intergalical. The data show a surprisingly long duration for both events extending up to over 10,000 years. The nominal 80 ka interstadial appears to be composed of two sea-level high-stands separated by approximately 3000 to 4000 years. There is a hint of a similar structure for the 100 ka interstadial. Multiple sea-level high-stands point to unexpected climate variability during the late part of marine Isotope Sub-Stage 5, reminiscent of climate instability observed for the last glacial period.

Uranium Isotopes in the Oceans

L. Kinsley, G. Mortimer, T. Esat and M.T. McCulloch

We have determined the operating characteristics and the precision obtainable from the newly acquired Finnigan multi-collector inductively-coupled mass spectrometer 'NEPTUNE' in measuring and lasted for 1_ hours. The 235U/238U ratio with 235U measured in a Faraday cup and in the electron multiplier (SEM) provided a direct calibration for the SEM gain, including any non-linearities, except for a correction in dead-time between different count-rates of 234U and 235U. The use of 235U for SEM calibration restricts the usable signal intensity to about uranium isotopes. Such a measurement places high demands on instrument performance as the isotope ratio of interest is small ~5x10-5 and susceptible to small amounts of interfering molecular beams. It involves combined use of Faraday-cups and an 'electron-multiplier' and the accounting for, or elimination of tailing from intense 238U beams. In addition, there appears to be a discrepancy in the U isotopic composition between modern corals and sea-water. We have determined the U isotopic composition of sea-water to help resolve the difference.

Data collection consisted of 30 2-second simultaneous integrations of 234U, 235U 238U, a peak jump, and 10 2-second integrations of 235U and 238U. Each experiment included 10 cycles of 6 blocks 2 volts 238U (1011 Ohm) so as not to overload the SEM.

The present results show that the isotopic composition of uranium can be measured to a precision better than 1 with Neptune SEM and retardation lense in a reproducible fashion. The instrument, and the particular measurement technique used, can achieve this independent of beam intensity. The measured 234U/238U ratio for the standard is identical to the secular equilibrium value (5.467x10-5). Indicating that standard 'ALH' is in secular equilibrium and also that the instrument can provide absolute values of this ratio when appropriately calibrated. Uranium isotopic composition of 'modern' sea-water is indistinguishable from uranium isotopic composition of 'modern' corals within the analytical precision.

The previously determined mean sea-water value of 144±2 (Chen et al., *EPSL* ***80***(1986)241) should be revised to ~148.4±0.5 in close agreement with the modern coral value of ~148-149 .

References

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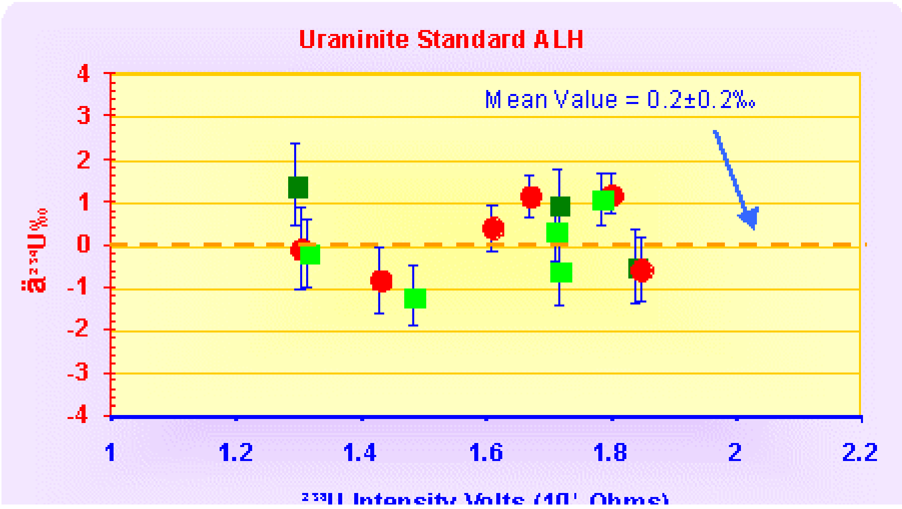


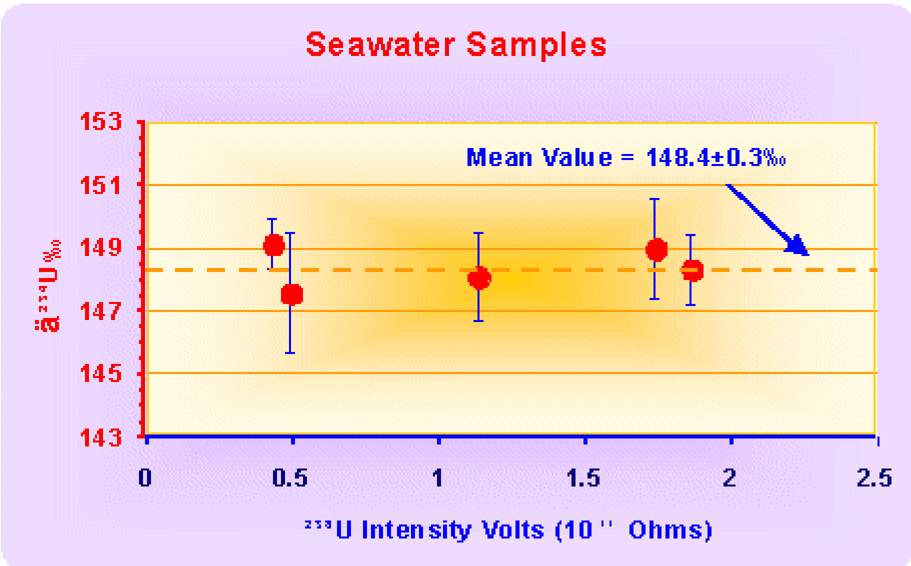


Figure 13: Results for the isotopic composition of uraninite standard 'ALH', assumed to be in secular equilibrium, are shown here. The 14 determinations over a period of two months yield a mean close to zero, relative to the secular equilibrium value of 5.467x10-5. This is a direct determination with Neptune without reference to any other standard.

Figure 14: Uranium from 50 to 100 ml seawater samples was extracted by co-precipitation with iron chloride and the Fe removed by ion-exchange. The results shown here (relative to 5.4709x10-5) are internally consistent and very similar to those measured in modern corals

River channels and floodplains of two coastal rivers, NSW

P. Rustomji

During 2002, significant progress has been made on the collection and analysis of geomorphologic data from two river catchments along the NSW coast, namely the Macdonald and Tuross Rivers. Both catchments are of about 2000 km2 in size, have highly confined floodplains, similar landuses, and climatic regimes, yet appear to have undergone different geomorphic evolution throughout the twentieth century despite similar climatic histories (though with different flood histories).

Along the Macdonald River, topographic surveying of the channel and associated flood plains has allowed clarification of the relationship between discharge events of various return periods and the various flood plain units evident in the valley. The sediments of the various morphologic units have been studied and described, and samples collected for OSL dating, which is underway. In addition, hydraulic modelling exploring boundary shear stress and mean stream power rates under various channel morphology and flow scenarios has begun, leading to estimates of the magnitude of these variables associated with different geomorphic processes such as bench accretion, minor channel scour and major bank erosion.

On the Tuross River, similar topographic surveying has been conducted on the channel and associated flood plains. The present day thalweg of the Tuross River from the lowest bedrock bar to mean sea level displays a concave upwards profile, which differs from the generally straight profile found along the Macdonald River. In addition, the Tuross River has a cobble bed along the upper lengths of the study reach (a feature absent along the lower Macdonald River). The relationship of this cobble bed to the flood plain units is under investigation. In a similar fashion to the Macdonald River, a number of morphologic flood plain units are evident along the Tuross River, each with a characteristic sedimentary profile. Sediment samples have been collected for OSL dating and being processed.

Striking similarities in flood plain stratigraphy and morphology occur between these two river systems. They share a high level alluvial bar feature with flood basins on their distal sides, and a lower alluvial bench unit apparently inset within this high level bar. Along both rivers, the high alluvial bars have similar sedimentology, consisting of fine to medium sands, dark grey to brown in colour, whilst the inset benches are commonly yellow sands with clearly defined dark horizons of finer sediments separating sand layers. The OSL dating of these features may indicate whether or not the formation of these morphologically and sedimentologically similar alluvial deposits was synchronous in time.

High resolution trace element and oxygen isotope ((18O) analyses of a modern speleothem

P. Treble

Annual resolution of speleothem proxy climate records is an attractive goal in Quaternary palaeoclimate studies. This is now attainable following advances in LA-ICP-MS and SIMS technology. In this study, 5 and 32 micron spatial resolution LA-ICP-MS trace element data were acquired alongside 20 micron resolution SIMS 18O data for a modern stalagmite from the Margaret River region of southwestern Australia.

The trace element data show clear cycles of positively correlated Sr, Ba, U, P and Na concentrations that are negatively correlated with Mg concentrations (Figure 23). These cycles are known to be annual since the age of the stalagmite is well-constrained by the date of placement of the cave tourist boardwalk on which it grew (1911-1992). These findings support earlier studies using lower resolution SIMS data (Roberts et al., 1998; Huang et al., 2001; Fairchild et al., 2001).

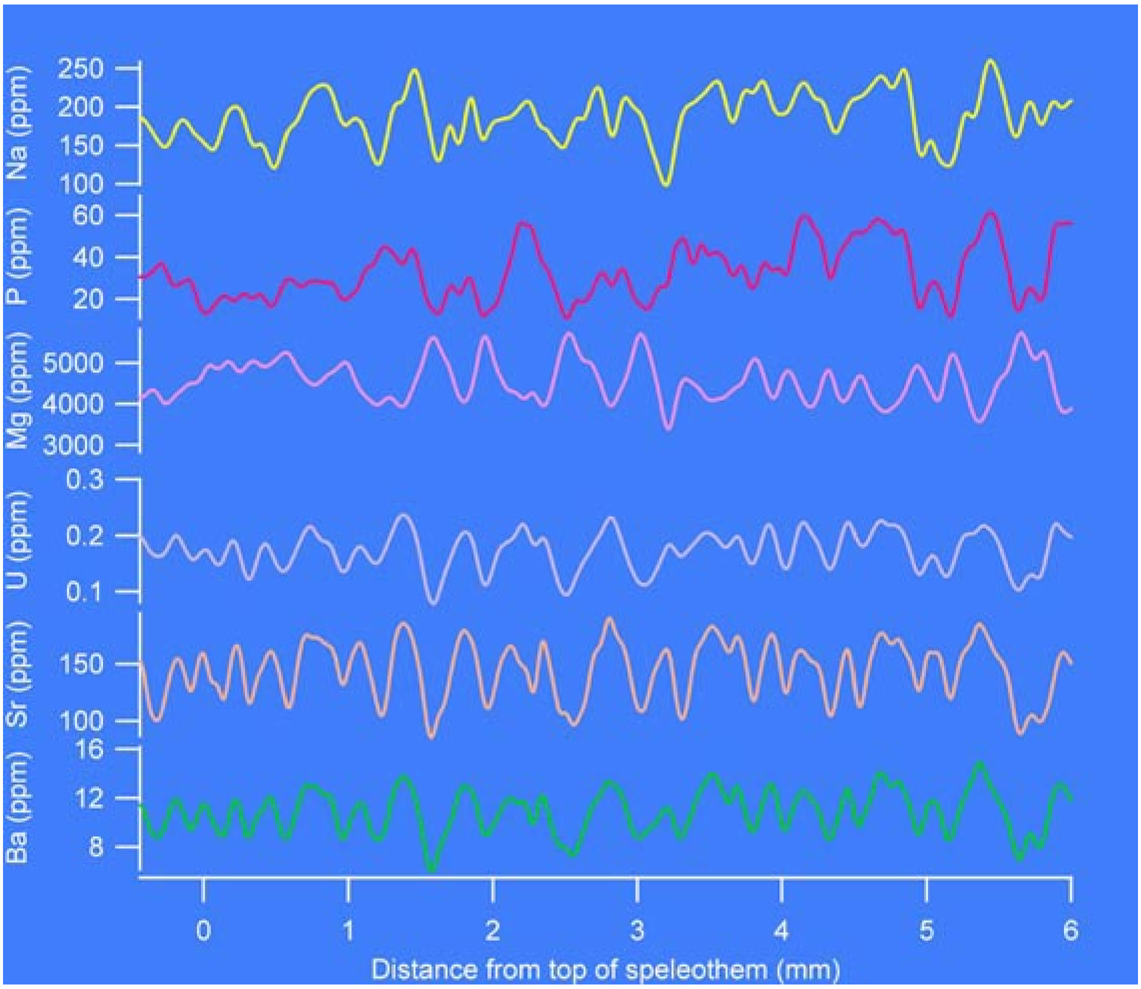


Figure 23: A portion of annual trace element cycles for the modern stalagmite from southwestern Australia.

ue to this study, the relatively fast growth rate, (approx. 350 ons per year) has enabled SIMS δ18O analyses to be performed gside a portion of the trace element data using the Cameca 270 ion microprobe at the University of California, Los Angeles, llaboration with Profs Mark Harrison (RSES, ANU), Kevin eegan (UCLA) and Dr Marty Grove (UCLA). These 18O data show an annual cycle of approximately 1, in sympathy with the magnesium concentratio variations. 18O is the most commonly used proxy in speleothem palaeo-environment reconstructions and is also the best tracer hydrological processes.

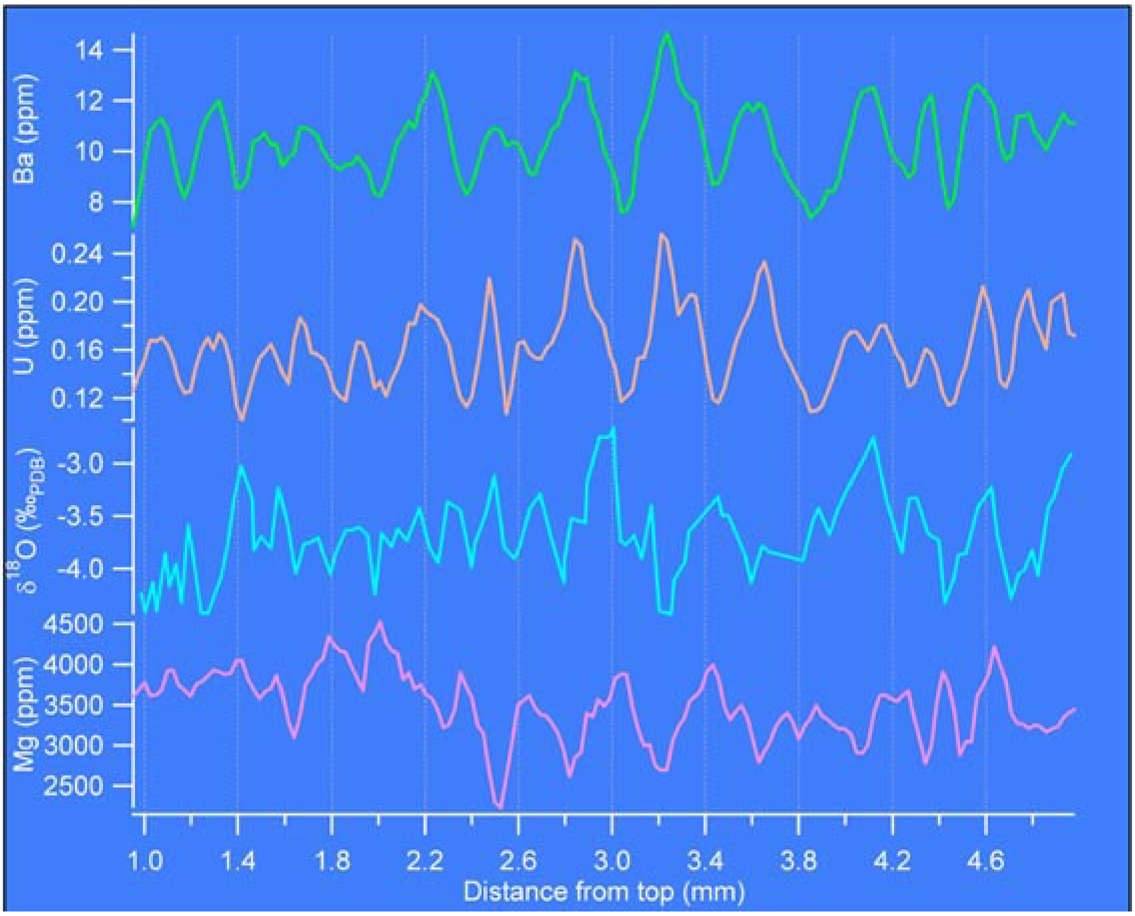
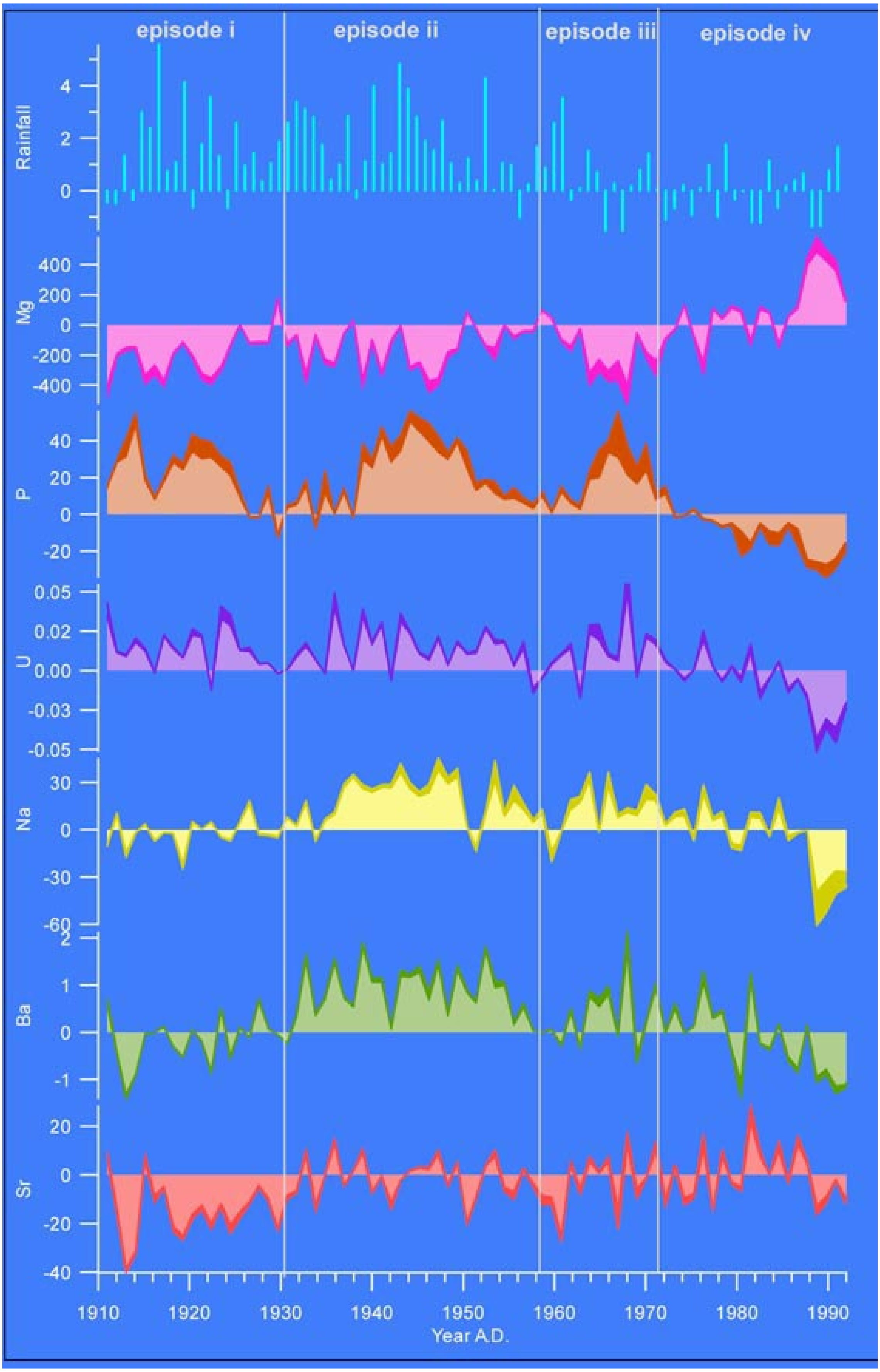


Figure 24: Annual cycles of (18O, Ba, Mg and U.

superior age control provided by the cave tourist boardwalk ther with the excellent annual growth rate control provided by race element data, make this sample ideal for conducting a ous examination of the trace element and 18O cycles with the umental climate data. This should bring us closer to decoupling the cave temperature and precipitation signal in speleothem records, and thus verification and validation of thes climatic proxies. To date, these trace element cycles have been stacked into a master record which allows the proxy data to be compared with the instrumental rainfall record (Figure 25).


episode i
episode ii
episode iii
episode iv
Rainfall
Mg
P
U
Na
Ba
Sr
Year A.D.
1910
1920
1930
1940
1950
1960
1970
1980
1990

re 25: Comparison of stacked maximum values of Ba, Sr, U, Na and P (and minimum Mg) occurring for each year with the amount of er rainfall (June-August). All element values have the mean of the period A.D.1961-1992 subtracted while rainfall is standardised (by racting the mean and dividing by the standard deviation). Darker envelopes represent the standard error of stacked master record.

hwestern Australia has suffered a dramatic 20% decrease in all since ~A.D.1965. To examine the response of the trace nents to this rainfall shift, variations are conveniently compared ur episodes: (i) pre-A.D.1930, (ii) A.D.1931-1956, (iii) A.D.1957-) and (iv) A.D.1970-1991. Figure 3 shows that Mg, P and U in cular, resemble many features of the rainfall record suggesting Mg, P and U may be useful palaeo-hydrological indicators. Ba, nd rainfall show similar trends during A.D.1930-1992, with er values during A.D.1931-1956 (ii), however the trend rds lower values after A.D.1970 (iv) is not as clear as it is for U, d Mg. Ba, Na and also Sr shows an opposite trend to rainfall r to A.D.1930 (i), where Ba, Sr and Na are all below the mean rainfall is above the mean. Overall, Sr shows the least resemblance to the rainfall record. Investigation of the promising behaviour of annually resolvable speleothem trac elements and (18O as palaeoclimate proxies is ongoing.

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Fairchild, I. J., Baker, A., Borsato, A., Frisia, S., Hinton W., McDermott, F. and Tooth, A. F. (2001) Journal of th Geological Society, London, 158, 831-841.

Conodont Geochemistry - proxies for understanding palaeoenvironments, bio-events and geo-events of the Palaeozoic

J A Trotter

The ubiquity and biostratigraphic significance of conodonts underscore their potential importance for geochemical studies, especially as potential recorders of past oceanic composition, with the aim to better reconstruct and understand palaeoenvironmental change during the Palaeozoic and early Mesozoic. They have great potential to help define the processes that were operating in palaeoceans, both regionally and globally, particularly in the context of bio- and geo-events, and thus the driving forces that determine the evolution of life. Understanding extinction events and the processes controlling life during Earth history has immediate implications for present and future life on Earth.

Despite the increasing focus on conodont apatite for such studies, their reliability as proxies of ambient seawater chemistry has been questioned by the geochemistry and palaeontology communities due to issues of data reproducibility and internal consistency, and is therefore yet to be effectively demonstrated. Chemical systematics of marine biogenic apatite in general is not well understood due to the lack of rigorous and systematic investigations to address potential diagenetic effects. Studies to date incorporate many assumptions on the integrity of conodont tissues and are based on bulk specimens of which details regarding taxonomy and morphology are generally lacking, yet are likely to have significant implications for the integrity of data generated. Detailed and high resolution geochemical studies are therefore required to determine the significance of such variables (including histology) that have been thusfar overlooked, to address these critical issues of sample and data integrity.

This study aims to determine the suitability of conodont apatite as a recorder of ambient seawater chemistry and the criteria to discriminate primary geochemical signatures from secondary effects and background noise. A multi-proxy approach of trace element and isotope geochemisty using an array of high-resolution instrumentation are being applied to key intervals through the Ordovician and Early Silurian to identify potential relationships between climate cycles, tectonics, fluxes in ambient seawater chemistry and the biosphere. Initial work has produced continuous, high-resolution chemical profiles of different components within single conodont elements using in-situ laser ablation ICPMS. Systematic variations in the chemistry of the component tissues have been recognised and related to conodont ultrastructure (SEM), and have significant implications for the integrity of conodont tissues and sampling strategies for further conodont geochemical studies. Current work is also utilising Transmission Electron Microscopy, Laser Raman Spectroscopy, Electron and Ion Micropobes and MC-ICPMS, targeting specific tissues to assess their chemical and isotopic heterogeneity, preserved textures, and relative susceptibility to diagenesis.

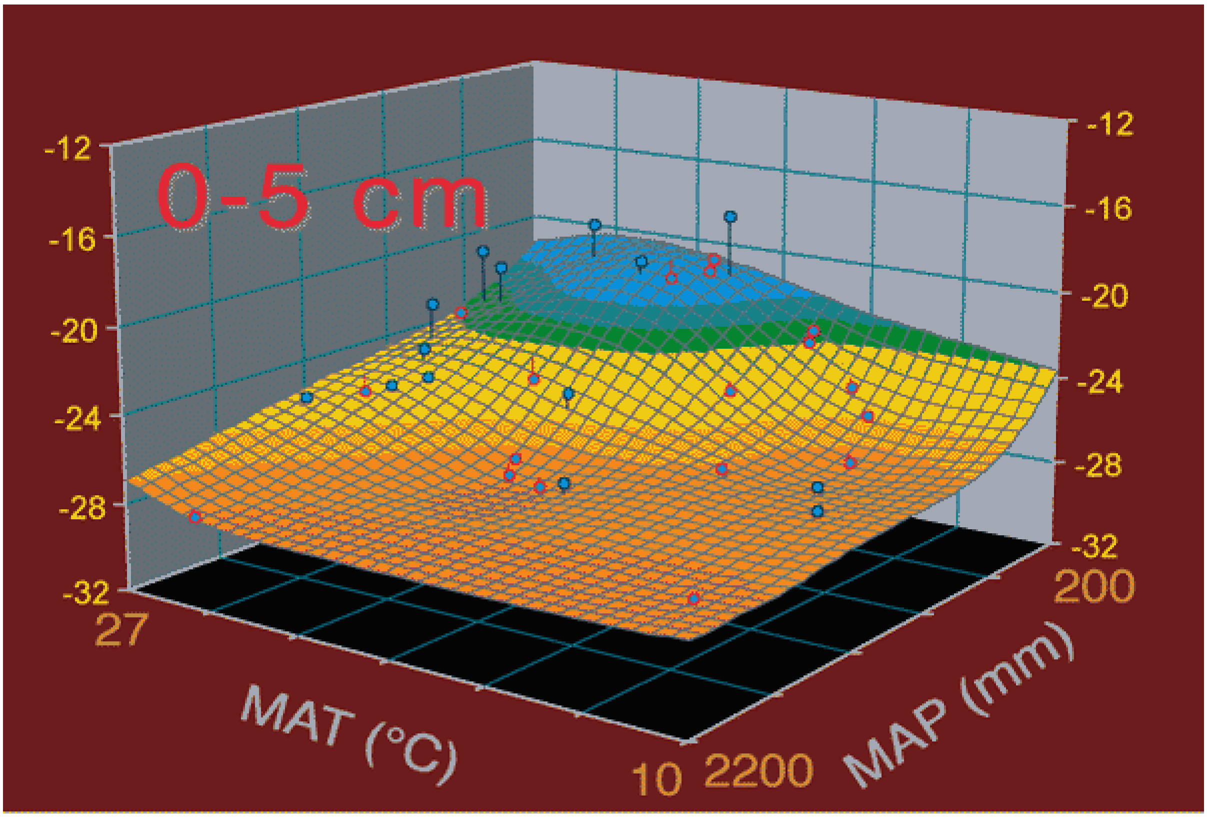
Continental-scale Organic Carbon and Carbon Isotope Inventory of Australian Soils.

J.G. Wynn, M.I. Bird, L. Vellen, J. Cowley, D. Barrett1 and J. Carter2
1 CSIRO, Plant Industry
2 QDNRE

Program B2(c) of the CRC for Greenhouse Accounting (Wynn & Bird, RSES, EE) has completed a continental-scale inventory of soil organic carbon (SOC) storage in well-drained sandy soils of the Australian continent. The SOC reservoir is known to vary spatially with primary variables of climate, texture, drainage, and vegetation conditions, which have all been addressed by this study to date. Early phases of this project developed a sampling and carbon analysis program for the determination of SOC and 13-Carbon pools on a continental scale, which is based on a stratified sampling methodology and simplified analytical techniques. The current analytical phase of this project has completed work on soils of coarse texture (sandy) in well-drained conditions, and established relationships of two depth-specific SOC pools to climatic conditions, while also taking into account the local variability with respect to the distribution of trees and grass (Figure 26). Forty three sites have been sampled across a wide range of climate regimes and analysed for percent organic carbon and _13C, among other key soil physical and chemical properties. Subsequent analysis has produced best-fit empirical relationships of the 0-5 cm and 0-30 cm pools of SOC and 13-Carbon isotopic ratios to mean annual temperature and mean annual precipitation, such that greater than 70 percent of the variance measured can be attributed to climatic constraints.

Although simple regression analyses shows good correlation with the observed data, these simple relationships do not allow one to explore more complex issues such as the effect grazing pressure, wind transport, or other factors affecting soil carbon input or output. In order to do so, we are employing conceptual models, such as the Century 4 model being used by J. Carter (QDNR), in conjunction with the model's design team (Dr. Bill Pardon), or the VAST model being developed by D. Barrett (CSIRO). The data set provided by this study is of great utility in both model validation and parameterization of these carbon cycle models.

Current research of this project is under way to assess the variability of SOC and 13-Carbon with soil textural conditions (particle size distribution), by analysis along soil texture gradients within specific climatic regions. The next analytical phase (Feb.-Jun. 2003) will continue with 14-Carbon analysis of SOC in order to establish turnover time of the SOC pool.



gure 26: Measured and modelled stable carbon isotopic composition (vertical axis, PDB scale) of the soil organic carbon pool at 0-5 n depth across the Australian sites measured. MAP = mean annual precipitation (mm); MAT = mean annual temperature (°C). Simila lationships can be defined for total SOC, and the 0-30 cm depth interval. Simple equations can be fit to the observations by least- juared regression, with R2 values > 0.7.

Earth Materials

Rock Physics Introduction - Annual Report 2002

Geological and geophysical observations of the response of the Earth to naturally applied stresses, which vary widely in intensity and timescale, provide much of the motivation for the Rock Physics Group's work. In the laboratory, ultrasonic wave propagation and lower frequency forced-oscillation methods are used to probe the elastic/anelastic behaviour which determines seismic wave speeds and attenuation. On longer time scales and at higher stresses, the mechanical behaviour of synthetic faults and fault gouge is studied with particular interest in the complex interaction between chemical reaction, crustal deformation and fluid flow. The fact that all but the simplest elastic behaviour of geological materials is controlled by microscopic defects such as dislocations and processes operative at grain boundaries, places a premium on the complementary microstructural studies involving light and electron microscopy.

Members of Rock Physics collaborate widely within RSES and beyond. Natural links with the Seismology Group are based on a common interest in the interpretation of seismological models for the Earth's interior. Preparation of synthetic rock specimens and their precursors and investigations of melt distribution within partially molten upper mantle rocks involve intensive collaboration between the Rock Physics and Petrochemistry and Experimental Petrology Groups under the banner of Earth Materials. The field-based observations of the structures and microstructures in naturally deformed rocks, and fluid-chemical studies by members of the Centre for Advanced Studies of Ore Systems (RSES and Geology Department, Faculty of Science), complement the experimental program in rock deformation.

Profs Ian Jackson and Stephen Cox are the long-term academic staff in Rock Physics. Their successful operation of novel equipment, and the further development and timely exploitation of associated experimental techniques, depend heavily upon the skill and commitment of research support staff Messrs Harri Kokkonen and Craig Saint and Ms. Lara Weston along with the staff of the School's Mechanical and Electronics Workshops. Mrs Kay Provins provides the critical administrative support for Group, including responsibility for website development and maintenance. These staff also support Drs Ulrich Faul, Stephen Micklethwaite and Eric Tenthorey who are engaged in postdoctoral research programs detailed throughout Rock Physics pages. The Group pursues this ambitious research agenda using core funding from RSES boosted by several ARC-funded projects.

Within the wider ANU community, the influence of the Rock Physics Group is felt in a variety of forums. For example, the ANU's flagship TEM which serves the needs of the campus materials science community is housed within the School and operated by John Fitz Gerald and David. Llewellyn on behalf of the ANU Electron Microscope Unit.

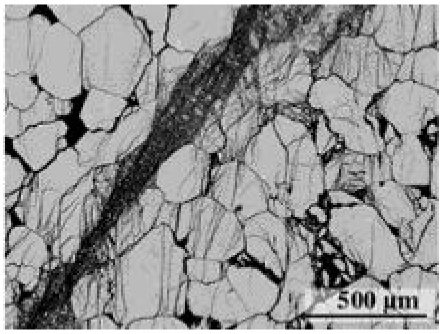
The group also is committed to undergraduate and graduate teaching, and for many years has participated in the CSIRO Student Scheme with Canberra secondary schools.

Research topics

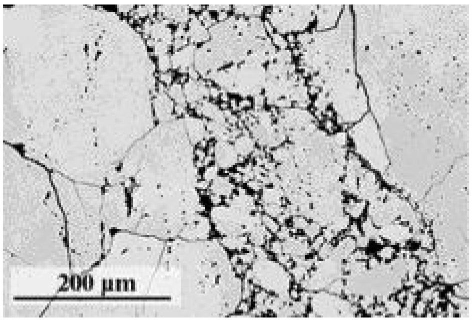
Evolution of strength recovery and permeability during fluid-rock reaction in experimental fault zones

Eric Tenthorey, Stephen Cox and Hilary Todd

Physical and chemical fluid-rock interactions are implicated in controlling earthquake nucleation and recurrence. In particular, interseismic compaction, sealing and healing of fractured fault rocks can lead to strength recovery and stabilization of fault zones. In contrast, these same processes can also assist increases in pore fluid pressures and consequent destabilization of faults. In 2002 we completed a series of high temperature, hydrothermal experiments designed to assess the evolution of strength of fault zones in previously intact rock, and also characterize the associated changes to porosity and permeability. In the experiments, cores of Fontainebleau sandstone were initially loaded to failure in a high-pressure gas-medium apparatus. The failed specimens were then hydrothermally reacted at 927°C for variable duration under isostatic conditions, and subsequently re-fractured to determine the "interseismic" strength recovery. In the most extreme case, hydrothermally-induced gouge compaction, cementation and crack healing resulted in 75% strength recovery after reaction for 12 hours. Isostatic hydrothermal treatment also resulted in dramatic reduction in porosity and permeability. Strength of the fault zone following hydrothermal reaction appears to be closely correlated to porosity, consistent with previous studies on brittle failure of porous aggregates. The experimental results show how hydrothermal reactions in fault zones may lead to two competing, time-dependent effects; fault strengthening due to increased cohesion in the fault zone and fault weakening arising from elevated pore pressures within a well cemented, low permeability gouge layer.



Fault zone created due to loading of intact sandstone. The internal damage zone is composed of poorly-sorted, angular fragments containing abundant extension microfractures oriented parallel to the maximum principal stress.



Healed and sealed fault zone. Wear products within the damage zone are less angular and have undergone substantial densification and cementation. Extension microfractures in the surrounding rock have healed, leaving linear arrays of small fluid inclusions

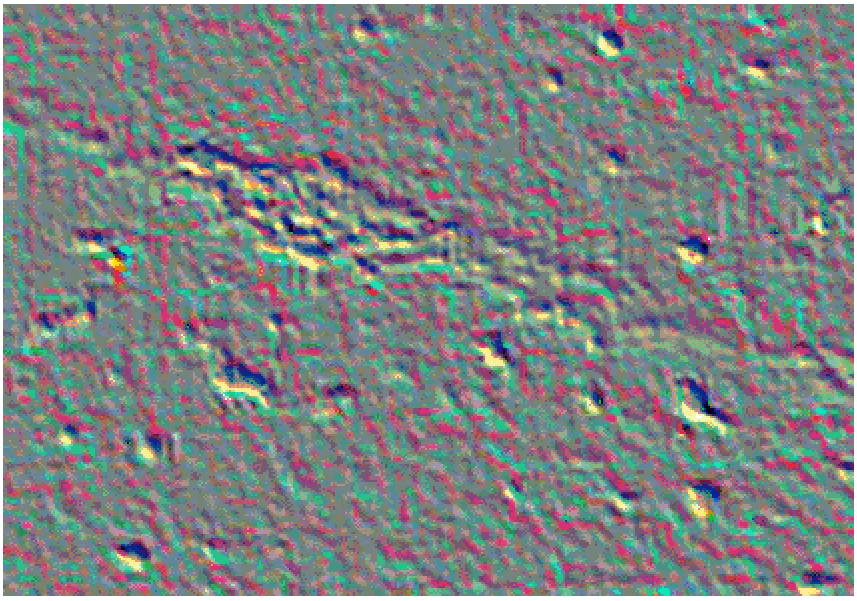
Publications & Abstracts:

Tenthorey, E., Cox, S.F. & Todd, H.F. (2002): Evolution of strength recovery and permeability during fluid-rock reaction in experimental fault zones. Earth and Planetary Science Letters, In Press.

Tenthorey, E., Cox, S.F. & Todd, H.F. (2002): Evolution of strength recovery and permeability during fluid-rock reaction in experimental fault zones. AGU Annual Meeting, San Francisco, USA.

X-Ray Microtomography of Porous Media

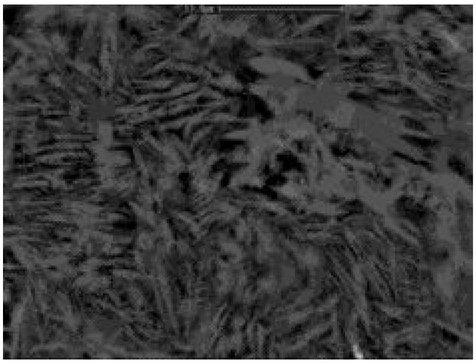
Eric Tenthorey and Stephen Cox



A 3D animation of a hydrothermally healed fault zone

Enhanced Permeability During Serpentinite Dehydration

Eric Tenthorey and Stephen Cox



Serpentine specimen that has dehydrated, leaving a mixture of olivine+talc.

Publications: Tenthorey, E & Cox, S.F. (2002): Enhanced Permeability During Serpentinite Dehydration: Experiments and Implications. In Preparation.

Quartz Vein Formation

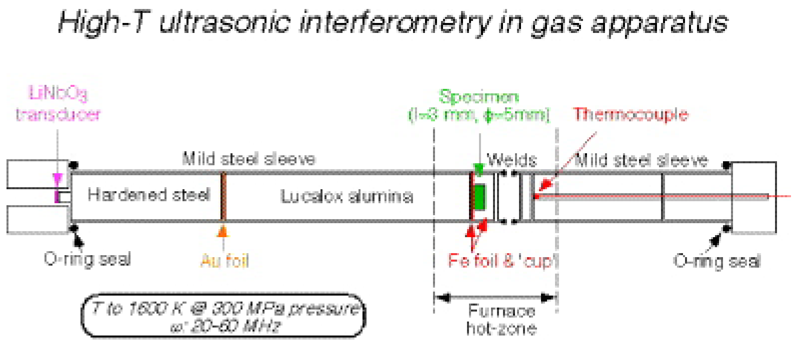
Christoph Hilgers, Eric Tenthorey, Stephen Cox and Janos Urai

In late 2001, the rock physics lab hosted Christoph Hilgers, a visiting researcher from RWTH-Aachen, Germany. Upon his arrival, a series of experiments were performed in which quartz interfaces were subjected to temperature gradients of up to 75°C, with the aim of understanding the physics of vein formation and the associated change to permeability. The experiments and data analysis were completed in the early part of 2002. In these experiments, trace metal concentrations showed that dissolution of quartz at the hot end of the specimen resulted in diffusion and precipitation of quartz at the cooler end. The presence of trace Fe and Al confirmed that the infilling of the original "crack" was in fact caused by sealing and not healing of quartz surfaces. One fluid flow experiment conducted at 700°C on a quartzite resulted in a large permeability drop over the course of the experiment.

Publications: Hilgers, C., Tenthorey, E., Cox, S.F. & Urai, J. (2002): Fracture sealing of quartzite under a temperature gradient: Experimental results. In Preparation.

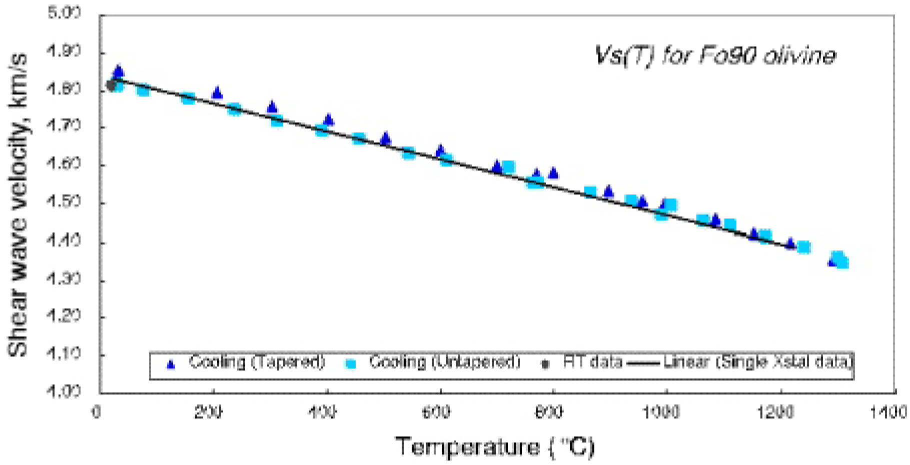
High-temperature elastic wave speeds by ultrasonic interferometry

Ian Jackson, Lara Weston and Simon Granville

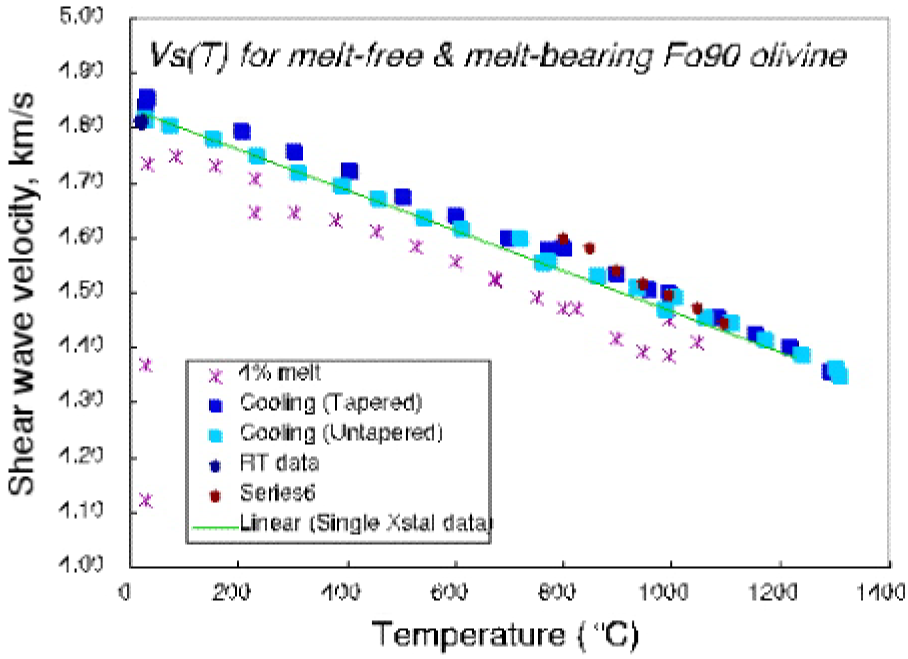


A compound acoustic buffer rod made of hardened steel and alumina provides an acoustic path that spans the temperature gradient between the transducer at ambient laboratory conditions and the specimen located within the hot zone of an internally heated pressure vessel. During the past year we have made two further refinements of the method intended to facilitate and streamline experiments on the necessarily small specimens (< 3 mm diameter) of high-pressure silicate minerals. The quality of the ultrasonic measurements is maximised when the echoes returning from the end of the buffer rod and from the far end of the specimen are comparable in amplitude. However, as the specimen diameter is reduced there is a systematic reduction in the amplitude of the echo returning from the far end of the specimen. During 2002 we have explored the possibility that a corresponding reduction in the amplitude of the buffer echo might be achieved by tapering the end of the buffer rod down to 3 mm to better match our small specimens. Measurements on a dense fine-grained Fo90 olivine specimen of 3 mm diameter with a tapered buffer rod have demonstrated a significant improvement in echo amplitude ratio without a significant perturbation in wave speeds.

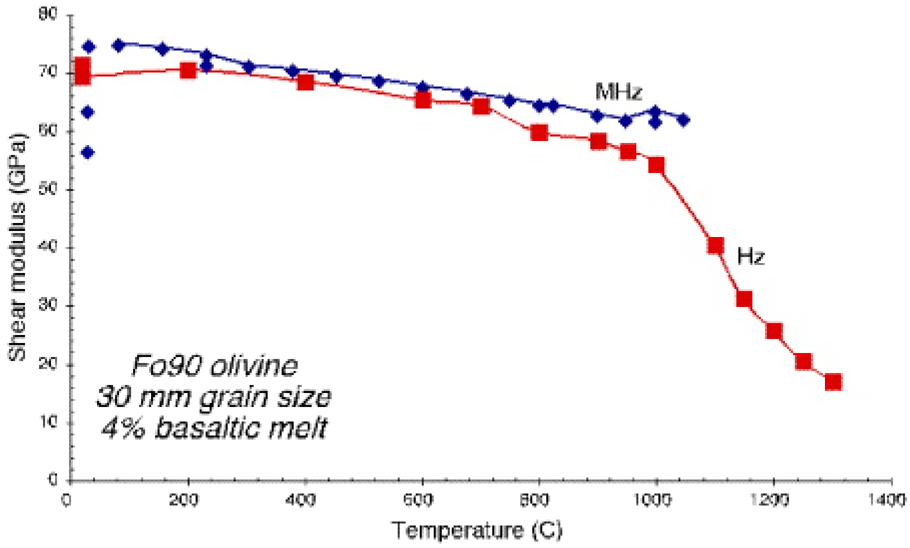
The second significant advance during 2002 was the trialling of a transducer capable of serving simultaneously as source and receiver for both P and S waves. Use of such a dual-mode transducer is advantageous because twice as much information is obtained during a given P-T cycle. Moreover, the P and S wave speeds thus measured apply to the same material under the same conditions – which cannot be guaranteed if the two wave speeds are measured in successive excursions to high pressure and temperature.



P and S-wave traveltimes were first successfully measured in this way in measurements on an Fo90 olivine specimen containing 4% added basaltic melt undertaken by Simon Granville as part of his Summer Research project. Signal quality was poor at temperatures above 1000¾C presumably as a consequence of the partial melting. For lower temperatures, satisfactory data were obtained – revealing VP(T) and VS(T) trends (*) parallel with those calculated from single-crystal elasticity data but lower by about 1% for P waves and 2% for shear waves. Sustained annealing of the specimen at 1300¾C followed by slow staged cooling largely eliminated this offset ( ).



Part of the motivation for this ultrasonic study of melt-bearing olivine was to allow a comparsion of high-temperature elastic properties measured at ultrasonic (20-60 MHz) and seismic frequencies (<1 Hz). Such a comparison for olivine with 4% basaltic melt reveals a consistent mild temperature dependence of shear modulus at MHz frequencies. The same is true of seismic-frequency torsional oscillation measurements on a similar specimen for temperatures below ~ 900¾C. At higher temperatures, however, the modulus measured at seismic frequencies becomes much more strongly temperature-dependent as a consequence of viscoelastic relaxation. These effects, although more muted at the larger mantle grain sizes, need to be taken into account in the interpretation of seismological models.



In the coming year we intend to apply these methods of high-temperature ultrasonic interferometry to small specimens of high-pressure silicate minerals. This work, to be performed in collaboration with colleagues from Stony Brook University and Delaware State University, will address key unresolved issues concerning the elasticity of the transition zone of the Earth's mantle including the magnitude of the mixed pressure-temperature derivatives of elastic moduli.

Experimental Petrology Group

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; ten solid-media piston-cylinder devices for generating pressures to 6 GPa and temperatures in excess of 2000ºC, some of which are large-capacity devices capable of synthesising relatively large volumes of high pressure phases for detailed mineralogical studies; a multi-anvil apparatus, which can achieve pressures of 26 GPa; and, through collaboration with the Department of Geology, the Faculties, a well-equipped hydrothermal laboratory. These high-temperature, high-pressure apparatuses are complimented by an array of microbeam analytical techniques, including electron microprobe, ion microprobe, laser-ablation ICP-MS, FTIR spectroscopy and visible-UV spectroscopy. The group has just taken delivery of a new electron microprobe, a Cameca SX100, which will be operated in collaboration with a consortium of other Canberra users. As well as providing better imaging capabilities and more stable operation (hence accuracy), the new instrument enables quantitative element mapping. It replaces our ageing Cameca Camebax, which is now entering its twentieth year of operation, having obtained over 300,000 quantitative analyses — an incontrovertible testament to the importance of the electron microprobe to the group's activities over the years. Major Equipment funding has been secured for a new powder X-ray diffractometer, which will replace the existing facilities in RSES, and provide the means to measure lattice parameters with extreme accuracy and do Rietveld structural refinements on the small quantities of material typically available from high-pressure experiments.

Most of the group's activities are concentrated into five areas: 1) Origin of the Earth and core formation; 2) Phase equilibria, including melting relations, in mantle systems; 3) Phase equilibria related to crustal evolution and ore deposits; 4) Physics of melting and melt extraction; and 5) Spectroscopic and thermodynamic property measurements on minerals and silicate melts. The latter area of research is undertaken in the belief that better understanding of large-scale geological processes often requires detailed, fundamental knowledge of the behaviour of minerals at the atomic scale.

The group continues to develop its use of X-ray absorption spectroscopy (XANES) and related techniques using synchrotron radiation. Dr A. J. Berry, together with Drs H. O'Neill and J. Mavrogenes, has determined the oxidation state and speciation of metal ions in fluids and melts. These experiments have been undertaken at the Photon Factory, Japan, and the Advanced Photon Source, USA. Recent results include a calibration for Fe oxidation states in silicate melts and the identification of complexes involved in the vapour phase transport of Cu. This type of work is important for establishing RSES at the forefront of synchrotron based research leading up to the completion in 2007 of the $206.3 million Australian synchrotron (Boomerang). Dr 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. The spectroscopic work on silicate melts compliments the thermodynamic and phase equilibrium studies carried out by the group.

Dr H. O'Neill and co-workers have measured the solubilities of several siderophile elements (Fe, Ni, Co, Mo, and W) in silicate melts as a function of melt composition, and are now using these data to work out generalised models for the activity coefficients of different groups of trace elements in silicate melts.

Drs J. Mavrogenes and H. O'Neill have extended their experimental work on the properties of sulfur in silicate melts by studying very oxidizing conditions, under which the sulfur dissolves as sulfate not sulfide. The effects of fO_2, fSO_2, melt composition and temperature have been quantified in this regime from experiments at atmospheric pressure; and these have been complimented by experiments at high pressure on the solubility of anhydrite (CaSO4). Dr U. Faul has been involved in laboratory measurements of seismic properties of melt-free and melt bearing upper mantle rocks. The data from carefully controlled sample suites allows for the first time a clear interpretation of grain scale processes at high temperatures and seismic frequencies and hence can be extrapolated to upper mantle conditions. Dr J. Hermann investigated element fluxes in subduction zones by combining high pressure, high temperature experiments with studies of eclogite facies rocks. The work highlights the importance of accessory phases for the trace element budget of subducted crust. Dr Hermann continued to collaborate with Dr. D. Rubatto (Department of Geology, ANU) on the relation between zircon and major metamorphic minerals in order to construct robust pressure-temperature-time path in metamorphic terrains.

The group contains four PhD students, Messrs Hack, Liu and Sommacal, and Ms L. Glass. Ms L. Glass has written up and submitted her study of what were formerly named the Antrim Plateau basalts of the Northern Territory and other related basalts of northern Australia; the stratigraphic part of her work has led her to suggest a new name, the Kalkarinji flood basalt province. Mr A Hack has been investigating the solubility of copper in high temperature and pressure fluids under a variety of buffered conditions; he has now completed his experiments and related measurements and is undertaking a detailed analysis of the results. He has also commenced writing his thesis. Mr S. Sommacal, in conjunction with Dr M. Sambridge, is developing new computational ways to handle the thermodynamics of compositionally complex, multisite solid solutions, with the immediate aim of developing a thermodynamic model for phase relations in the upper mantle. Mr Xi Liu has almost completed an experimental investigation of the effects of Cr_2O_3, K_2O and H_2O on mantle melting in the simplified model mantle system CaO-MgO-Al_2O_3-SiO_2 at 1.1 GPa.

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 Professor D. H. Green continues actively in the group, and collaborated with another visitor, Professor M. W. Schmidt, on an experimental study of the origin of ankaramitic magmas from island arc environments. Dr A. Glikson, formerly of AGSO, continues his work on the investigation of impact structures in Australia. Dr J.-P. Li, of the Chinese Academy of Sciences, Guangzhou, continued his investigation of the origin of the high-K magmas of the Tibetan Plateau; and Dr S. Redfern of Cambridge University, continued his work on the relationships between the crystal structure of minerals and their physical and thermodynamic properties.

For the first time, members of the group were eligible this year to apply for ARC funding, for projects commencing in 2003. Successful ARC "Discovery" applications were those of Drs H. O'Neill, J. Mavrogenes, J. Hermann and Professor R. J. Arculus, for "Properties of hydrous fluids and silicate melts at very high temperatures and pressures", and Drs A. J. Berry and J. Hermann for "Water storage in the Earth's mantle – understanding the process of OH incorporation in olivine".

Of the technical staff, Mr M. Shelley has built a new sample cell for the laser-ablation ICP-MS apparatus. Mr W. Hibberson and Mr D. Scott have continued the development of the 6-7 GPa piston-cylinder apparatus, and have been extensively engaged in sample synthesis for many of the group's activities. Dr S. Kesson continues to develop expertise for the group in the field of powder X-ray diffraction using the Rietveld method, which technique is becoming an increasingly important part of the group's activities. Mr N. Ware supervised the installation of the new Cameca SX100, while also nursing the ageing Camebax through its senescence.

Research Activities

Origin and significance of Cr-diopside suite segregations in mantle peridotites

H.StC. O'Neill

Mantle peridotites ubiquitously contain abundant "segregations" (a genetically neutral term for layers, veins, dikes, lenses, etc.) of pyroxene-rich rocks, which have a high-pressure mineralogy showing that they formed in the upper mantle. These segregations come in many varieties, both chemically and mineralogically, attesting to a number of different processes for their formation. It has been suggested that pyroxenites (usually of unspecified type) may contribute significantly to melt generation during adiabatic upwelling. Probably the commonest type of pyroxene-rich rocks are the Cr-diopside suite. These seem to occur in all alpine-type peridotites, and in spinel-lherzolite facies xenoliths from alkali basalts as well, implying that they were formed by a universal upper-mantle process. A diverse array of hypotheses have been put forward to explain their origin, some of them fairly exotic. These hypotheses have been based on field relations and trace-element and isotope geochemistry, but the phase-equilibrium constraints from their major-element chemistry and mineralogy have received scant attention. Because of the great variety of pyroxenites in mantle peridotites, it is important to specify exactly what is under discussion here. Cr-diopside suite pyroxenites consist of cpx+opx±sp±sulfide. Chemically, they are characterized by high Cr and Cr# (molar Cr/(Al+Cr)), similar to the adjacent peridotites. Mg#s are primitive (molar Mg/(Mg+ ΣFe > 0.89). Two-pyroxene geothermometry shows that the pyroxenes have completely recrystallized at >150ºC below the anhydrous peridotite solidus at 10–20 kb, and contain exsolution lamellae corresponding to cooling below 950ºC. The clinopyroxenes are relatively refractory in terms of their incompatible-element contents (Na, Ti, REE, etc); both cpx and opx are compositionally similar, if not identical, to these phases in the adjacent peridotites. This similarity extends to isotopic compositions. Proportions of cpx to opx are variable. Related types of pyroxenites exist, namely Cr-rich olivine-websterites and bronzitites, albeit generally with slightly lower Mg# and Cr#. For simplicity, these will not be considered here. In very depleted cpx-free harzburgites like the Massif du Sud, New Caledonia, the Cr-di suite is represented by bronzitites.

In most (all?) peridotites, Cr-di suite pyroxenites are the earliest of all segregations, being cross-cut by later pyroxenites of other types (e.g., Al-augite suite), gabbros, etc. Usually, many episodes of Cr-di activity can be recognised from cross-cutting relations (e.g., in the Balmuccia peridotite). The youngest segregations form dikes with sharp margins cutting the peridotite foliation, and contain no olivine. Field relations show that with increasing deformation these dikes are rotated into the plane of the foliation, becoming stretched and smeared out; the sharp margins are lost, and olivine from adjacent peridotite is tectonically introduced into the pyroxenite. Ultimately the pyroxenite is more-or-less completely reworked back into the peridotite, with only diffuse layers enriched in pyroxene (± spinel) remaining. This accounts for those otherwise enigmatic peridotites with MgO <36wt% (dry). Apparent variations in the amount of melt extracted in some peridotite suites (as represented on plots of CaO, Al_2O_3, etc vs. MgO) may instead represent different degrees of pyroxene depletion and re-enrichment caused by this process. Balmuccia is a possible example.

It is widely recognized that Cr-di pyroxenites are not melt compositions (the Mg# and Cr contents are too high, Al_2O_3 too low, etc.). Partial melting of peridotite in the spinel-lherzolite pressure regime of the mantle occurs peritectically, according to the melting reaction: opx + cpx ± sp = ol + melt. On decompression, the ol primary phase field expands, such that ol is always the first phase to crystallize (apart from Cr-rich sp, which often also accompanies ol). Ol+sp fractionation would rapidly lower the Mg# and the Cr# of the system below that observed in the Cr-di suite, while melt separated from ol would evolve down a line of descent to lower temperatures than the peridotite solidus, due to the peritectic melting. These two constraints of the expanding ol primary phase field and the peritectic melting mean that an archetypical ol-free Cr-di websterite can only form as an *initial* precipitate (i.e., at an infinitesimally small degree of fractional crystallization) at essentially the same pressure at which it was produced. This requires that the pyroxenite is precipitated adjacent to, and in equilibrium with, its source peridotite. The process is similar to the "pressure solution creep", as proposed by Dick and Sinton (1975) from field relations. Importantly, the melt is only an agent of transport; there is no trace of its composition in the pyroxenite, which initially has phase compositions the same as those in the host peridotite. The different proportions of phases (including ol and sp) cause small divergences in mineral compositions between the segregations and the adjacent peridotites during subsequent subsolidus recrystallization. Why the proportions of initial cpx to opx are variable is an interesting question.

The phase relations of a sp-free websterite from Ronda and two sp-websterites from Balmuccia (one with a conspicuous amount of accessory sulfide) have been experimentally determined at 1 atm., and 10, 15 and 20 kb. These examples were chosen for their sharp boundaries with peridotite, and none contain olivine. All three have a granular texture with ~0.5 cm pyroxenes, and cpx:opx in the ratio 3:1. The results for the Ronda example are summarized in Figure 1. The solidus lies ~100°C above the anhydrous peridotite solidus (Hirschmann, 2000), showing that Cr-di pyroxenites cannot contribute to enhanced melt productivity. In all three cases opx is completely resorbed into cpx well below the solidus (but other Cr-di websterites with lower CaO must have both opx and cpx at the solidus).

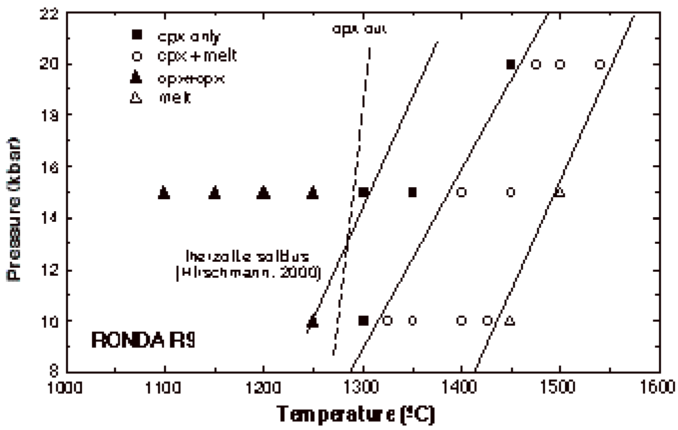


Figure 1: Experimentally determined phase relations in a sp-free websterite from Ronda. The original rock forms a ~6 m cross-cutting dike in cpx-poor lherzolite

An electrochemical cell across the core-mantle boundary

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Partial melting experiments in the system CaO-MgO-Al_2O_3-SiO_2-H_2O-CO_2 (CMAS-H_2O-CO_2) at 11 kbars

X. Liu, H.StC. O'Neill and A.J. Berry

H_2O and CO_2 have a strong effect on magma-generating process of the upper mantle and they have been the subject of experimental investigations for more than 30 years. Due to the lack of a reliable analysing method for fluid content in melt and the difficulty in preparing small experimental samples as thin sections for infra-red spectroscopy, existing literature data is incomplete and usually does not report the volatile contents of the melts.

In this study, piston-cylinder experiments have been carried out at 11 kbar in systems CMAS-H_2O-CO_2-Na_2O (trace) and CMAS-Na_2O to study the effect of H_2O and CO_2 on melt composition and melting temperature. Phase composition data have been collected for all phases by electron microprobe analysis and Fourier transform infrared (FTIR) spectroscopy (for melt only). Our results represent the only complete data set available to date.

Preliminary results suggest that every 1% increase in the O in the melt produced by the partial melting of a spinel lherzolite in the system CMAS-H_2O at 11 kbar reduces SiO_2 by 0.01%, MgO by 1.06%, CaO by 0.41% but enhances Al_2O_3 by 0.48%; every 1% CO_2 increase, however, reduces SiO_2 by 1.8% and Al_2O_3 by 0.97% but enhances MgO by 0.46%, CaO by 0.43% and H_2O by 0.93% in the system CMAS-H_2O-CO_2. Every 1% H_2O increase depresses the solidus by ~ 43°. The partial melting reactions are Opx + Cpx + Sp -> Melt + Fo at high temperature and Opx + Sp -> Melt + Fo + Cpx at low temperature. Partial melting extent is strongly dependent on temperature at high temperatures but almost independent at low temperatures.

Cr effect on the partial melting process of simplified spinel lherzolite in the system CaO-MgO-Al_2O_3-SiO_2-Cr_2O_3 (CMAS-Cr) at 11 kbars

X. Liu and H.StC. O'Neill

Chromium oxide mainly occurs as Cr_2O_3 on the earth and is the 6th most abundant component of the upper mantle. Its effect on subsolidus phase relationship has been established for a long time, its effect on partial melting, however, is currently poorly understood due to some special experimental difficulties. In this study, new experimental techniques are used to study the effect of Cr_2O_3 on the partial melting of simplified spinel lherzolite in the system CMAS-Cr at 11 kbars.

Cr_2O_3 behaviours compatibly during the partial melting process so that it mostly remains in the solid phases. A small amount of Cr_2O_3 in the melt, however, has very strong effect on the solidus and the melt composition. Specifically, 0.1 wt% Cr_2O_3 in melt raises the solidus by ~ 10 degrees, increases the SiO_2 content of melt by ~ 0.5 wt% and the MgO content by ~ 0.7 wt%, but decreases the Al_2O_3 content by 1.4 wt%. The CaO content of melt is almost unaffected by Cr_2O_3. Melt changes from olivine-normative to quartz-normative as its Cr_2O_3 content changes from 0 to ~ 0.15 wt%. This explains why silicate-rich melt can be produced when the source is getting more refractory. With an almost constant CaO content but a decreasing Al_2O_3 content of melt, the CaO/Al_2O_3 ratio of melt increases from ~ 0.7 up to ~ 4 when the Cr_2O_3 content of the melt changes from 0 to ~ 0.85 wt%.

The partial melting reaction for spinel lherzolite in the system CMAS-Cr at 11 kbar is Opx+Cpx+Sp -> Melt + Fo for the whole composition range. Sp might be absent at medial temperatures but rejoin the game at high temperature. The exact temperature interval for the absence of Sp is dependent on the bulk composition. This particular behaviour may explain the spinel composition gap observed in nature.

The meteorite Shergotty from Mars bears a strong Cr_2O_3 signature, and a very low Al_2O_3 content. This suggestes that the mantle of Mars might contain more Cr_2O_3, compared to the Cr_2O_3 content of the Earth's upper mantle. The very high SiO_2 content, the high K_2O content and the very low MgO content of Martian rocks suggest that K_2O and H_2O might be important in the magma-generating process on Mars.

Accurate determination of solidus, and melt composition on solidus, of spinel lherzolite in the system CaO-MgO-Al_2O_3-SiO_2 (CMAS) and partial melting of spinel lherzolite in the system CMAS±K_2O (CMAS±K) at 11 kbars

X. Liu and H.StC. O'Neill

The composition of multiply saturated partial melt at the solidus of simplified mantle peridotite in the system CMAS is valuable for the thermodynamic information that it contains, but it is difficult to accurately determine melt composition in the low variance assemblage, Fo+Sp+Opx+Cpx+Melt, because it exists only over a narrow temperature range at a given pressure.

Here we tried a new experimental method for determining this solidus melt composition in the system CMAS at 11 kbars by adding various amounts of K_2O to the system and extrapolating results to zero K_2O. Special experimental techniques include: 1) A new cell arrangement which featured an Fe_2O_3 sleeve to keep the water content in the experiments at a negligible level; 2) the "sandwich" experimental method was used to minimize problems caused by quench modification; and 3) Opx and Cpx were previously synthesised at conditions near to those of the melting experiments to ensure they had their appropriate compositions. Results were then checked by reversal crystallisation experiments and excellent agreement was observed between the forward experiments and the reversal experiments.

The results are in good agreement with previous work using conventional methods so that the new experimental method is considered to be successful. The newly established anhydrous solidus of spinel lherzolite in CMAS is considered to be 1320±10ºC at 11 kbars, 30 degrees lower than the literature data. The newly observed solidus melt composition, almost identical to the literature data, is 49.09% SiO_2, 20.12% Al_2O_3, 15.45%MgO and 15.33% CaO.

Our data also enables us to study the partial melting behaviour of spinel lherzolite in the system CMASK which has not been studied before. The effect of K_2O is to depress the solidus by ~ 5.8° per weight percent, while the melt composition becomes increasingly enriched in SiO_2, being quartz-normative above ~ 4 wt% K_2O. Compared to Na_2O, K_2O has a much stronger effect in depressing the solidus and modifying melt compositions. The partial melting reaction is simple at high temperatures but complicated at low temperatures. The extent of partial melting is strongly dependent on temperature at high temperatures but is almost independent of temperature at low temperatures.

The isobarically invariant point in the system CMAS-K_2O at which Ol+Opx+Cpx+Sp+Melt is joined by sanidine (San) was located at ~ 1240±10 ºC and the invariant melt composition is 58% SiO_2, 22% Al_2O_3, 4.5% MgO, 5.8% CaO and 9.7% K_2O.

During the course of the study several other isobarically invariant points were identified and their crystal and melt compositions determined in unreversed experiments, namely Opx+Cpx+Sp+An+Melt in the system CMAS at 1320±10 ºC, Opx+Cpx+Sp+An+San+Melt in the system CMASK at 1230±10 ºC, and Opx+Sp+An+San+Sapph+Melt in the system CMASK at 1230±10 ºC, where An is anorthite and Sapph is sapphirine.

The composition of coexisting San and An in three experiments suggests that the mutual solubility of An and San is much higher than any speculation or deduction from experiments in the literature and almost all thermodynamic models can not reproduce the new experimental data so that recalibration is needed.

Determining Fe oxidation states by X-ray absorption near edge structure (XANES) spectroscopy

A.J. Berry, H.StC. O'Neill, G.J. Foran[1], K.D. Jayasuriya[2] and S.J. Campbell[2]

1. *ANSTO*
2. *School of Physics, Australian Defence Force Academy*

Fe is the most common element in the Earth that exhibits a variable oxidation state, occurring as both Fe^{2+} and Fe^{3+}. The $Fe^{3+}/\Sigma Fe$ ratio of geological samples can be used as an indicator of the redox conditions (or oxygen fugacity, fO_2) under which a mineral or melt formed. Although Fe oxidation state ratios can be determined routinely by wet chemistry and Mössbauer spectroscopy, these techniques lack the micron spatial resolution achievable in XANES experiments and required for the analysis of melt inclusions.

Fe *K*-edge XANES spectra were recorded for a series of anorthite-diopside eutectic glasses containing 1 wt% $^{57}Fe_2O_3$ quenched from melts equilibrated over a range of oxygen fugacities at ~1400˚C. The $Fe^{3+}/\Sigma Fe$ ratios were determined previously by ^{57}Fe Mössbauer spectroscopy and vary between 0 (fully reduced) and 1 (fully oxidised). Using the Mössbauer results as a reference, various methods for extracting $Fe^{3+}/\Sigma Fe$ ratios from XANES spectra were investigated. The energy of the 1*s*→ 3*d* pre-edge transition centroid was found to correlate linearly with the oxidation state. The uncertainty in the $Fe^{3+}/\Sigma Fe$ ratio determined from the resulting best fit calibration curve is ±0.02 (one standard deviation). This linear trend is similar, but distinctly different, from a literature calibration based on mineral standards which appears to give accurate $Fe^{3+}/\Sigma Fe$ ratios for octahedrally coordinated Fe. The general applicability of any XANES calibration is limited by variations in the Fe coordination environment which affects both the intensity and energy of spectral features. Thus the calibration based on mineral spectra is not appropriate for Fe in the range of coordination environments found in silicate glasses. Further, it may be necessary to determine separate calibration curves for glasses of different composition or which quenched under different conditions. Variables such as melt composition, pressure, and glass transition temperature may modify the melt structure and hence the Fe coordination. The most accurate method for determining the $Fe^{3+}/\Sigma Fe$ ratio of a glass would be to compare the spectrum of the unknown to a series of standards, with the same chemical composition, equilibrated over a range of fO_2s.

Modelling of the transitions comprising XANES features (and hence high spectral resolution) is not important for determining accurate oxidation state ratios when a feature can be referenced to an empirical calibration curve. This work indicates the potential of XANES spectroscopy to determine the oxidation state of Fe in silicate glasses (and hence the redox conditions under which a melt equilibrated) with an accuracy comparable to that attained by Mössbauer spectroscopy.

Nuclear magnetic resonance (NMR) spectroscopy of wadsleyite

A.J. Berry, S.E. Ashbrook[1] and S. Wimperis[1]
1. School of Chemistry, University of Exeter, UK

Satellite-transition magic angle spinning (STMAS) NMR techniques have been used to record high-resolution ^{17}O NMR spectra of wadsleyite (β-Mg_2SiO_4). These experiments were attempted on less than 10 mg of sample produced in a single multi-anvil experiment at 16 GPa and 1500˚C. This is the first time that high resolution ^{17}O NMR spectra have been recorded from a sample of this size. Four discrete resonances were observed, assignable to the four oxygen sites in wadsleyite. Assignments were made with reference to the chemical shifts of crystallographically similar oxygen environments in model compounds (such as forsterite and enstatite) and by differences in transition intensities associated with the relative number of oxygens of each type. The chemical shifts exhibit an approximately linear correlation with Si-O bond length, consistent with a trend we have determined previously for a range of Mg silicate minerals.

This work is a precursor to ^{17}O NMR studies aimed at determining the O site to which H is coordinated in hydrous or nominally anhydrous minerals. In a continuation of our work on clinohumite ($4Mg_2SiO_4.Mg(OH)_2$) and chondrodite ($2Mg_2SiO_4.Mg(OH)_2$), differences were noted between the multiple-quantum MAS (MQMAS) and STMAS spectra. In the STMAS experiments, those peaks attributed to oxygen sites involved in hydrogen bonding are broadened to such a degree that they are effectively removed from the spectrum. As a result only those oxygen sites not associated with H are observed. This suggest a potential method of defining the H coordination environment. The broadening is attributed to modulation of the electric field gradient, and hence the quadrupolar interaction, of the ^{17}O nuclei due to motion of H between two partially occupied H sites of similar energy.

STMAS experiments on hydrous wadsleyite ($Mg_{1.75}SiH_{0.5}O_4$) and Ti substituted clinohumite are currently being undertaken.

X-ray absorption spectroscopy of Cu in hydrothermal fluids

A.J. Berry, J.A. Mavrogenes, A. Hack, M. Newville[1] and S.R. Sutton[1]
1. Consortium for Advanced Radiation Sources, University of Chicago, USA

Hydrothermal ore deposits are the world's principal source of copper and gold. To understand the formation of these deposits, it is necessary to determine the speciation of the metal complexes in solution. Samples of hydrothermal fluid trapped as fluid inclusions in quartz can be re-heated to the entrapment temperature allowing their use as cells (natural pressure vessels) for high temperature studies. The ideal tool for analysing these samples is the X-ray microprobe, which combines the necessary spatial resolution with spectroscopic techniques (XANES and EXAFS) capable of determining metal coordination at temperatures similar to those of ore transport and deposition.

Of particular interest is the geochemistry of Cu. In some cases a boiling hydrothermal fluid separates into a high density brine forming a Cu porphyry and a low density S-rich vapor which migrates towards the surface before precipitating a high sulfidation Au(Cu) epithermal deposit. This suggests that phase separation may simultaneously form deposits at different levels in the crust. If during boiling Cu partitions into the vapor phase, shallow high sulfidation deposits may be enriched in Cu at the expense of deep-seated porphyry systems. Cu mineralisation may occur in both settings depending upon partition coefficients. The key to understanding the relationship between these ore systems (with implications for predictive exploration) is how chemical and physical variables control the behaviour of Cu through changes in speciation.

We have studied natural fluid inclusions of a system which trapped a boiling fluid in quartz (Mole Granite). Two types of inclusions corresponding to the trapped high density (brine) and low density (vapor) phases coexist. As a result of cooling to room temperature the low density vapor-phase inclusion contains a large bubble and a small amount of condensed liquid (see Figure 1). In this system Cu preferentially partitions into the vapor phase with the X-ray fluorescence map showing the Cu distribution. Opaque precipitates in these inclusions do not contain Cu (as assumed previously). The absorption spectra identify the stable complexes as $[Cu(H_2O)_6]^{2+}$ at 25˚C, $[CuCl_2]^-$ at 200˚C, and either $[CuCl_2]^-$ or $[CuCl(H_2O)]$ at

400˚C. These changes in Cu coordination and oxidation state are fully reversible. S is also present in these inclusions and it has been suggested that Cu may partition into the vapor as a volatile Cu-S complex. This work suggests that this is not the case, although it is not clear how or why Cu should segregate as a Cl complex from a Cl rich brine.

Currently we are investigating Cu speciation in synthetic fluid inclusions. Inclusions can be synthesised to capture a desired metal-ligand combination at a particular temperature, pressure, pH, oxygen fugacity (fO_2), and sulfur fugacity. For example, one major problem in the interpretation of EXAFS spectra recorded from natural inclusions is the difficulty of distinguishing S from Cl; synthetic Cu-Cl bearing inclusions can be produced under S free conditions. The synthetic inclusion method was used to trap fluids (brines) in equilibrium with Cu metal at 700˚C and 3 kbar. Cu concentrations of between 0.1 and 10 wt% were determined by PIXE and LA-ICPMS for a series of experiments in which the Cl content was varied from 1-30 wt%. The pH and fO_2 of the solutions were buffered by various mineral assemblages. Typical inclusion sizes exceed 50 mm, all solid phases dissolve by 325˚C, and the inclusions can withstand re-heating to at least 500˚C. Preliminary EXAFS results suggest that [CuCl(H_2O)], the same complex identified in the Mole Granite vapor inclusions, is the stable Cu species in brines at 400˚C. Future work will focus on the partitioning behaviour of this complex.

Experiments of this type will allow the aqueous behaviour of Cu under geological conditions to be defined and related to natural samples. This research will potentially allow the metal distribution between epithermal and porphyry type environments in hydrothermal systems to be predicted. The methodology is applicable to most economically important ore metals and experiments are also planned for determining the high temperature speciation of Au and Ag.

Relating zircon and monazite domains to garnet growth zones: Age and duration of granulite facies metamorphism in the Val Malenco lower crust

J. Hermann and D. Rubatto

Metamorphic rocks generally display a multistage evolution and therefore dating of metamorphic processes is a difficult task because it requires the connection of pressure, temperature and fluid sensors to chronometers. Up to amphibolite facies conditions, several metamorphic minerals such as biotite, muscovite, amphibole and garnet can be used for dating, facilitating the relation of metamorphic conditions to time. At granulite facies conditions, determining formation ages is only possible with isotopic systems that have high closure temperatures, such as U-Pb in zircon and monazite. Zircons from a lower crustal metapelitic granulite (Val Malenco, N-Italy) display inherited cores with apparent ages spanning from 520 to 3050 Ma, and three metamorphic overgrowths with ages of 281±2, 269±3 and 258±4 Ma. Monazites record the same three metamorphic stages at 280±5, 270±5 and 258±4 Ma. Using mineral inclusions in zircon, monazite and garnet and the rare earth element characteristics of these three minerals it was possible to relate the ages to distinct stages of granulite facies metamorphism. The first zircon and monazite overgrowths are in equilibrium with the garnet core. They formed during fluid absent partial melting of phengite and biotite caused by the intrusion of a Permian gabbro complex. The second metamorphic zircon and monazite domains grew after formation of peak garnet, during cooling from

850°C to ~700°C. They crystallised from partial melts that were depleted in heavy rare earth elements because of previous, extensive garnet crystallisation. The third overgrowth is related to fluid present melting at about 700°C, which produced a new garnet generation. The obtained ages indicate that the granulite facies metamorphism lasted for about 20 Ma and that heating rates were significantly higher than cooling rates.

Twenty Ma of high-temperature metamorphism led to a complete homogenisation of major elements in 1 cm large garnets. However, Y and HREE still preserve zoning and change over at least one order of magnitude. This indicates that diffusion of Y and HREE in garnet is extremely low and that trace element profiles in garnets are a useful tool to decipher high temperature metamorphic processes.

Allanite: Thorium and light rare earth element carrier in subducted crust

J. Hermann and D. Rubatto

The investigation of deeply subducted eclogites from the Dora-Maira massif, Western Alps reveals that accessory minerals are important hosts for trace elements. Rutile contains most of the bulk rock Ti, Nb and Ta while zircon hosts nearly all Zr and Hf. More than 90% of the bulk rock light rare earth elements and Th and about 75% of U are incorporated in accessory allanite. Phengite is the most interesting major mineral because it hosts more than 95% of Rb, Ba and Cs (Figure 1).

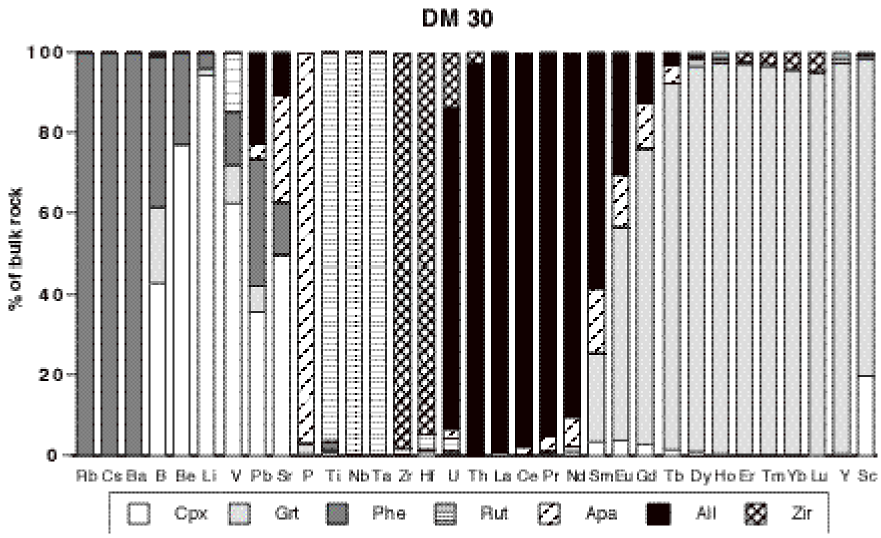


Figure 1: Trace element distribution in a phengite eclogite from the Dora-Maira massif containing 36% omphacite, 35% garnet, 14% quartz, 12% phengite, 2.5% rutile, 0.52% apatite, 0.1% allanite and 0.032% zircon. Note the high amount of trace elements, which are stored in accessory phases.

Synthesis piston cylinder experiments in a model crustal composition in the range 2.0–4.5 GPa, 680–1150°C doped with trace elements demonstrate that accessory allanite forms at the expense of the major mineral zoisite at temperatures above 700°C and 2.0 GPa. Allanite is stabilised by the incorporation of light rare earth elements and was found up to temperatures of 1050°C and to pressures of at least 4.5 GPa. Disappearance of allanite is caused by dissolution in a coexisting hydrous granitic melt and is not related to the breakdown of any major phase. Experimentally determined element partitioning between allanite and a hydrous granitic melt at 900°C, 2.0 GPa yield $D_{LREE}^{all/melt}$ of about 200, $D_{Th}^{all/melt}$ of 60 and $D_{U}^{all/melt}$ of 20. These results, combined with literature data, are used to estimate light rare earth element saturation levels of subduction zone liquids as a function of temperature. Allanite is a residual phase up to temperatures of at least 900°C and 1000°C for metabasalts and metasediments, respectively, at ≤10% partial melting. Allanite is therefore capable of controlling LREE and to a lesser extent Th contents for the critical temperature range of subduction zone liquid extraction. Low temperature fluids coexisting with allanite are not capable of transporting significant amounts of light rare earth elements and therefore arc lavas showing enrichment of these elements probably originate from a mantle source that experienced metasomatism by a hydrous granitic melt.

High-temperature and -pressure calibration of the piston-cylinder apparatus using synthetic fluid inclusions and insights into PVTX relations in the system SiO_2-H_2O

A.C. Hack, W.O. Hibberson and D.R. Scott

A new temperature and pressure calibration of the 30 mm piston cylinder apparatus at RSES was undertaken. The temperature calibration data show that despite the relatively large size (Ø15 mm, length 31 mm) of the capsule, the temperature over its length was remarkably uniform, the variation being ±5°C for the entire temperature range investigated (150 to 950°C). This low temperature gradient is attributed to the large mass and high thermal conductivity of the capsule metal, pure Cu.

Following the temperature calibration, a series of synthetic fluid inclusion experiments, in Pt capsules, in the system SiO_2-H_2O were carried out. These experiments were designed to measure the friction correction required, if any, for standard 30 mm talc- and salt cell assemblies. The calibration technique relies on having accurate knowledge of the experimental temperature, which was determined independently earlier, and the specific volume of water at the run conditions (the PVT properties of pure water are independently precisely known) to calculate an isochore for the fluid in the inclusion from the post-run vapor-liquid homogenisation temperature (T_h) and solve for the pressure. Corrections for the isothermal expansivity and isobaric compressibility of the quartz host and the effect of quench precipitated silica on the raw molar volume measured at T_h were applied. Where a difference between the nominal and isochore-derived pressure occurs this, normally, would be interpreted as the friction correction for the experimental set-up.

Experiments conducted at relatively low pressure (~3.5 kb) in the talc-assemblage result in corrected water isochors that, after propagation of the small experimental uncertainties, coincide with the nominal experimental pressure and temperature (Figures 1 & 2). This indicates friction is negligible in our large volume talc-cell piston cylinder assembly. We attribute this finding to the decay of the friction with time over the relatively long run durations, a process which is likely to be hastened in the case of our experiments through the imposition of a hydrostatic environment on the assembly caused by the relatively large mass of fluid (~1g) combined with the extreme ductility of the capsule. A similar time-dependant friction decay in the piston-cylinder apparatus was found by Bose and Ganguly (1995, Am. Min. 80:231-238), their data also indicate that internal friction decays more rapidly as the assembly size increases. Thus, it seems that long-duration runs using large volume talc assemblies, even at low-pressure, do not require a friction correction to the nominal pressure.

Interestingly, however, at higher pressure and temperature (approaching the second critical point system SiO_2-H_2) where friction effects are expected to be even less severe, the technique appears to fail, as extreme friction corrections are necessary to retrieve the *PVT* properties of pure water recorded in the fluid inclusions. Since previous investigations, by us and other workers, demonstrate that fluid inclusions do display isochoric (constant volume) behaviour and our low pressure experiments record fluid densities consistent with the run conditions (additional credence to our low pressure results is lent by similar fluid inclusion results of other workers for runs in hydrothermal pressure media apparatus at the same *PT* that yield the identical V_{H2O}), we have faith in the experimental technique. Thus our measurements lead us to conclude that either there is a problem with the equation of state of water at high pressure, which seems unlikely, or that the dissolved silica in the fluid is effecting the *PVT* properties unexpectedly at high pressure (Figures 1 & 2). Note, however, the apparent excess volume of mixing is not observed at lower pressure.

Our data indicate that either mixing in the system SiO_2-H_2O is significantly non-ideal at high pressures, assuming silica dissolves as simple monomer species, or alternatively that polymerisation of the dissolved silica must be considered in order to explain the mixing relations.

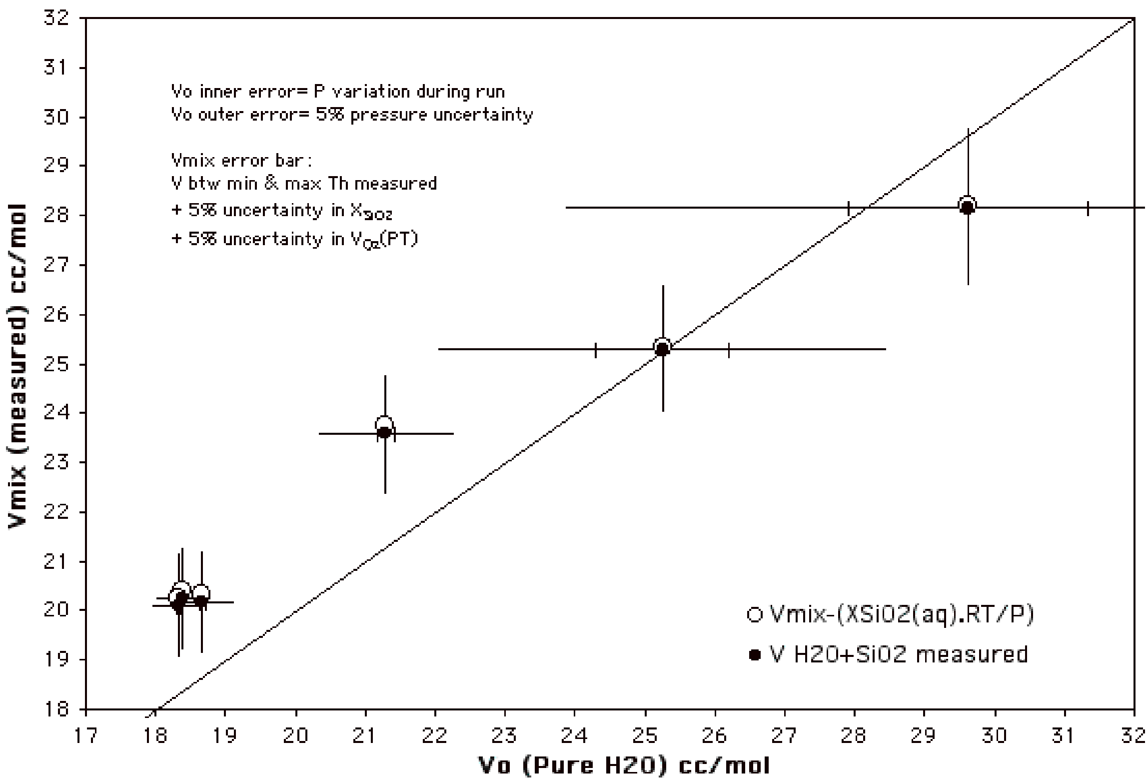


Figure 1: Volumetric data obtained from fluid inclusions in the system SiO_2-H_2O. Each point represents a separate PTX condition. Vmix (measured) refers to the bulk fluid (SiO_2 (aq) + H_2O) volume determined (solid circles) after corrections for the PVT properties of

quartz and precipitation of dissolved quartz between the homogenisation temperature (T_h) and the experimental conditions. Vo (pure water) is the volume of pure water at the experimental conditions. Experimental and measurement uncertainty indicated (error bars for observed pressure variation during the run only shown and also the effect of an additional 5% pressure uncertainty). Open circles show the partial molar volume of water required if silica were dissolved as an ideal gas. Note deviation of the apparent molar volume of water from Vo at high fluid densities; this is attributed to a fundamental change in the solution structure caused by dissolved silica at high pressure.

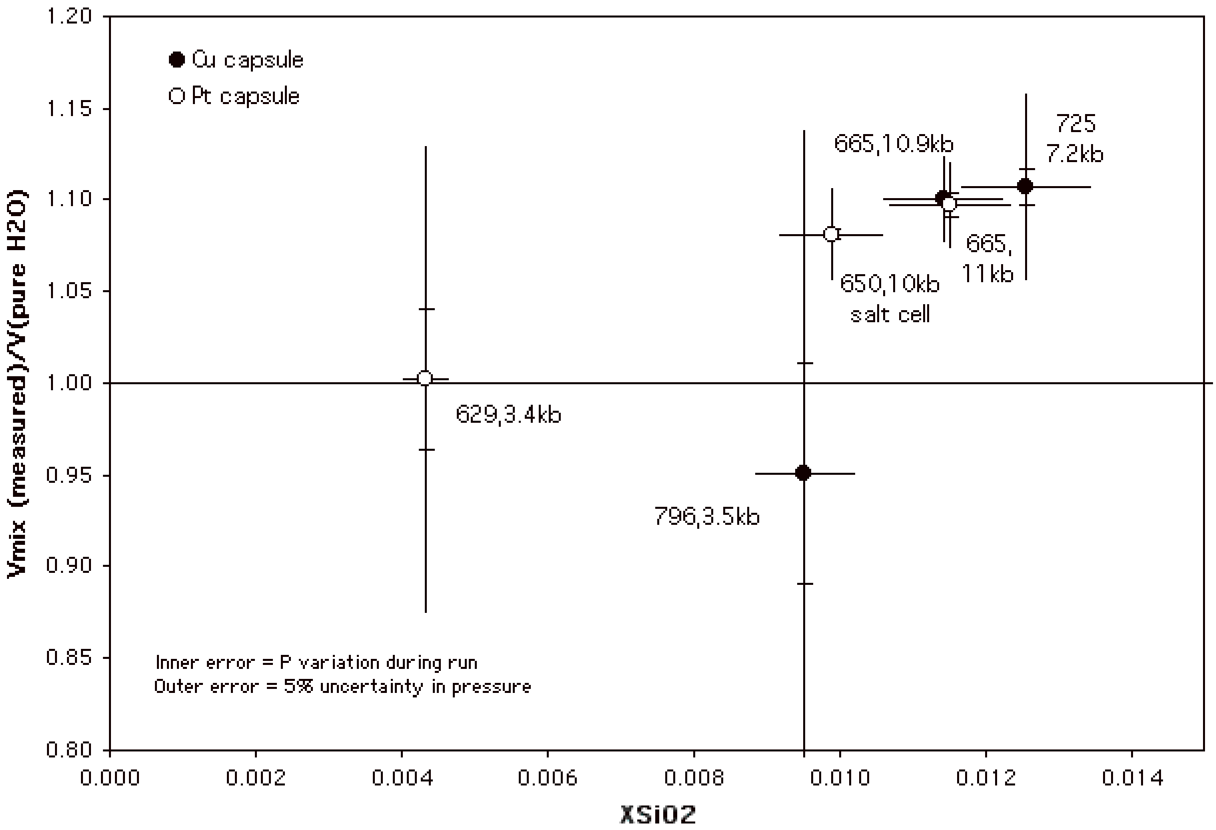


Figure 2: Composition-volume relations in the system SiO_2-H_2O as measured using fluid inclusions. V(measured) is the bulk fluid volume determined after corrections for the PVT properties of quartz and precipitation of dissolved quartz between T_h and the experimental conditions. Vo (pure water) is the volume of pure water at the experimental conditions. $XSiO_2$ is the molar fraction of dissolved SiO_2 at the experimental pressure and temperature, calculated from Manning (1994) Geochim. Cosmochim. Acta 58:4831-39. 'Salt cell' refers to an experiment conducted in a 'low-friction' NaCl piston cylinder assembly (with this cell pressure is known to better than 5%), all other experiments conducted in talc-pyrophyllite assemblies. Open and filled circled referred to experiments run in platinum and copper capsules respectively. Note the deviation from ideality/change in speciation only appears at high pressure (>5kb?).

Although much is known about solubility relations in the system SiO_2-H_2O the nature of silica complexation at high-pressure and temperature approaching and beyond the second critical point remains uncertain. Consequently, predictions regarding the geochemical behaviour of silica in deep crustal hydrothermal and subduction zone environments cannot be rigorously constrained. However, by understanding the volumetric properties of the system SiO_2-H_2O at high-pressure and -temperature, in addition to the solubility relations, the details of the silica speciation can be determined. Non-ideal mixing of dissolved silicate components (or polymerisation of these components into melt-like structures) in water may be the norm at high pressure. Volumetric data, as obtained here, provides a means of resolving discrepancies between high pressure quartz-saturated and -undersaturated (buffered) silica solubility measurements. Moreover, our observations are more widely applicable, in that they may help explain perennially encountered petrological problems related to high-pressure hydrothermal phenomena and the stability of hydrous phases. Further synthetic fluid inclusion experiments to determine the *PVTX* properties in the SiO_2-H_2O system are being undertaken.

Excimer laser ablation analysis of single fluid inclusions in quartz: factors affecting accuracy and precision

A.C. Hack, J.M.G. Shelley and J.A. Mavrogenes

A number of aspects of the technique of laser (ArF 193nm) ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) affect accuracy and precision when analysing fluid inclusions. These include: physical and chemical compositional matrix effects, inclusion signal corrections, ablation rate, sample carrier gas composition and ICP-MS configuration, and standards used for determining absolute element concentrations.

Our experiments indicate that using the NIST silicate glass standards as reference materials for quartz-hosted fluid inclusion analysis generally does not introduce matrix-related calibration effects. Calibration errors can arise from interferences usually considered negligible, where there are extreme compositional differences between fluid inclusions and standards.

Extended ablation times lead to elementally fractionated ablation yields as the aspect ratio of the hole at the sampling site increases. Because fluid inclusions may be encountered at different depths in the sample, a depth related fractionation correction should be made by correlating inclusion depth (using time from beginning of ablation as a proxy) with an equivalent depth on the bracketing standards which are also used to monitor and correct for instrumental drift.

Ablation of host materials containing inclusion analyte elements of interest results in elevated background signals. Such host-related background signals are modelled and subtracted from the fluid inclusion signal. Because there is inter-mass fractionation during progressive ablation, the use of a single mass, like $^{29}Si^+$, which only occurs in the host, as a proxy for the behaviour of all other masses degrades the quality of the analysis because such effects are not taken into consideration. To avoid this, we recommend selecting at least two intervals containing only the host background signal then calculating a background model for each individual mass. The host model can then be interpolated/extrapolated to the inclusion interval and removed from the raw inclusion signal.

Deposition of ablation-related condensate material on the sample substrate is inevitable, even when ablating in a helium atmosphere. These deposits can severely compromise the quality of data obtained from shallow inclusions, where the surface signal cannot be resolved from or overlaps the inclusion signal. Experiments show that removing ablation condensate-type contamination by single light pulses is ineffective, as there is always some recondensation of material after each pulse over the ablation site. Thus, we recommend rejecting data obtained from shallow inclusions, where the surface component of the analysis cannot be clearly separated from the true inclusion signal.

Synthetic fluid inclusion samples were analysed by LA-ICP-MS using various composition sample carrier gases and ICP-torch configurations. Results indicate no significant difference in measured fluid composition between instrument conditions. However, the analytical set-up strongly influences analyte mass backgrounds and sensitivity and therefore the analytical conditions need to be optimised for the specific element list.

Optimum fluid inclusion sampling conditions occur over a limited range of laser repetition rate. The definition of the inclusion signal and the signal to background intensity improves with increased laser pulse repetition rate, but these gains are offset by loss of spatial resolution in the LA-ICP-MS data due to signal smoothing averaging large volumes of ablated material (because of faster sampling) and the rapid excavation of high-aspect ratio ablation sites where down-hole signal attenuation and inter-mass fractionation effects become increasingly difficult to correct for using the bracketing standards.

In contrast with the study by *Günther et al. (1998), J. Anal. Atom. Spect. 13:263-270*, we find no difference in the analytical accuracy or precision between solute-saturated (i.e. daughter crystal containing) and solution-only inclusions when ablated using a constant beam diameter.

Petrogensis of the Kalkarinji low-Ti continental flood basalt province

L.M. Glass

The Kalkarinji low-Ti continental flood basalt province represents a voluminous outpouring of lava covering an extensive area of northern Australia in Cambrian times at 508 ±2 Ma (1s) (RSES Annual Report, 2001). The province includes the Antrim Plateau, Helen Springs, Nutwood Downs, Peaker Piker and Colless Volcanics and most likely coeval basalts and dolerites to the south (the Boondawari dolerite and the Table Hill Volcanics). The volume of the erupted basalts is estimated to be at least 0.15 million km^3. However, this is a minimum estimate and does not take into account basalts since eroded.

The Kalkarinji basalts and dolerites have an enriched trace element signature resembling continental crust. Moreover, they show marked Nd and Sr isotopic enrichment, i.e. initial $^{87}Sr/^{86}Sr$ varies between 0.707 and 0.723 with 20 out of 23 samples lying within a restricted range from 0.707 to 0.709. Initial e_{Nd} values vary from -2.7 to -9.6, with 19 out of 23 clustering in a narrow range between -3.0 and -4.5.

Crystal fractionation was the dominant process responsible for the chemical evolution of basalts containing between ~9 and 3 wt% MgO. However, subtle up-stratigraphic variations in crust-sensitive trace element ratios, e.g. Ba/Rb, Nb/U, Nb/Ta and Th/U, are mirrored by shifts in isotopic ratios suggesting involvement of minor but measurable high-level crustal contamination.

Isotopic compositions and key crust-sensitive trace element ratios do not correlate with indices of fractionation, e.g.$^{87}Sr/^{86}Sr$, Delta^{18}O and Ba/Rb show negligible variation over a range of Mg#, indicating that the crust-like signature of the Kalkarinji basalts was acquired at compositions more primitive than 9 wt% MgO. Furthermore, a ~12 wt% MgO melt inclusion in chromian spinel has the distinctive trace element signature characteristic of the Kalkarinji basalts, indicating that the enriched signature was already present in picritic precursor magmas.

One of the most distinctive features of this province (and many other low-Ti continental flood basalt provinces) is the relative depletion of the HFSE, notably Ti, P and Nb. In addition, the Kalkarinji basalts are enriched in Th and U and have the most extreme Th/U ratios observed for any flood basalt province, these features are compatible with a contamination overprint by Proterozoic North Australian felsic crust, Figure 1.

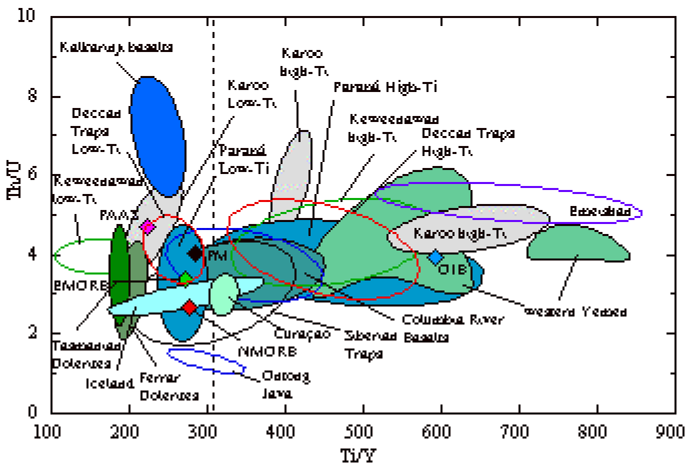


Figure 1: Trace Element Variation Diagram showing Ti/Y versus Th/U for Kalkarinji flood basalts comparing world distribution of high and low-Ti flood basalts and dolerites and Iceland and Curaçao picrites relative to Primitive Mantle (PM), OIB (Oceanic Island Basalt), EMORB (Enriched MORB) and NMORB (Normal MORB). Note the distinctive elevated Th/U ratio for the Kalkarinji province, a feature shared with average North Australian Felsic Crust.

Crystal-liquid partition coefficients determined for Kalkarinji plagioclase and clinopyroxene (RSES Annual Report, 2001) were used for trace element modelling. Trace element, Sr and Nd isotopic geochemical signatures for the majority of the Kalkarinji basalts can be reproduced by ~10% crustal contamination assuming average Proterozoic North Australian Felsic Crust (NAFC) as the assimilant and either Iceland (NMORB) picrite or Curaçao (primitive mantle) picrite as the initial magma composition, Figures 2, 3,4 and 5.

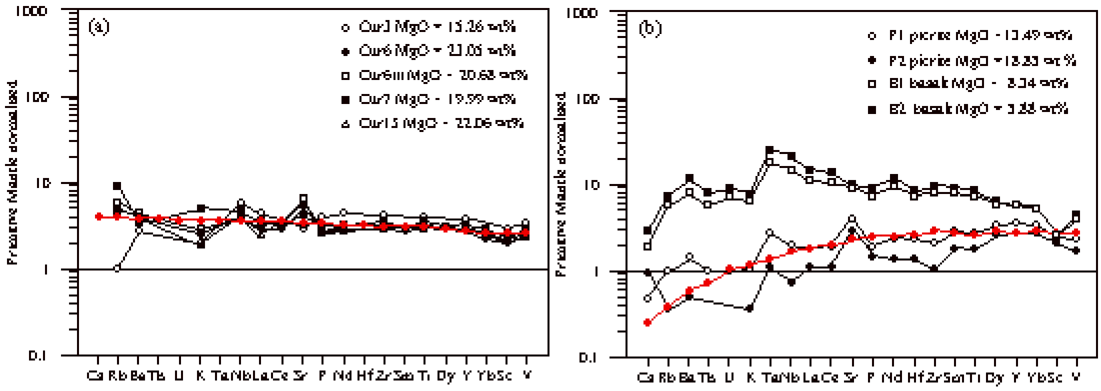
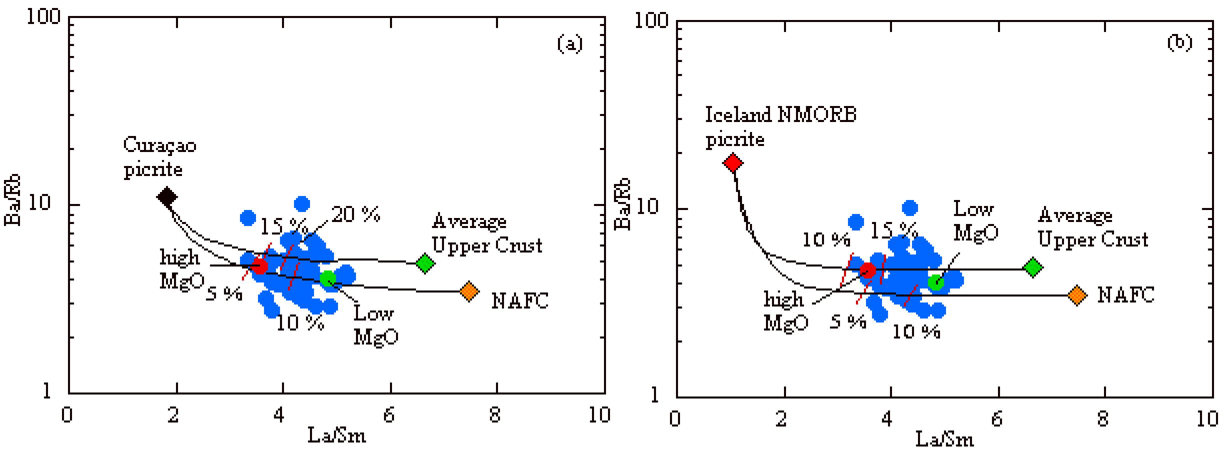


Figure 2: (a) Primitive mantle-normalised diagram showing Curaçao picrites. Overlain in red is the initial magma composition based on incompatible element abundances ~2.5 to 4x primitive mantle (pyrolite), McDonough & Sun (1995). Curaçao data from Kerr et al. (1996). (b) Primitive mantle-normalised diagram showing Iceland picrites and basalts. Overlain in red is the initial magma composition with incompatible elements having abundances close to NMORB x 0.3, (NMORB values from Sun & McDonough (1989). Iceland data from Révillon et al., 1999. Primitive mantle normalising values from McDonough & Sun (1995).

Larger, and hence less realistic amounts of crustal contamination are required if other potential crustal compositions, such as global average upper crust, are used for trace element modelling; this highlights the importance of selecting the most appropriate contaminants for assimilation and fractional crystallisation modelling exercises, Figure 3.



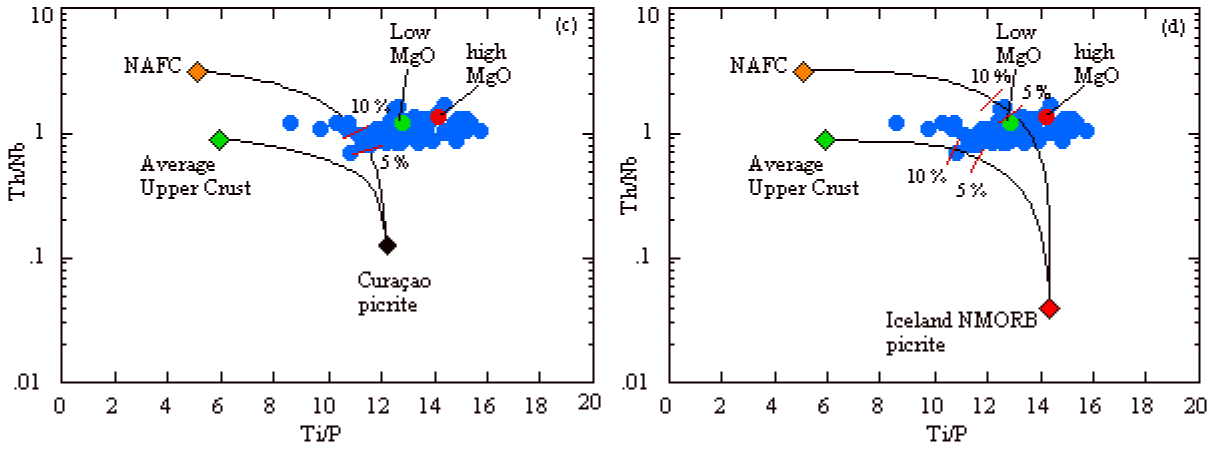


Figure 3 a-d: Trace element discrimination plots for Kalkarinji basalts with two component mixing curves for preferred initial magma compositions for Curaçao picrite and Iceland NMORB picrite based on Curaçao and Iceland picrites and average global upper crust composition of McLennan (2001) and average North Australian felsic crust (NAFC).

Most importantly, the distinctive low-Ti signature of the Kalkarinji basalts can be modelled by contamination of either Iceland NMORB or Curaçao picrite parental liquid with average NAFC, without the requirement for melting of refractory, depleted peridotite. Results for trace element assimilation and fractional crystallisation modelling using the chosen end-member components are shown in Figure 4.

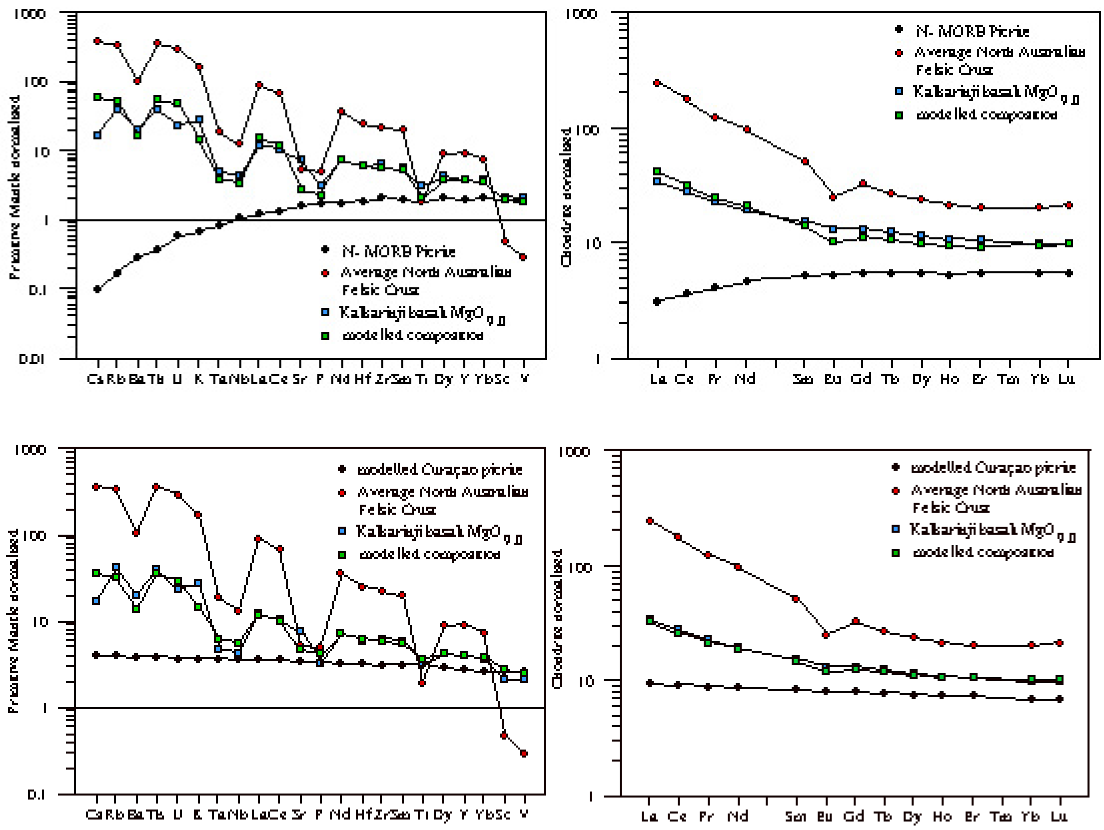


Figure 4: Primitive mantle-normalised and Chondrite-normalised plots showing results for assimilation and fractional crystallisation of initial liquid compositions NMORB and Curaçao picrites with the assimilant NAFC (North Australian felsic crust). Normalising values from McDonough & Sun (1995).

Considering that Sr isotopic ratios and abundances are extremely variable over northern Australia, a range of potential assimilant compositions were chosen. Of the three highly isotopically enriched Kalkarinji samples, two require a greater component of assimilation of the same crust, while the most isotopically evolved sample (MR001) can be modelled by a two-stage mixing process, with the second enrichment event involving crust of different (older) isotopic composition, Figure 5.

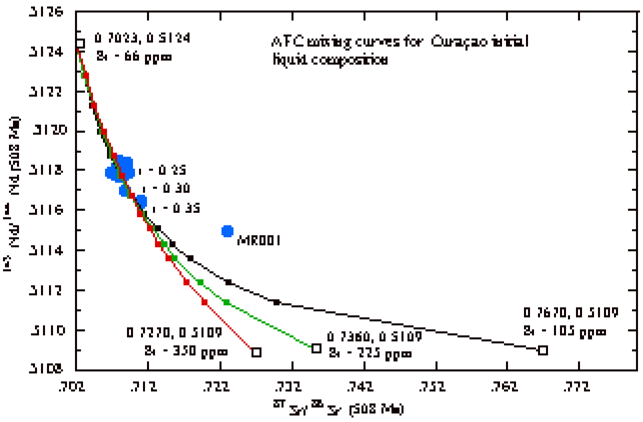


Figure 5: Initial $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ for the Kalkarinji basalt and dolerites, showing Assimilation and Fractional Crystallisation (AFC) mixing curves for Curaçao picrite using variable Sr concentrations and model Nd crustal compositions with Archaean inheritance . Values of r (mass assimilated/mass crystallised) are indicated for the main array of data and for the two slightly more enriched samples. Approximately 10% of assimilation is required for the majority of the Kalkarinji province.

An estimate of segregation depth for the Kalkarinji parental picrite magma can be calculated from the 9% wt MgO basalt composition by the removal of 10–15% NAFC and addition of olivine to achieve equilibrium with mantle olivine. The resulting composition was projected into the basalt tetrahedron and compared with partial melting cotectics of Falloon & Green (1988) see Figure 6. On this basis, it is determined that the parental picrite magma segregated from its source peridotite at ~15–20 kbar equivalent to shallow depths of ~50–70 km in the mantle.

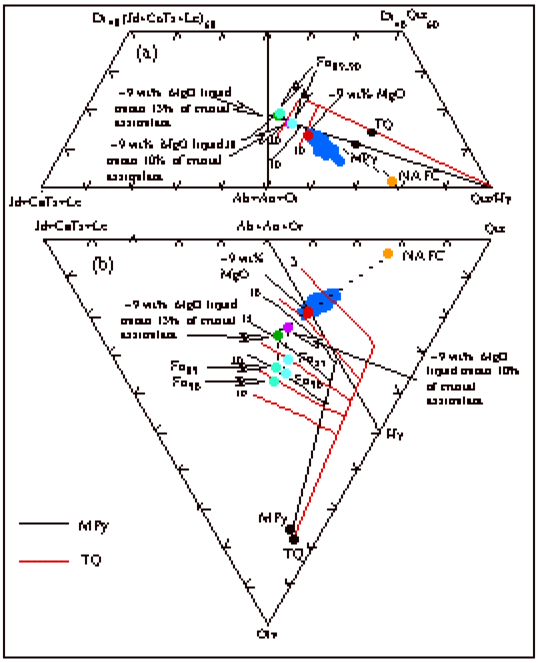
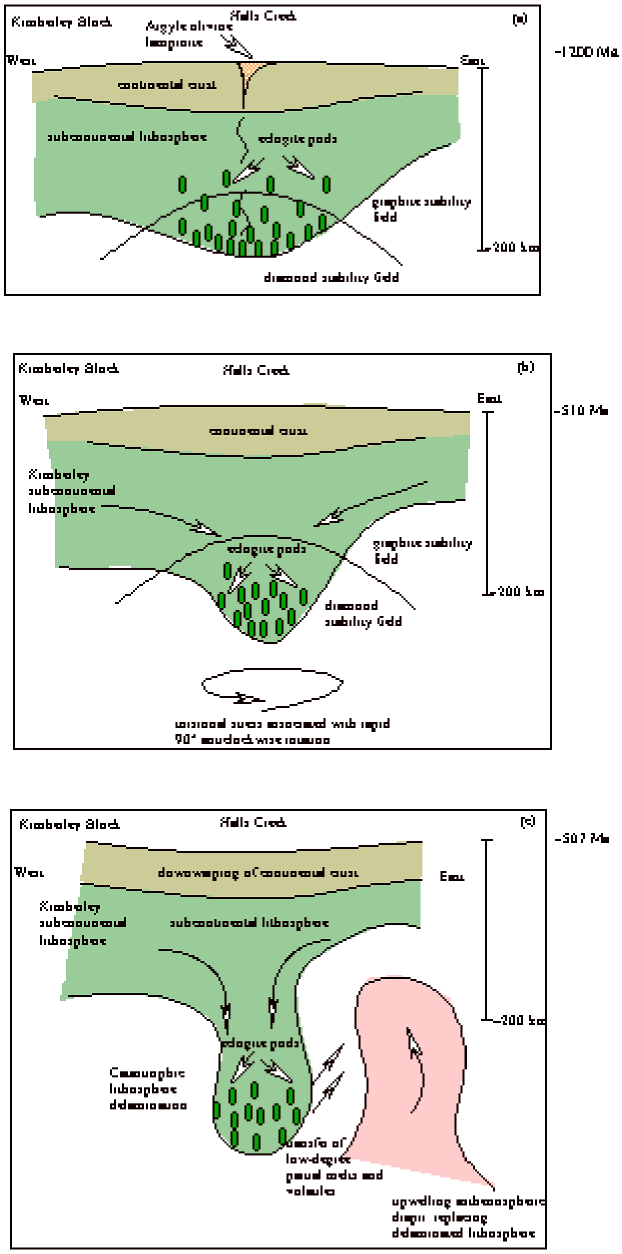


Figure 6: Peridotite partial melting cotectics projected into the basalt tetrahedron. After Green (1970), Falloon & Green (1988) and Falloon et al. (1999). Picture (a) shows the projection from olivine and (b) the projection from diopside. Di = diopside, Jd = jadeite, CaTs = calcium tschermak, Lc = leucite, Ab = albite, An = anorthite, Or = orthoclase, Hy = hypersthene, Olv = olivine, Qtz = quartz, TQ = Tinaquillo lherzolite, Mpy = MORB pyrolite and NAFC = average North Australian Felsic Crust (shown in yellow). The dark blue field defines the range of the most fresh Kalkarinji basalts. The dashed line shows the relationship between the pre-assimilant composition and the crustal contaminant. Pressure expressed as kilobars. The red dots represent the most primitive Kalkarinji basalt, ~9 wt% MgO. The pink dots represent this composition with 10% NAFC removed and the green dots with 15% removed. The pale blue dots represent the final compositions in equilibrium with mantle olivine, Fo_{89-90}.

Although the determined segregation depth is ~50–70 km, in Proterozoic times, eclogite-rich, sub-continental lithosphere at least 200 km thick underlaid the future centre of Kalkarinji volcanism in the East Kimberley region. The presence of such thick lithosphere presents great difficulties for mantle plume models because the plume cannot rise to realistic segregation depths beneath such a barrier. The plume centre would need to be located on the continental shelf, e.g. Bonaparte Gulf to the north, where the lithosphere is considerably thinner, however, this is hundreds of kilometres north of the inferred locus of Kalkarinji volcanicity. Alternatively, in order for parental picritic magmas to segregate from their source at 50–70 km, a substantial portion of the lithosphere would need to be removed by 508 Ma. It is possible that the anomalous ~90° rapid anticlockwise rotation of the Australian continent around the time of basalt eruption was a trigger for catastrophic failure of dense, unstable, eclogite-rich subcontinental lithosphere beneath the East Kimberley region, the presumed locus of Kalkarinji volcanism. The sinking lithospheric delaminate would be replaced by an equal volume of upwelling asthenosphere. It is postulated that the upwelling asthenospheric diapir experienced partial melting assisted by degassing of volatiles released from the sinking lithosphere, Figure 7. This model can explain features of some continental flood basalt provinces that cannot be explained by mantle plumes including the absence of regional uplift and association between continental flood basalt provinces and cratonic margins.



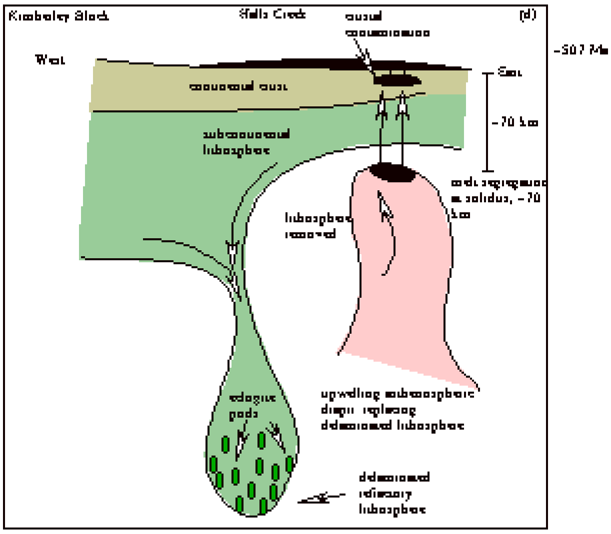


Figure 7: Raleigh-Taylor instability model based on the gravitational instability model of Houseman & Molnar (2001) showing the effect of torsional stress on the eclogite-rich, sub-continental lithosphere as a function of rapid 90° anticlockwise rotation of the Australian continent during the Early Cambrian. (a) At ~1200 Ma, at the time of Argyle olivine lamproite emplacement, mineral inclusions in diamond indicate that the depth of lamproite segregation was ~60 kbars, equivalent to ~180 km depth. This implies that the subcontinental lithosphere had to have been at least this thick at this time. In addition, mineral inclusions in diamond are dominantly eclogitic, implying that dense eclogite is present in the lithosphere in this region. (b) At ~510 Ma the Australian part of the Gondwana landmass underwent rapid 90° anticlockwise rotation. This sudden change in plate orientation may have provided the required torsional stress to weaken the dense, eclogite-rich lithosphere. (c) The weakened lithosphere may then have catastrophically delaminated allowing a rising asthenospheric diapir to rise. More easily fusible components of the lithosphere and volatiles (e.g. phlogopite in lamproites and lamprophyres) may be incorporated into the uprising diapir. (d) Melt segregation of the asthenosphere would occur when the solidus is intercepted, ~50–70 km. The partial melts of picritic composition would rise through the thinned lithosphere and assimilate North Australian felsic crust in shallow magma chambers in the crust prior to volcanism.

Crustal contamination of the Kalkarinji parental picritic magma by average North Australian Felsic Crust (NAFC) and subsequent mixing in magma chambers or sills, was followed by extensive crystal fractionation accompanied by further minimal but measurable assimilation of crust prior to the extrusion of mafic lavas and intrusion of dyke/sill systems in the upper crust.

Computational petrology and pyroxene thermodynamics

S. Sommacal, M. Sambridge and H.StC. O'Neill

A thermodynamically based algorithm to describe phase equilibria between coexisting clinopyroxene and orthopyroxene as a function of composition, temperature and pressure has been developed. Included in the algorithm is a new way to represent the Gibbs free energy (***G***) for any multi-phase system, which has, at this stage, been formulated for silicate/oxide systems.

For every phase *ø* in the system the molar Gibbs free energy $G^{\phi} = G(T,P,X_{ik}^{\phi})$, is a function of temperature (T), pressure (P) and composition, as expressed by (X_{ik}^{ϕ}), the site occupancy of cation *'i'* in sublattice *'k'*. The usual expression of G^{ϕ}:

$$G^{f} = G^{end\text{-}members} + G^{ideal} + G^{excess}$$

is given by the sum of contributions from: 1) the Gibbs free energy of all possible stoichiometric, charge-balanced end-members, 2) ideal entropy mixing on sites, and 3) excess mixing terms. The principle underlying the formulation of the term due to the Gibbs free energy of the end-members has been elucidated. As an example, the expression of this term for a general (Na-Ca-Mg-Fe^{2+}-Al-Cr-Fe^{3+}-Si-Ti) pyroxene system (32 end-members) has been derived. Appropriate expressions for the ideal and excess parts of G^{ϕ} were found in the literature. The total **G** of a system is then given by $G = \sum_{\phi=1}^{p} n^{\phi} G^{\phi}$, where n^{ϕ} = number of moles of phase *ø*, G^{ϕ}= free energy per mole of phase *ø*, and *p* = number of phases *ø* in the system.

The Gibbs Free Energy Minimum Principle states that the equilibrium value of any unconstrained parameter in a system in contact with a temperature and pressure reservoir minimizes the Gibbs free energy (***G***) at constant temperature and pressure. It follows that at any given temperature and pressure a closed multi-phase system is at its equilibrium condition when the chemical composition of the phases present in the system and the number of moles of each are such that the Gibbs free energy of the system reaches its minimum value.

From a mathematical point of view, the determination of equilibrium phase assemblages can, in short, be defined as a constrained minimization problem. To solve the Gibbs free energy minimization problem two different approaches ('*inverse*' and '*forward*') have been undertaken. For the 'inverse' problem, a *chi-square* measure method of data-fitting is used while in the 'forward' the minimization is carried out with a 'Feasible Iterate Sequential Quadratic Programming' method (FSQP). The system's Gibbs free energy is minimized under mass balance, stoichiometry, charge balance and positivity constraints.

Initial application of the programs is to assemblages of coexisting pyroxenes (orthopyroxene, and low Ca- and high Ca clinopyroxene) in CaO-MgO-FeO-SiO_2 (i.e. CMFS), CaO-MgO-Al_2O_3-SiO_2 (i.e. CMAS) and CMFAS systems. Solid solution parameters and thermodynamic data for mineral end-members in such systems have been refined and, when necessary, new parameters/data have been derived. Phase relations within the above systems and their subsystems have been calculated over a wide range of temperatures and pressures and favourably compared with experimental constraints.

Ultra-calcic magmas generated from Ca-depleted mantle

M.W. Schmidt[1,] D.H. Green and W.O. Hibberson
1. ETH, Zürich

Ultracalcic or ankaramitic magmas are ubiquitous in arc, ocean island and mid ocean ridge settings either as lavas or melt inclusions. They are primitive in character (X_{Mg}>0.65) and have CaO-contents (>14 wt%) and CaO/Al_2O_3-ratios (>1.1) which are beyond the values of picritic or basaltic magmas other than olivine melilitites and related extremely undersaturated magmas. Experiments on an ankaramite from Epi, VanuAtu arc, demonstrate that its liquidus surface only has clinopyroxene at pressures of 15 and 20 kbar, and X_{CO2} in the volatile component from 0 to 0.86. The parental Epi-ankaramite is thus not an unfractionated melt. However, forcing the above ankaramite experimentally into saturation with olivine, orthopyroxene, and spinel, ultracalcic magmas with CaO/Al_2O_3 of 1.21 to 1.58 are obtained. The experimental magmas are not extremely Ca-rich but high in CaO/Al_2O_3-ratio (to 1.58) and in MgO (up to 18.5 wt%), and would evolve to high CaO-magmas through olivine fractionation. Fractionation models show that the Epi-parent magma can be derived from such ultracalcic magmas through mainly olivine fractionation.

We show that the experimental ultracalcic magmas would form through low degree melting of somewhat refractory mantle. The latter would be depleted by previous melt extraction which increases the CaO/Al_2O_3 ratio in the residue as long as some clinopyroxene remains residual. The above finding corrects the common assumption that ultracalcic magmas must come from a Ca-rich pyroxenite-type source. The temperatures necessary for the generation of ultracalcic magmas are 31350°C, their presence in arcs would thus suggest melting regimes in the arc environment which are at the upper temperature end of previous interpretations made on the basis of arc picritic and boninitic magmas.

Island arc ankaramites from refractory lherzolitic mantle

D.H. Green, M.W. Schmidt[1] and W.O. Hibberson
1. Institute of Mineralogy and Petrology, ETH, Zürich

The distinctive island arc ankaramites exemplified by the active VanuAtu Arc may be produced by melting of refractory lherzolite under conditions in which melting is fluxed by ($H_2O + CO_2$). Parental picritic ankaramite magmas with maximum CaO/Al_2O_3 ratios to 1.5 are produced by melt segregation from residual chromite-bearing harzburgite at 1.5 GPa and ~1320-1350°C. Dissolved C-H-O fluids lower liquidus temperatures by ~150°C. A pre-condition for derivation of such high CaO/Al_2O_3 melts from orthopyroxene-bearing sources/residues is that the residual spinel has Cr#70 and residual pyroxenes have low Al_2O_3 (< 2 wt%) and high Cr_2O_3 (> 1 wt%). These characteristics of source composition and melt fluxing by volatiles are achieved in those island arcs in which a dolomitic carbonatite melt [developed in the P,T environment of the inverted geotherms of the mantle wedge] is able to migrate into the overlying higher temperature back-arc to wedge mantle flow. The parental ankaramitic picrites begin degassing CO_2-rich (C-H-O) fluids at ~1 GPa and their phenocryst characteristics [olivine with Mg#94, low NiO (~0.3%) and high CaO content (0.3%) and spinel with Cr#70, relatively high Fe_2O_3 contents] reflect both the degassing reactions and the distinctive melt composition.

Other primitive arc and back-arc magmas such as boninites (low-Ca and high Ca) share the primitive signatures of island arc ankaramites (liquidus olivine >Mg_{90}, spinels with Cr#>70). Consideration of relative proportions of Na_2O, CaO and Al_2O_3 in these primitive arc magmas leads to the inference of a common factor of refractory mantle source which has already lost a melt fraction in MOR or Back-Arc settings. Melting of this material may be fluxed by H_2O-rich fluid in which case the major element characteristics (including low Na_2O/CaO and CaO/Al_2O_3) of the refractory source are reflected in the primitive melts (high CaO-boninites, tholeiitic picrites). Alternatively, melting may be fluxed by hydrous dacitic to rhyodacitic melt derived from the subducted slab (garnet amphibolite to eclogite melting). In this case, higher Na_2O/CaO, lower CaO/Al_2O_3 and higher SiO_2 contents characterize the low-CaO boninites and residues are refractory harzburgites (olivine, orthopyroxene and chromite (Cr#80). If melting is fluxed by dolomitic-carbonatite melt [with or without additional water-rich fluid], then parental magmas are island arc ankaramites with low to variable Na_2O/CaO and high CaO/Al_2O_3.

A 3.46 Ga impact tsunami breccia/conglomerate and geochemical meteoritic signatures of Archaean impact clusters, Pilbara Craton, Western Australia

A.Y. Glikson, J. Vickers[1], B.M. Simonson[2], A.H. Hickman[3], I. Williams[3], M. Van Kranendonk[3] and C. Allen

1. Department of Geology, ANU2.
2. Oberlin College, Oberlin, Ohio
3. Geological Survey of Western Australia

Pioneering research of asteroid impact fallout units in the Pilbara Craton (Lowe and Byerly, 1986; Byerly et al., 2002; Simonson, 1992; Simonson and Hassler, 1997; Simonson et al., 1998, 2000a,b; Hassler et al., 2000; Hassler and Simonson, 2001) identified microkrystite (impact vapor-condensate) spherules and microtektite (impact melt fragments and droplets)-rich units, including (a) bands, lenses and dispersed microspherules in ~3.46 Ga chert/arenite intercalations in the Apex Basalt, Warrawoona Group (Figure 1); (b) >2.63 Ga spherule lenses and spherule-bearing intraclast conglomerate (JIL) associated with the transition from the Jeerinah Formation to the Marra Mamba Iron Member; (c) stratigraphically consistent spherule beds in the 2.56 Ga shale/carbonate Bee Gorge Member, Wittenoom Formation (SMB) and in probably contemporaneous tsunami-disrupted carbonates of the Carawine Dolomite (STM), and (d) thick (<80 cm) spherule-rich units in 2.49 Ga S4 Macroband of Dales Gorge Member (S4M), Brockman iron Formation.

New observations (Glikson and Vickers, in preparation) include (1) identification of microkrystite-bearing conglomerate located stratigraphically about 200 m below the original impact fallout unit of the Apex Basalt and microkrystite-bearing chert pebbles, indicating multiple impacts and intermittent volcanism; (2) suggested multiple impacts in the SMB, Wittenoom Formation, based on consistent undisturbed intermediate sediments; (3)

observation of Ni-rich Fe oxides in the JIL and S4M, and of Ni metal, oxide, sulphide, and arsenide micron-scale particles in the S4M; (4) identification of high Ni/Co, Ni/Cr, Ni/Mg and Ni/Fe ratios in microkrystites, consistent with meteoritic contributions (Figure 2); (5) identification of low Pd/Ir and Pt/Ir ratios in microkrystites, interpreted in terms of loss of volatile PGE (Pd, Au) relative to more refractory PGE (Ir, Pt) upon microkrystite condensation. Complete gradations are observed between vapor condensate products (microkrystite spherules) and meta-glass particles (fragmental microtektites), attesting to melt/volatile fractionation in the vapor cloud. The domination of pseudomorphs of quench crystallites (after olivine? and pyroxene?) and of chlorite in spherules and the apparent absence of shocked PDF-bearing quartz grains support the suggestion by Simonson et al. (1998) of oceanic impact sites.

The dominance of K-feldspar shells in microkrystites and microlitic K-feldspar in microtektites is attributed to resorption of potassium from sea water into settling glass droplets and fragments, followed by devitrification represented by characteristic inward-radiating K-feldspar crystal fans first described by Simonson (1992). Preservation of Ni metal particles and quench ilmenite within the K-feldspar places limits on subsequent deuteric/burial alteration. Attempts at determining the K-Ar and O isotopes of the K-feldspars (Uysal and Golding, in progress) may clarify temperature and age parameters.

Regional mapping of the microkrystite and microtektite-bearing tsunami mega-breccia marker unit (STM) of the lower Carawine Dolomite in the East Pilbara (Rippon Hills and Warrie Warrie Creek area) indicates a distribution over an area in excess of 100 km N-S. The chaotic-structured megabreccia is interpreted in terms of autochthonous to subautochthonous tsunami disruption of the sea bed, including excavation of consolidated sedimentary substratum, attested by meter-scale blocks and near-absence of imbricated mass-flow structures. Deformed semi-ductile blocks are present. Field relations indicate injection of liquefied microkrystite-rich muds/microbreccia into fractures in the substratum under hydraulic pressures in excess of friction/grinding pressures, evidenced by near-perfect preservation of impact spherules and microtektites within breccia and microbreccia veins. The correlation of Pb-Pb whole rock carbonate age of the STM with the 2.56 Ga age of the SMB (Woodhead et al., 1998) supports their contemporaneity and a propagation of the tsunami wave from NE to SW suggested by Simonson and Hassler (1997) and Hassler and Simonson (2001). Meter-size chert and BIF boulders within the S4M impact fallout unit are interpreted as erratic tsunami-transported blocks.

Estimates of projectile diameters based on Ir mass balance calculations and on thermodynamic modeling of melt/vapor atmospheric fractionation of the ejecta (Melosh and Vickery, 1991) indicate JIL and SMB projectiles in the order of ~ 10 km and a Dales-S4 projectile several tens of km large. The few hundred micron-scale of Warrawoona Group microkrystites, with ensuing difficulty in field identification, suggests possible wider occurrence and encourages further field search. The close similarity in appearance between S4M-type impact fallout units and fine volcanic ash likewise justifies further investigation of the Brockman Iron Formation and similar units. Considering the methodological difficulties in field recognition of new impact fallout units, impact signatures may be more common in Archaean terrains than hitherto recognized, with significant implications for the understanding of the origin of the early terrestrial crust.

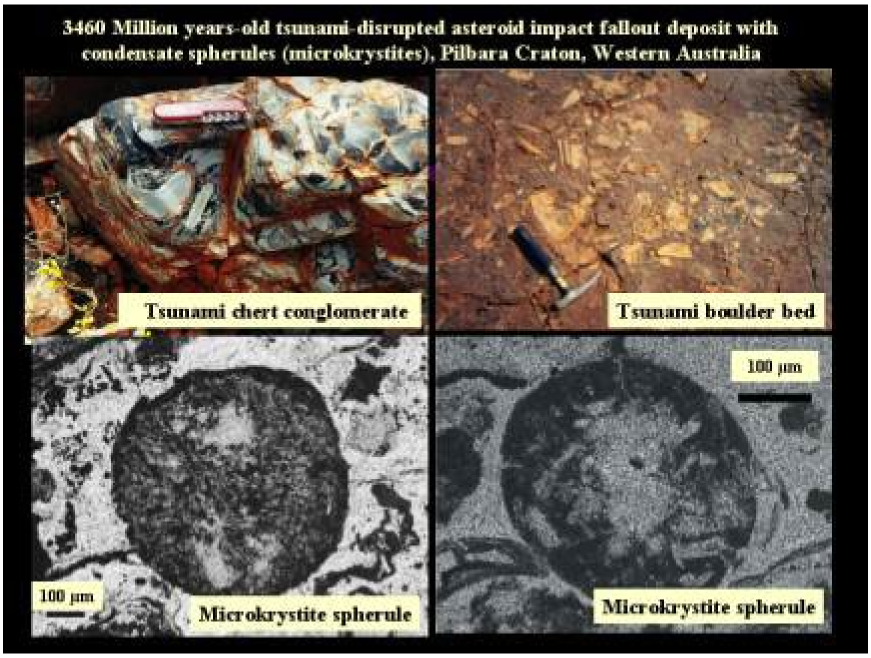


Figure 1 Chert conglomerate, boulder breccia, and microkrystite spherules within sedimentary chert/arenite intercalation of the 3.46 Ga Apex Basalt, North Pole dome, central Pilbara Craton, Western Australia.

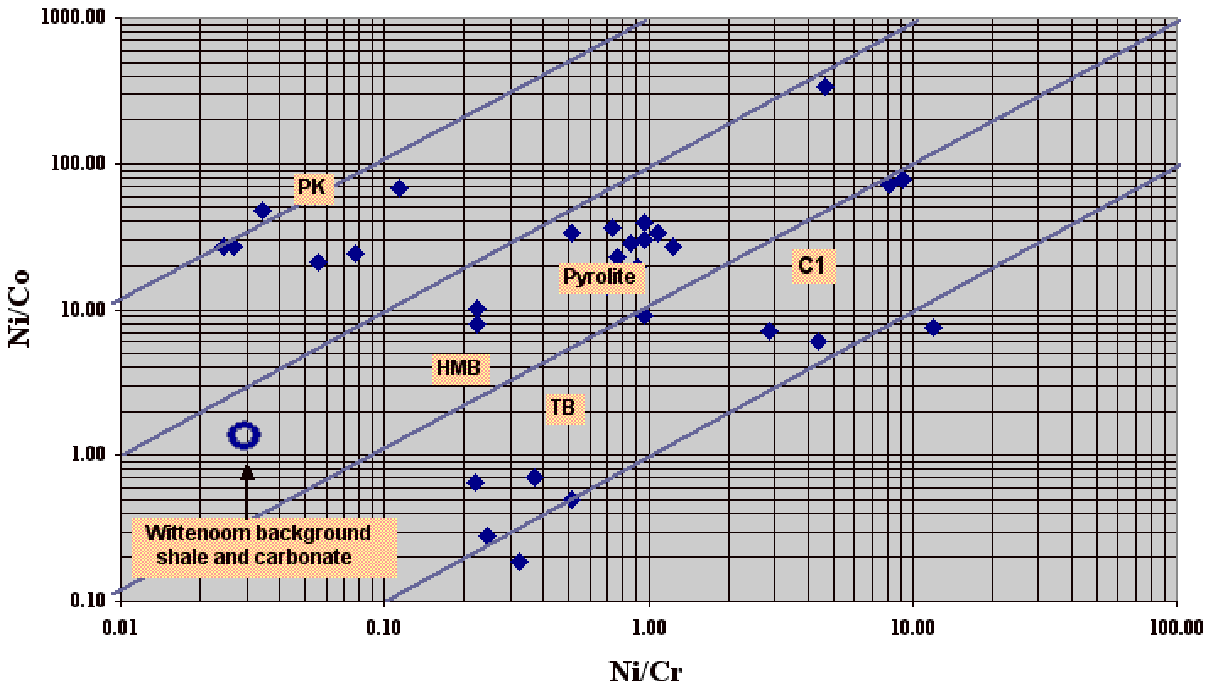


Figure 2: Ni/Co - Ni/Cr relations in Pilbara and Hamersley microkrystite impact condensate spherules (diamond symbols) compared to the mean composition of Archaean Pilbara volcanics. TB - tholeiitic basalt; HMB - high Mg basalt; PK - peridotitic basalt; C1 - C1 chondrite; Pyrolite - model mantle peridotite; Circle - average composition of Hamersley basin shales and carbonates

Mineralogy and chemistry of hydrothermally altered shock metamorphosed granitoids, Woodleigh impact structure, Carnarvon Basin, Western Australia

A.Y. Glikson, S. Eggins, S. Golding[1], P.W. Haines[2], R.P. Iasky[3], T.P. Mernagh[4], A.J. Mory[3], F. Pirajno[3], and T. Uysal[1]

1. Department of Earth Science, The University of Queensland, QLD
2. School of Earth Science, University of Tasmania, Hobart, TAS
3. Geological Survey of Western Australia., East Perth, WA
4. Australian Geological Survey Organization, Canberra, ACT

Shock metamorphosed biotite K-feldspar Na-rich-alkali-feldspar plagioclase quartz granitoids from the uplifted basement core of the Woodleigh impact structure, Western Australia, consist of crush-banded granitoids, containing evidence of derivation from regionally metamorphosed granitoid gneiss. The crushed gneisses are pervaded by clay-dominated intergranular and intragranular veins of cryptocrystalline components which display marked departures from host rock and mineral compositions. Feldspar planar deformation features (PDF)-hosted reticulate vein networks result in checkerboard-like to irregular ameboid-like patterns, attributed to preferential replacement of shock-damaged PDF and twin lamella by clay minerals. XRD analysis identifies the cryptocrystalline components as interleaved illite/smectite, illite and chlorite, while laser Raman analysis identifies high fluorescence submicron clay assemblage, feldspar, quartz and minor mica. SEM/EDS-probe and laser-ICPMS analysis indicate low-K high-Mg clay mineral compositions, corresponding to montmorillonite. Quartz PDF-hosted cryptocrystalline laminae (Figure 1) display distinct enrichments in Al, Mg, Ca and K. Altered intergranular veins and feldspar-hosted cryptocrystalline components show consistent enrichment in the relatively refractory elements (Al, Ca, Mg, Fe) and depletion in relatively volatile elements (Si, K, Na). The clay alteration does not allow determination of the origin of the clay-dominated networks as due to either (1) replacement of shock-induced pseudotachylite veins, diaplectic zones and shock-damaged twin lamella, or/and development of these textures as clay alteration patterns, including chemical differentiation associated with penetration of hydrothermal fluids into intergranular and intragranular positions. Overall enrichment of the shocked granitoids and of the cryptocrystalline components in Mg and trace siderophile elements (Ni, Co, Cr) and anomalously high Ni/Cr and Ni/Co values of the cryptocrystalline components may be attributed to contamination of the hydrothermal fluids by dolomites surrounding the basement uplift or introduction from the projectile. In the latter case, the shocked granitoids were located below the transient crater floor and melt sheet, within reach of melt and/or vapor released by the impact. The consistent depletion of intergranular and intragranular cryptocrystalline components in K may be related to open system flushing of alkalies by hydrothermal fluids, with potential implications to the formation of K-rich fenite aureoles associated with some impact structures.

Shock features in quartz grains, Woodleigh impact structure (P. Haines, University of Tasmania)

Crystallographic orientations of planar deformation features (PDFs) in quartz in two thin sections of Woodleigh shocked granitoid were measured with a Leitz universal using the methods of von Engelhardt and Bertsch, (1969) and Stöffler and Langenhorst (1994). Shocked quartz grains display irregular and sub-planar fractures and common PDFs in multiple sets of up to 4 per grain. Measured PDF sets conform in appearance and spacing (2–10 mm) to the criteria set out in Stöffler and Langenhorst (1994). The sets are sharp and show little or no decoration by fluid inclusions. In total 51 sets were measured in 19 multi-set quartz grains, 80% of which could be indexed to rational crystallographic directions within the error limits allowed by the template. The majority of indexed sets are parallel to ω {10–13} or ω {01–13} with poles ~23° from the c-axis. A small number of sets lie in the basal plane (0001), with poles that coincide with the c-axis. Significantly 2 sets are parallel to π {10–12} or π' {01–12} (poles at ~32°), and one at r,z {10–11} (pole at ~52°) (Figure 2). Following Grieve et al.'s (1996) scheme for classifying progressive stages of shock metamorphism in non-porous (crystalline) targets the samples exhibit characteristics of shock stage 2 ("weakly shocked") to stage 3 ("moderately shocked"). In non-porous rocks PDFs parallel to π {10–12} first form at about 20 GPa (Grieve et al. 1996), therefore the minor occurrence of such sets suggest that peak shock pressures were approximately 20 GPa in the analyzed samples. The sharp fresh nature of the PDFs imply a minimal post-impact thermal history suggesting that these samples were close to the original surface and thus cooled rapidly after impact.

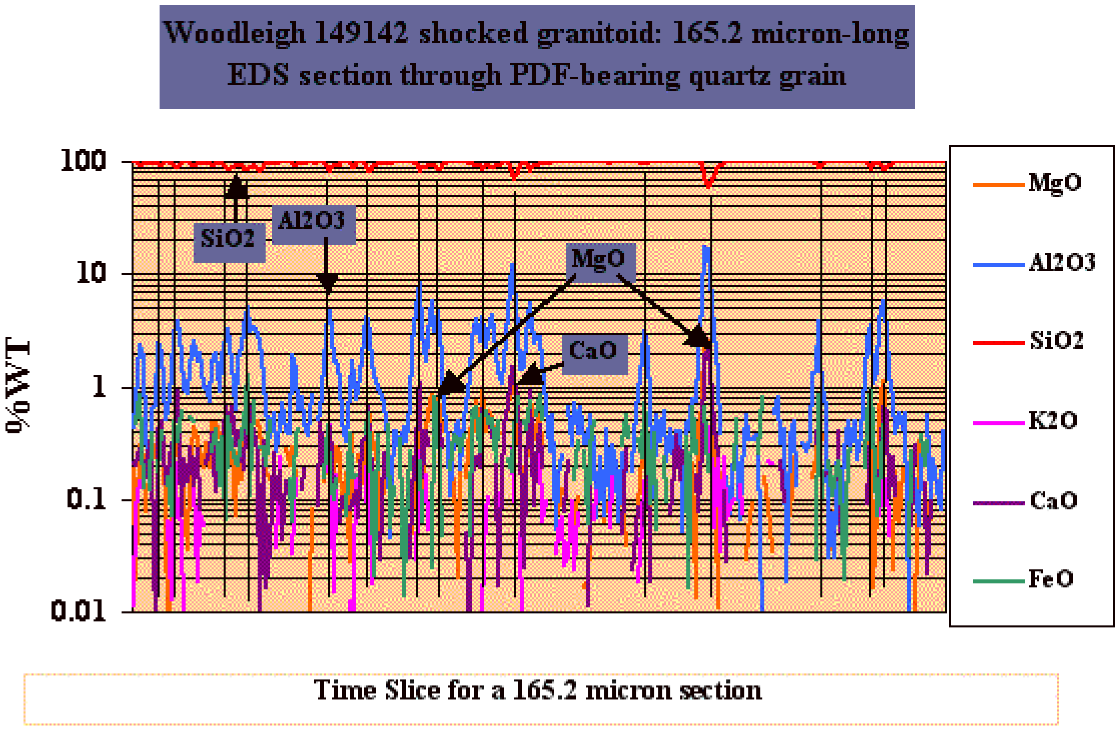


Figure 1: Laser ICPMS traverse through shocked grain of quartz with planar deformation features (PDF) showing chemical anomalies associated with PDFs due to clay mineral alteration products of original diaplectic glass lamina.

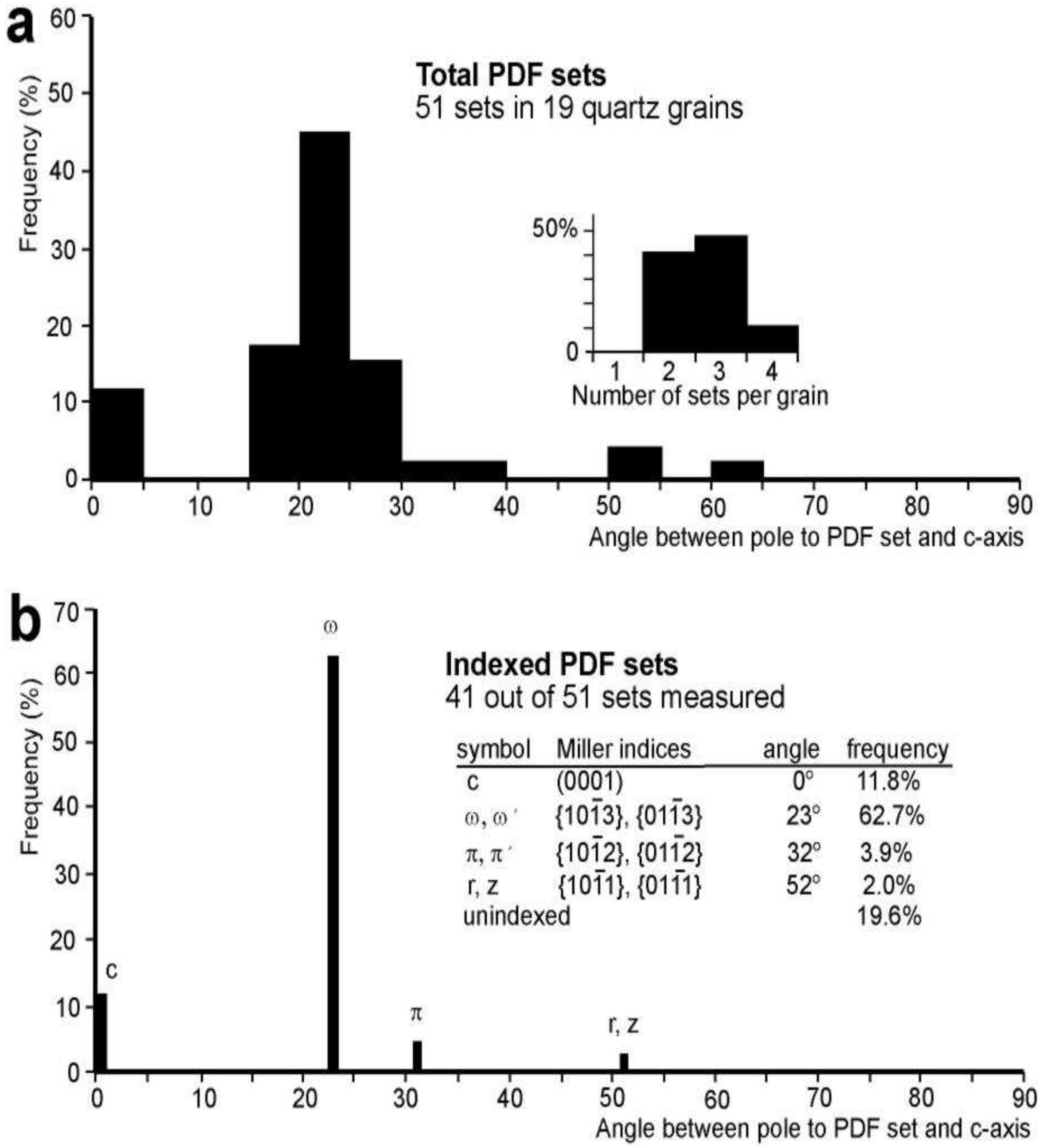


Figure 2: PDF orientation of shocked quartz grains. (a) Frequency histogram of all PDF measurements plotted in 5° bins of angle between the pole to the set and the c-axis. (b) Inset - histogram of frequency of number of measured sets per grain.

Progress in the study of Australian impact structures

The period 1997–2002 saw a spate of discoveries of exposed and buried medium to large impact structures on the Australian continent, including proven impact structures including Woodleigh, WA (Iasky and Mory, 1999, Mory et al., 2000); Flaxman and Crawford, SA (Haines et al., 1999), Foelsche, NT (Haines and Rawlings, 2002); Yarrabooba, WA (J. Bunting, F. Pirajno, F. Macdonald, pers. com., 2002) and Amelia Creek, NT (K. Mitchell and F. Macdonald, pers.com., 2002). Several likely impact structures have been identified (Camooweal, Qld (Glikson, 1996); Gulpuliyul, NT (Sweet et al., 1999), Gnargoo, WA, and structures in the Officer Basin, WA, R.P. Iasky, pers.com. Several circular structures have been examined as candidate impact structures, including Lorne Basin, NSW (Tonkin, 1989), Deniliquin geophysical anomaly, east Murray Basin (A.N. Yeates et al., pers.com., 1999), a ~100 km-large TEM (Thematic Elevation Model)-defined circular structure in the Throssell 1:250 000 Sheet area, WA (A. Whittaker, pers.com.), the submarine buried Fohn structure, Timor Sea (Gorter and Glikson, 2000) —which turned out to be a diatreme overlying a lamproite intrusion (Gorter and Glikson, AJES, in press), and submarine geophysical anomalies including Bedout (Gorter, 1996), Mercury (Gorter, 1998) and Mingobar (Gorter, 1998).

Earth Physics

Research into the structure and dynamics of the Earth uses a range of modern physical and mathematical techniques grouped into the three broad areas of Geodynamics, Geophysical Fluid Dynamics and Seismology. 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.

The observational component in 2002 has been varied with geodetic studies in Papua New Guinea, a detailed seismic experiment in southern Victoria and Tasmania, 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 models for the behaviour of the mantle under early earth conditions.

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 Australian region incorporating new data from western Australia.

Studies of the impact of glaciation and deglaciation have revealed that the sea level changes in the period 100-75 Ma are more complex than previously thought and as a result climate variability in that interval is not due simply to forcing through insolation.

In the middle of 2002 Geoscience Australia made a transfer of assets and so the Australian National Seismic Imaging Resource (ANSIR) Major National Research Facility is now based at RSES in Earth Physics with Porf. Kennett as Directror.

The facility sustains both reflection profiling equipment and portable recording instrumentation for use in major field experiments.

Geophysical Fluid Dynamics (GFD) is the study of fluid flows and their roles in transporting heat, mass and momentum in the oceans, atmosphere and the earth's deep interior. It examines the dynamical processes underlying the climate system, climate change and the evolution of the solid earth. In RSES, the research in GFD 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 the convection of the solid silicate mantle, with its implications for plate tectonics.

GFD emphasises the importance of dynamical modelling, and much of the research program at RSES is anchored strongly in experimental fluid dynamics. The research relies on the excellent facilities of a new 400 sq. m laboratory and workshop area, opened in March 2000, with services designed to cater specifically for a range of geophysical scale experiments. The program relies also on advanced computing facilities, both within the Research School and in the National Facility of the Australian Partnership for Advanced Computing (APAC) located at ANU.

Figure 1: Work in progress in the GFD laboratory. Claire Menesguin (left) is a MSc student visiting from ENS, France, for a 6 month research project, and is working with Dr Andrew Kiss (centre). They are using Particle Image Velocimetry software to analyse the vorticity dynamics and stability of a model Western Boundary Current similar to the East Australia Current. The flow is generated in the experimental apparatus on the rotating table (seen in the background and cloaked in a black curtain for photographic purposes).

The ocean dynamics projects in GFD this year included basin-scale circulation driven by the surface wind-stress and mechanisms important to the buoyancy-driven thermohaline circulation. Numerical and laboratory modelling of wind-driven circulation, and the instabilities of intense Western Boundary Currents generated by this forcing, was continued by A. E. Kiss, an Australian Postdoctoral Fellow (ARC). He used a laboratory model flow driven by a horizontal surface stress and placed on the rotating table (figures 1 and 2), along with a numerical scheme designed to simulate the laboratory experiment.

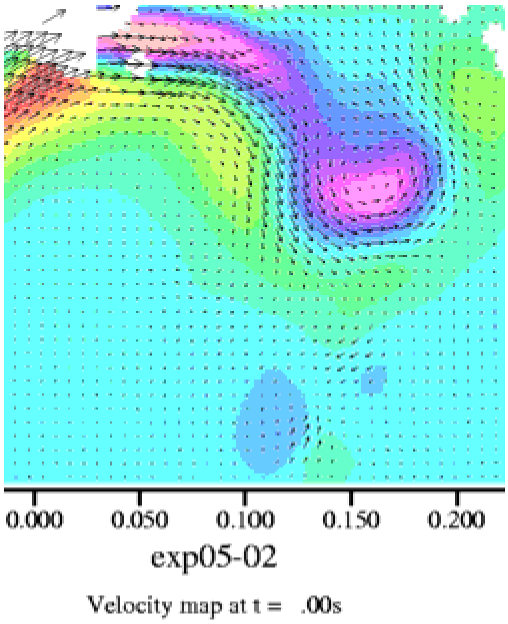


Figure2. Velocity vectors (arrows) and vorticity (colours) obtained from laboratory experiments, showing eddy shedding from a separated western boundary current.

A study of processes relevant to the global thermohaline circulation of the oceans and its climatically important fluctuations was continued by Prof. R. W. Griffiths, Dr G. O. Hughes and PhD student J. C. Mullarney. In this study a convective circulation was driven by a horizontal gradient of surface heat flux and a simultaneous input of relatively fresh water at one end, the latter mimicking greater freshwater inflow to the oceans at high latitudes. The system was found to have oscillatory behaviour for steady forcing under some values of the ratio of heat and freshwater buoyancy fluxes. Numerical solutions were obtained for the purely thermally-forced case at very large Rayleigh numbers and for a basin width much wider than the water depth.

The laboratory was host to an undergraduate research project, on buoyancy-driven exchange flows, of a student from the Department of Physics and Theoretical Physics. A Visiting Fellow, Prof. G. Veronis of the Department of Geology & Geophysics, Yale University, spent 5 months carrying out experiments with Prof. J. S. Turner on horizontal and vertical heat transport and rates of surface ice melting in the presence of a density stratification. The latter was motivated by observations of a large thermal anomaly at depth in the Arctic Ocean and provided measurements of heat transport with which theoretical analyses will be compared.

In the area of mantle dynamics Dr Davies continued modelling of the stirring of chemical heterogeneities in the convecting mantle, where motion is driven by internal heating and the subduction of lithospheric plates. One conclusion is that the concentrations of radioactive heat sources in much of the "depleted" mantle are still quite uncertain, and in particular that they could be substantially higher than has usually been inferred. It is also possible that residual primitive helium (helium-3) could persist in subducted remnants of early mafic crust. In examining the dynamics of the very early mantle the stirring models have shown that a low viscosity in the upper mantle can permit relatively rapid settling of the heavier basaltic component, which sinks into the lower mantle. The result is that two compositional zones develop.

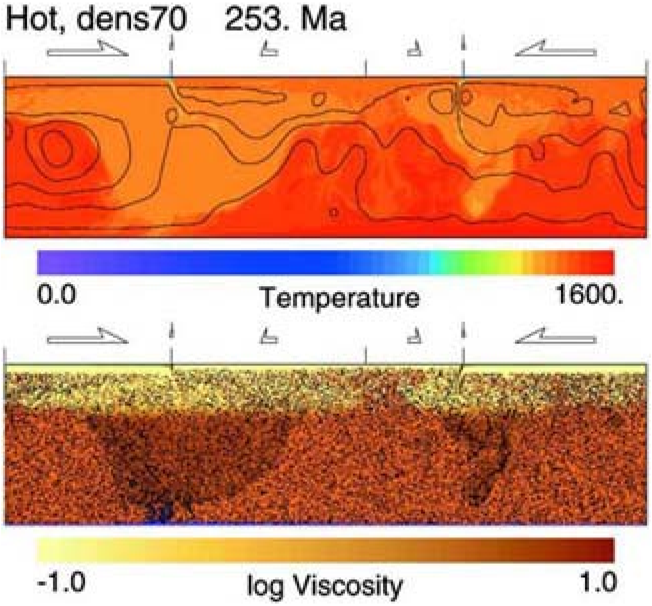


Figure 3. Images from a numerical model of the Hadean mantle. Upper panel: temperature and streamlines. Lower panel: tracers plotted over the viscosity structure. Viscosity is temperature-dependent with a superimposed increase by a factor of 30 entering the lower mantle. Tracers simulate basaltic component (orange), which melts to form oceanic crust (green) before being subducted (black). Blue tracers have passed through the lower 20 km of the model, which is a potential plume-feeding zone. Tracers have a density excess of 70 kg/m3, which causes them to settle out of the low-viscosity upper mantle, but not out of the higher-viscosity lower mantle. Two "fluids" have developed, a cooler depleted fluid over a hotter, enriched fluid.

In another project examining stirring in the mantle, Dr C. Meriaux and Dr R. C. Kerr carried out experiments in which they determined the pattern of tracers expected at the Earth's surface due to hot up-welling plumes, if these draw on compositional heterogeneities at their source.

Novel laboratory experiments in mantle dynamics were also carried out by a Visiting Fellow, Prof, C. Kincaid, who spent 12 months at ANU while on sabbatical from the Graduate School of Oceanography, University of Rhode Island. These experiments explored the thermal evolution of slab surface temperature and the mantle circulation as an oceanic plate subducts into the hotter mantle. Effects of slab sinking speed, slab dip and roll-back subduction were studied by forcing a rigid model plate into a tank of very viscous syrup with various components of motion. The results showed marked differences in the temperature-depth trajectories for the slab surface (implying different melting histories), and these are can be related to the differing patterns of three-dimensional flow in the surrounding mantle.

The modelling of physical processes in volcanology was again a highlight in the laboratory activity. In collaborative work with volcanologist Professor K.V. Cashman from the University of Oregon, Prof. R. W. Griffiths and Dr R. C. Kerr carried out experiments to study the solidification of channellized basaltic lava flows. In the experiments polyethylene glycol flowed down a long sloping channel under cold water. The flow surface solidified in different patterns depending on the thermal conditions, slope and flow rate, and could form either a well-insulated flow through a lava tube or flow with only a relatively small amount of mobile solid crust on its surface. This work provided a criterion that distinguishes between conditions giving lava tubes and those giving open lava channels. More generally, it demonstrates the usefulness of fluid dynamics experiments as a tool for learning about the complicated processes that govern solidifying lava flows. In related experiments A. Lyman, a PhD student who commenced this year, is using rapid dam releases of yield-strength slurries, with and without surface cooling, to investigate the dynamics of rapid emplacement of large andesite flows.

The group hosted a number of visitors. Two long-stay visitors, Prof G. Veronis, Yale University, and Prof. C. Kincaid, University of Rhode Island, have been mentioned above. Dr N. Stevens, from the Institute of Geological and Nuclear Sciences, New Zealand, visited for two weeks to discuss large andesite lava flows, and the group continued to enjoy the presence of Emeritus Professor J.S. Turner. Mr A. Lyman, previously of Arizona State University, commenced his PhD program and is working on the dynamics of lava flows. Prof. Griffiths again taught an undergraduate course on fluid dynamics and ocean-atmosphere dynamics in the Department of Physics and Theoretical Physics, ANU, and the laboratory hosted an undergraduate student project for the unit 'Research Projects in Physics'. Dr C. Meriaux left the Group and returned to Paris at the end of the year. The staff, students and visitors all acknowledge the vital contributions of our technical support staff, R. Wylde-Browne (who retired this year and moved to the coast to follow his sailing interests), A.R. Beasley and C.J. Morgan to our research program. Collaboration continued with Australian Scientific Instruments in sales of the 'Geophysical Flows Rotating Table'.

Research Projects

Thermal history and flow patterns in the mantle wedge above subducting plates.

C. Kincaid* and R. W. Griffiths Prof.

Chris Kincaid spent 2002 as a Visiting Fellow at RSES on sabbatical leave from the Graduate School of Oceanography, University of Rhode Island.

The aim of his visit was to carry out the first ever laboratory experiments modelling both the thermal evolution of subducting lithosphere and the three-dimensional circulation in the mantle wedge (the region between the sinking plate and the over-riding lithosphere) during 'rollback' subduction. The experiments were carried out in the new temperature-isolation facility in the Geophysical Fluid Dynamics laboratory. In the experiments a tank of glucose syrup was used to simulate the Earth's mantle (figure 4).

A plate of phenolic, or laminated plastic, was used to represent the oceanic lithosphere. Different modes of subduction were represented by driving the plate into the fluid using up to three hydraulic pistons to produce three components of motion: down-dip and rollback plate motions, and a mode of plate steepening with time. The plate was chilled to 5 degrees C and at the start of an experiment the tank of syrup is moved into the cold room so that a thermal boundary layer grows at the surface of the fluid. Over forty experiments were run covering a range in subduction parameters, including different thermal boundary layer thicknesses and the effect of back-arc spreading.

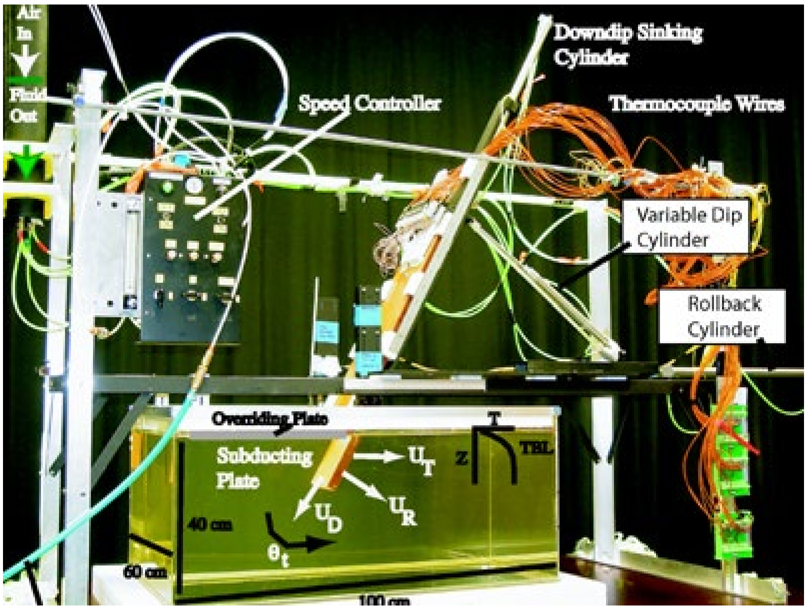


Figure 4. A photograph of the apparatus used for experiments with subducting plates. with the tank of glucose syrup that simulates the mantle. Three hydraulic piston-cylinders generate down-dip and roll-back velocities, and a variable dip angle. Rates are controlled with precision flow meters in the hydraulic lines. A Plexiglass sheet overlies the wedge region of the fluid to simulate an overriding plate, and migrates with the trench. Six rows of thermocouples (5 per row) record plate surface temperatures. The experiment is carried out in a low-temperature laboratory after a cold boundary layer has developed on the surface of the syrup.

The results with and without rollback plate motion show very different flow patterns in the wedge. When there is no rollback motion, the plate edges heated up faster than the centre of plate segments whereas, with rollback motion, plate centres heated up faster than plate edges. This was a response to focusing of mantle flow towards the centreline of the plate. Flow trajectories became steeper in the wedge (more favourable for decompression melting) in response to rollback motion and back-arc spreading, and when the dip of a plate steepened as it sank.

The experiments with and without rollback sinking also revealed distinct patterns in return flow of material into the wedge from behind the sinking slab. This has implications for models of geochemical recycling in arcs. The work is particularly timely given the recent explosion of research papers appealing to rollback plate motion in reconciling patterns found in geochemical and seismic data.

Sources of heat and helium in the dynamic mantle.

G. F. Davies

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Work has continued on the task of reconciling geochemical and geophysical constraints on mantle structure, dynamics and history. Two particularly puzzling questions regarding the geochemical constraints are where sufficient radioactive heat sources can be located and where anomalously unradiogenic helium is coming from.

Each of these questions has become so enigmatic that radical possibilities need to be explored. The argument has been developed that the concentrations of radioactive heat sources in much of the "depleted" mantle are still quite uncertain, and in particular that they could be substantially higher than has usually been inferred. Three factors are invoked to support this contention: (a) gravitational segregation, within the upper mantle, of buoyant depleted material from denser former oceanic crust, which implies that the immediate source of MORB is more depleted than average "depleted" mantle, (b) a bias towards the most depleted oceanic basalt compositions in conventional estimates and (c) refreezing of melt forming in a heterogeneous source region, which could trap a significant proportion of heat sources in "depleted" residual regions. Factor (a) is evident in recent numerical models. Factor (c) is the least constrained but potentially the most important.

An argument is also being developed that residual primitive helium (helium-3) could persist in subducted remnants of early mafic crust. Although such crust would have been substantially degassed during its formation, there would also have been higher abundances of noble gases very early in Earth's history, so the net effect could be that a significant amount of primitive noble gases are retained. The early mafic crust remnants could persist at the base of the mantle as part of the anomalous D" zone, which is plausibly interpreted as a reservoir of foundered basaltic oceanic crust, and which transforms to dense phase assemblages under mantle pressures. Recent numerical models (below) provide some initial support for the preservation of ancient subducted material in this way.

Dynamics of the Hadean Mantle.

G. F. Davies

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Initial numerical models of thermo-chemical convection in the early, hot mantle have yielded a compositionally stratified mantle through a novel interaction of compositional buoyancies with viscosity stratification. This work extends the modelling reported last year, in which models at present mantle conditions yielded long residence times and some gravitational segregation of simulated subducted basaltic oceanic crust. The basaltic component is included in the models using a large number of tracer points. The models assume an upper mantle temperature of 1550 degrees C, appropriate for the pre-4 Ga (Hadean) mantle. Because of the high temperature, the mantle viscosity is about 15 times lower than the modern mantle.

The lower mantle is assumed to be about 30 times the viscosity of the upper mantle, for which there is good independent evidence at present. The low viscosity in the upper mantle permits relatively rapid settling of the heavier basaltic component, which sinks into the lower mantle. However the lower mantle viscosity is still high enough that segregation there is slow, so most of the basaltic material remains entrained in the circulation in the lower mantle. The result is that two compositional zones develop (Figure 5): a depleted but cooler upper mantle and an enriched but warmer lower mantle.

The interface between these zones is quite sharp, although its position varies in space and time: the cooler upper layer forms large intrusions into the lower layer.

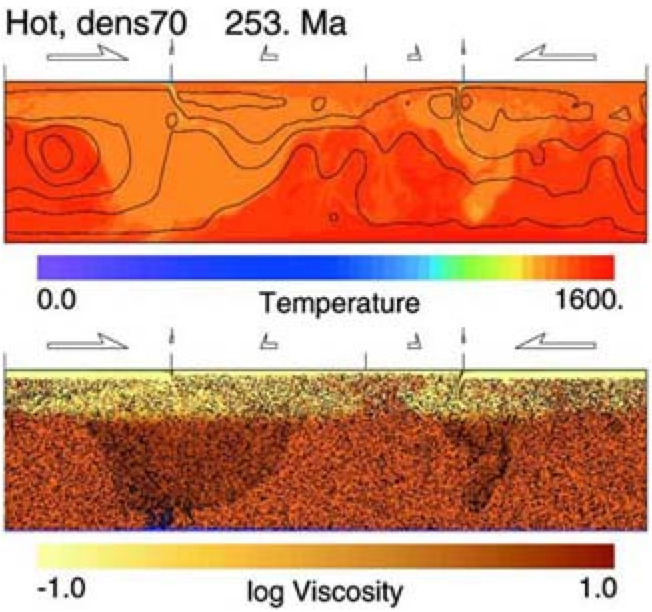

Figure 5. Images from a numerical model of the Hadean mantle. Upper panel: temperature and streamlines. Lower panel: tracers plotted over the viscosity structure. Viscosity is temperature-dependent with a superimposed increase by a factor of 30 entering the lower mantle. Tracers simulate basaltic component (orange), which melts to form oceanic crust (green) before being subducted (black). Blue tracers have passed through the lower 20 km of the model, which is a potential plume-feeding zone. Tracers have a density excess of 70 kg/m3, which causes them to settle out of the low-viscosity upper mantle, but not out of the higher-viscosity lower mantle. Two "fluids" have developed, a cooler depleted fluid over a hotter, enriched fluid.

The evolution of this system remains to be explored. It is possible that the layers could episodically mix if the upper layer cools and the lower layer heats sufficiently. In the longer term the layering is expected to dissipate, since models run at present mantle conditions do not develop this layering. However if there is a time lag in the dissipation, it is possible that some remnant could persist in the deep mantle at present.

This is a potential explanation for evidence from seismic tomography for large anomalous volumes below Africa and the Pacific (sometimes misleadingly called superplumes). The models potentially have important implications for the chronology of the accumulation of continental crust, for the geochemical evolution of the mantle and for interpreting the apparent episodic accumulation of the continental crust.

The structure of mantle plumes sheared by mantle flow.

C. Meriaux and R.C. Kerr

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This year we continued a series of laboratory experiments aimed at understanding the behaviour of "heterogeneities" rising in mantle plumes as they are sheared by overlying plate motion. In the experiments, a hot plume was generated by a circular hot plate on the base of a cylindrical tank of glycerol. The plume was then sheared by a horizontally rotating lid at the surface of the fluid. To observe the flow, two small tubes released dyed glycerol at opposite sides of the hot plate. The flow is characterised by 5 dimensionless parameters: a Rayleigh number, a Prandtl number, an aspect ratio, a viscosity ratio, and a ratio of the lid velocity to the plume rise velocity.

Our experiments are systematically varying the values of these parameters to elucidate how each affects the flow field. With no shear, we observed a vertical conduit where there was simple stretching and thinning of heterogeneities. When a weak shear was imposed, the plume was slightly tilted, and the dye stream from the upstream edge of the plate bifurcated dramatically. The hottest fluid rose close to the lid and was then dragged downstream over the downstream dye, while the cooler fluid initially flowed upstream before it then flowed down, out, and around the laterally spreading plume (figure 6a). When a strong shear was imposed, the plume was strongly tilted, which led to a cross-stream recirculation in the plume and rotation of the upstream dye to the sides of plume, while the downstream dye was dragged close to the surface (figure 6b).

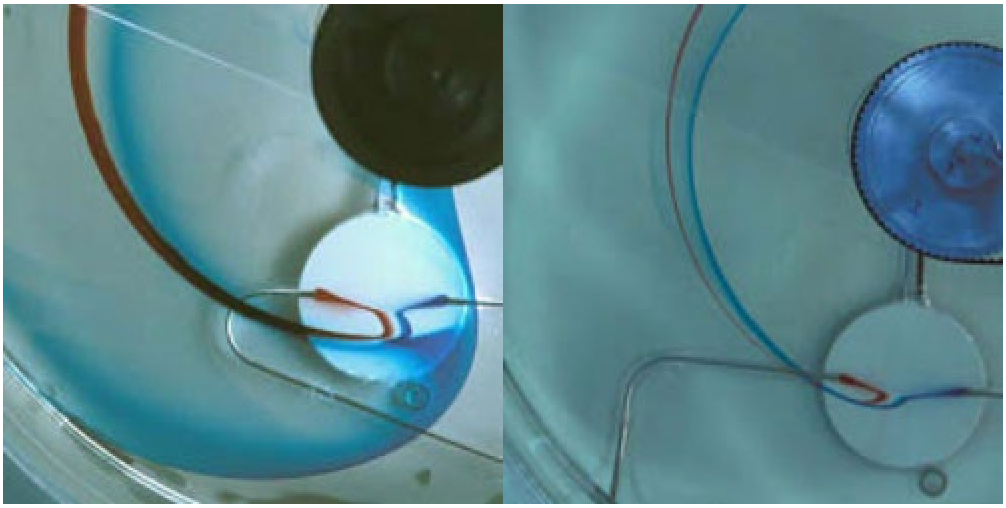

Figure 6: Overhead views of sheared thermal plumes. Left: weak shear. Right: strong shear.

Patterns of Solidification in Long Channelized Lava Flows.

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

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In a project begun last year, and in collaboration with volcanologist Professor K.V. Cashman of the University of Oregon, we are exploring the behaviour of basaltic lava flowing through long channels, with the aim of understanding the factors influencing the amount of solidification of the flow, and the resulting flow behaviour.

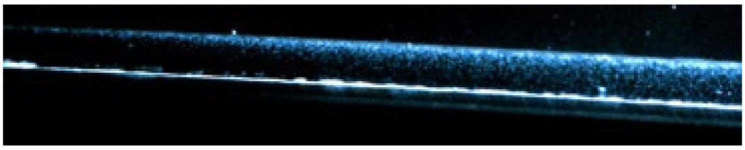

Figure 7a

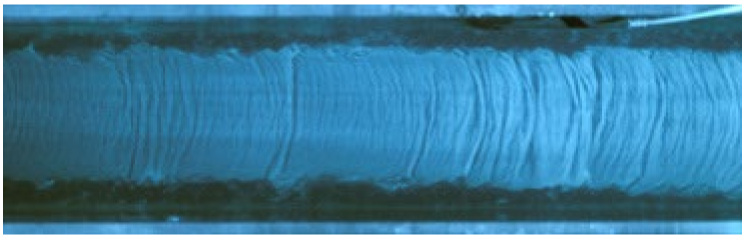

Figure 7b

Figure 7. Photographs of a steady state regime of solidification in a sloping channel flow of PEG cooled from above: a) from the side and 0 to 30 cm from the vent; b) 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 back wall and base of the tank are black. Flow is from left to right. The photographs correspond to distances from the entrance sluice gate of 0 to 60cm.

The experiments use polyethylene glycol (PEG) flows generated under cold water and flowing down a 3m-long, inclined channel. Our flows are laminar, having Reynolds numbers of 0.2 Ð 70 based on flow depth and centre-line 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 that the condition for tubes is $(U_0 t_s/H)(Ra/R_0)^{1/3} < 25 \pm 5$, where U_0 is the surface speed without cooling at the centre-line, t_s is the predicted time for onset of solidification (in an idealised initial-value problem), W is the channel width, Ra is a Rayleigh number and $R_0 = 100$ is a constant. At larger values of this parameter grouping, solid forms a raft along the channel centre-line on the flow surface, with open shear zones along the edges (figure 7). In basalt flows, the side wall shear zones expose incandescent material at the surface (figure 8) and much of the heat loss is from these zones.

Figure 8. A basaltic lava channel in Hawaii. The red stripes along the edges of the flow indicate exposure of hotter melt in those regions, whereas the dark surface along the centre of the channel is cooler solid. The flow is about 20 m wide.

Gravitational collapse of yield-strength materials - rapid emplacement of andesite flows.

A. Lyman, R.W. Griffiths and R.C. Kerr

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Motivated by the question of how rapidly large andesite flows may have been erupted and emplaced, new 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 mixtures of kaolin clay and polyethylene glycol (PEG) wax are suddenly released by removing a dam wall at the end of an inclined channel 1.8 m long and 0.15 m wide. The horizontal distance travelled and the elapsed times are recorded and, in the case of isothermal flows, are being compared with theoretical predictions. The first experiments allowed us to determine the range of ratios of clay to wax best suited to model lava flows.

Modelling processes that drive the ocean thermohaline circulation *J.C. Mullarney, R.W. Griffiths and G.O. Hughes*

Localised mixing due to a turbulent patch *G.O. Hughes*

The influence of double-diffusive processes on the melting of ice in the Arctic Ocean *J.S. Turner and G. Veronis*

Internal waves as a source of finestructure at ocean fronts. *A.A. Bidokhti and R.W. Griffiths*

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

Geodynamics

Research in the Geodynamics Group of RSES covers three principal areas: (i) modelling of tectonic processes, including surface processes; (ii) the geodetic monitoring of crustal deformation due to tectonic and glacial processes; and (iii) glacial rebound and sea-level change.

Tectonic studies have included the modelling of the evolution of the Lachlan Fold Belt of eastern Australia from Late Ordovician to Early Carboniferous time as a single continuous subduction process. The geodetic studies continue with the long-term monitoring of crustal deformation in Papua New Guinea and the monitoring of isostatic rebound in Eastern Antarctica. Three sites are now in operation and the fourth is being installed in the 2002-2003 season at Mt Komsomolskiy nearly 800km inland. The glacial rebound studies have focussed on the Scandinavian and western Russian ice sheets and on the refinement of the timing of glacial cycles during the marine isotope stage 5. One outcome of the latter is that the sea-level change during the sub-stages 5a and 5c is more complex than previously suggested and that during this period climate variability is not due simply to insolation forcing.

The following short reports represent a cross-section of the group's research activities for 2002.

First order constrains on the tectonic evolution of the Lachlan Fold Belt, Southeastern Australia from a non-linear numerical model of crustal deformation

J. Braun, C. Pauselli [1]

We have used a coupled thermo-mechanical finite element model of crustal deformation driven by mantle/oceanic subduction to demonstrate that the tectonic evolution of the Lachlan Fold Belt during the mid-Palaeozoic (late Ordovician to Early Carboniferous) can be linked to continuous subduction along a single subduction zone. This contrasts with most models proposed to-date which assume that separate subduction zones were active beneath the western, central and eastern sections of the Lachlan Orogen. We demonstrated how the existing data on the structural, volcanic and erosional evolution of the Lachlan Fold Belt can be accounted for by our model. We focused particularly on the timing of fault movement in the various sectors of the orogen. We demonstrated that the presence of the weak basal decollement on which most of the Lachlan Fold Belt is constructed effectively decouples crustal structures from those in the underlying mantle. The patterns of faulting in the upper crust appears therefore to be controlled by lateral strength contrasts inherited from previous orogenic events rather than the location of one or several subduction zones. Our model also predicts that the uplift and deep exhumation of the Wagga-Omeo Metamorphic Belt is associated with the advection of this terrane above the subduction point and is the only tectonic event that gives us direct constrain on the location of the subduction zone. Our model has also implications for the nature of the basement underlying the present-day orogen.

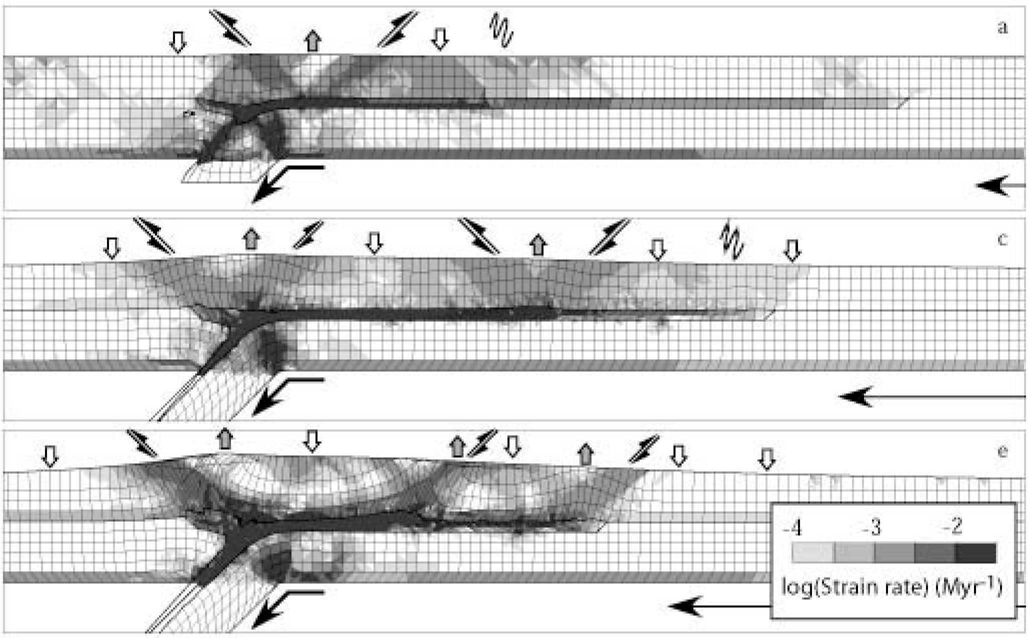

Figure 1: Results from a numerical model experiment. Contours of computed strain rate are superimposed on an originally rectangular Lagrangian grid (i.e. attached to the deforming crust). Each panel shows the solution at a different time in the evolution of the system. Symbols representing faulting, folding, erosion and sedimentation have been superimposed on the diagrams to help with interpretation of model results. The large arrow on the bottom right corner of each panel indicates the amount of convergence that the system has undergone at that time.

Numerical models of a passive margin inversion and their implications for the Rhenohercynian fold-and-thrust belt, Belgium and Germany

Y. Vanbrabant [2], J. Braun and D. Jongmans [3]

Positive tectonic inversion is related to the transmission of compressional stresses along a décollement into the foreland of an orogenic zone. This stress and strain concentration in regions remote from the main orogenic front is commonly related to the presence of pre-existing rheological heterogenities such as normal syn-sedimentary faults. During inversion, these normal faults are reactivated into reverse faults. Tectonic inversion in the Rhenohercynian fold-and-thrust belt during the Variscan Orogeny shows that inversion is usually synchronous with the onset of collision in the hinterland. We have developed a simple 1D thermomechanical model to study strain partitioning between two orogenic zones. We have shown that, if the two orogenic zones have the same mechanical properties, the viscosity of the décollement which links them controls the initial strain partitioning. During subsequent finite shortening, erosional processes determine the partitioning of strain rate. The presence of a weak structure in the inverted zone and of a low-viscosity décollement lead to initial strain concentration in the inverted track rather than in the collision zone and a progressive decrease in strain partitioning between the two orogenic zones. The results of the 1D-model are in good agreement with results of a 2D finite-element model. In the western part of the Rhenohercynian Massif, simultaneous uplift and deformation within the Mid-German Crystalline Rise (the main collision zone) and the Ardenne Anticlinorium (the inverted zone) has therefore led us to interpret this orogenic event as a case of vise tectonic within the western part of the Rhenohercynian Massif, rather than the propagation of a 'wave of folding' towards the Variscan front, as suggested by previous authors.

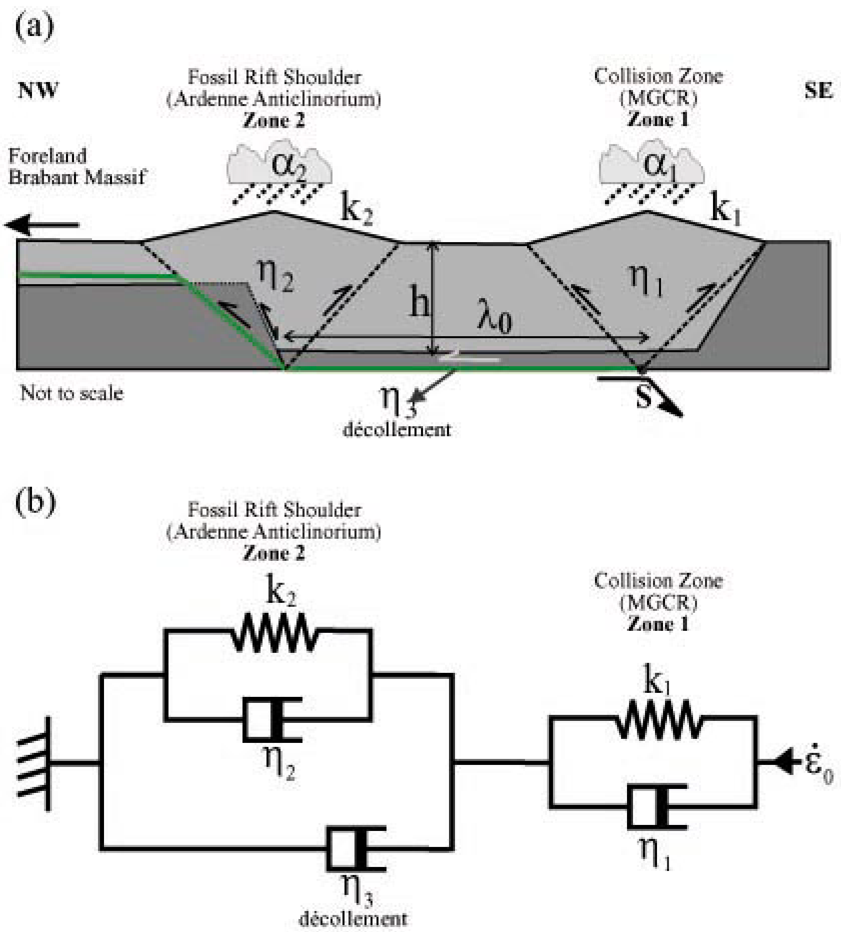

Figure 2: 1D Model results. a) General concept of strain distribution between two orogenic zones separated by a décollement with an effective viscosity (eta3). The S point represents the subduction zone from which the upper crust is forced to accommodate the convergence by deformation while the lower crust and mantle part of the lithosphere continue to subduct. b) Equivalent 1D-model represented by two Kelvin bodies (spring and dashpot in parallel) for the orogenic zones and a viscous element for the décollement level (dashpot). The system is forced to shorten at a fixed strain rate.

Geodetic monitoring of movements and deformation of the crust - Papua New Guinea

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

The tectonic monitoring of Papua New Guinea using GPS continued in 2002, with observations being made on several sites by staff/students at University of Technology, Lae (Unitech), Rabaul Volcano Observatory, local surveying companies and RSES personnel. The GPS network around Lae was densified by Richard Stanaway as part of his masters study into the effects of tectonic motion on the geodetic datum of Papua New Guinea. Observations made by RVO staff continued in the New Ireland/New Britain region to continue monitoring the post-seismic relaxation after the major seismic events of November 2000.

In September 2002, a Mw=7.0 earthquake occurred off the New Guinea coast near Wewak. In response, a team of 5 staff from Unitech reobserved several sites in the surrounding region in order to estimate the co-seismic displacements caused by the earthquake. Uplift estimates of ~30 cm, derived from raised coral terraces at one of the islands, were confirmed by the GPS-estimated site positions, along with significant lateral movements.

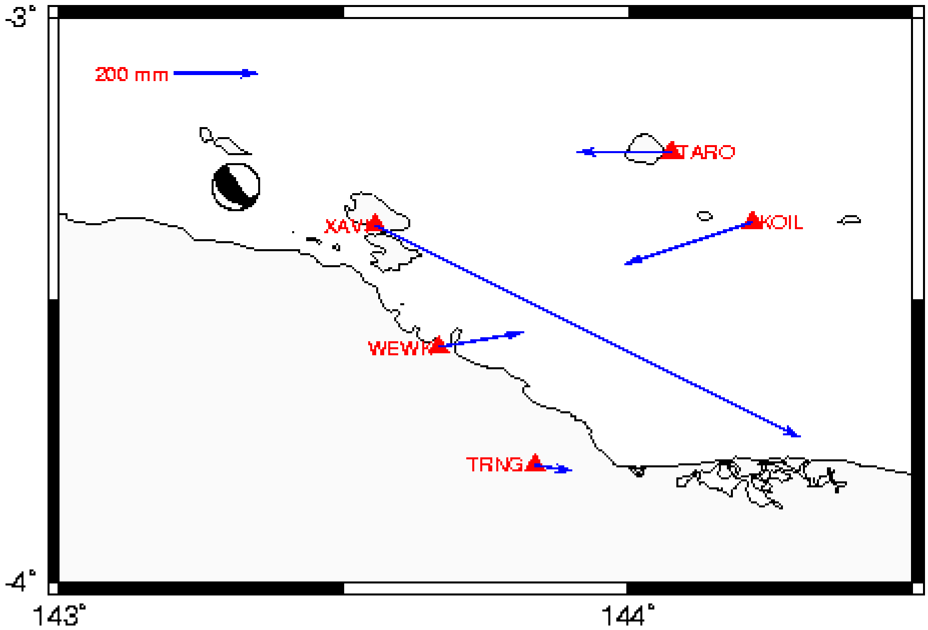

Figure 3: Co-seismic horizontal site displacements as a result of the September 2002 earthquake. The NEIC epicentre location and focal mechanism is also indicated.

Analysis of the GPS and seismic data collected after the November 2000 earthquakes in New Britain/New Ireland is ongoing. Using a process developed while Dr Tregoning was on sabbatical at Geosciences Azur, (CNRS, Nice, France), it has become clear that the geodetic network was deformed by three earthquakes (Mw_7.8) on 16-17 November, with co-seismic offsets of betweeen 0.05 and 5.7 m being recorded at the GPS sites.

Antarctica – Glacial Isostatic Adjustment

P.Tregoning, H. McQueen, A. Welsh, N. Schram, K. Lambeck

The initial aim of the GPS project in the Prince Charles Mountains, Antarctica, was to install four sites along a transect from the coast to 600 km inland in order to monitor any present-day glacial isostatic adjustment (GIA) occurring in the Lambert Glacier region. The status at the end of 2002 is that three of the four sites are operational, with the fourth expected to be installed by the end of the 2002/03 summer field season. Data are being transmitted by satellite from two of the three sites, while the phone at the third site has malfunctioned and will be repaired in January 2003.

As a result of a successful ARC Linkage-Infrastructure grant, an additional 4 GPS receivers and two electronics systems were acquired for installation in Antarctica as part of the long-term program to monitor any present-day glacial isostatic adjustment (GIA) occurring in the Lambert Glacier 2002/03 summer season.

Two Iridium satellite modems and free satellite air time were provided to Dr Tregoning as part of the National Office for Integrated and Sustained Ocean Observations Iridium Project. These satellite modems will be deployed at the two most southerly GPS sites (Dalton Corner and Komsomolskiy Peak), where the Inmarsat system will not function. Already, data have been transmitted from the Dalton Corner site, thereby providing valuable information that the equipment is functioning correctly and also permitting the data to be analysed one year sooner than previous years when the data could only be recovered when the site was next visited in the following season.

Analyses of the data collected to date at Landing Bluff, Beaver Lake and Dalton Corner since 1998 indicates that the relative vertical motion between the sites is less than 3 mm/yr, while there is no significant motion of any of the sites with respect to a rigid Antarctic Plate at the 2 mm/yr level.

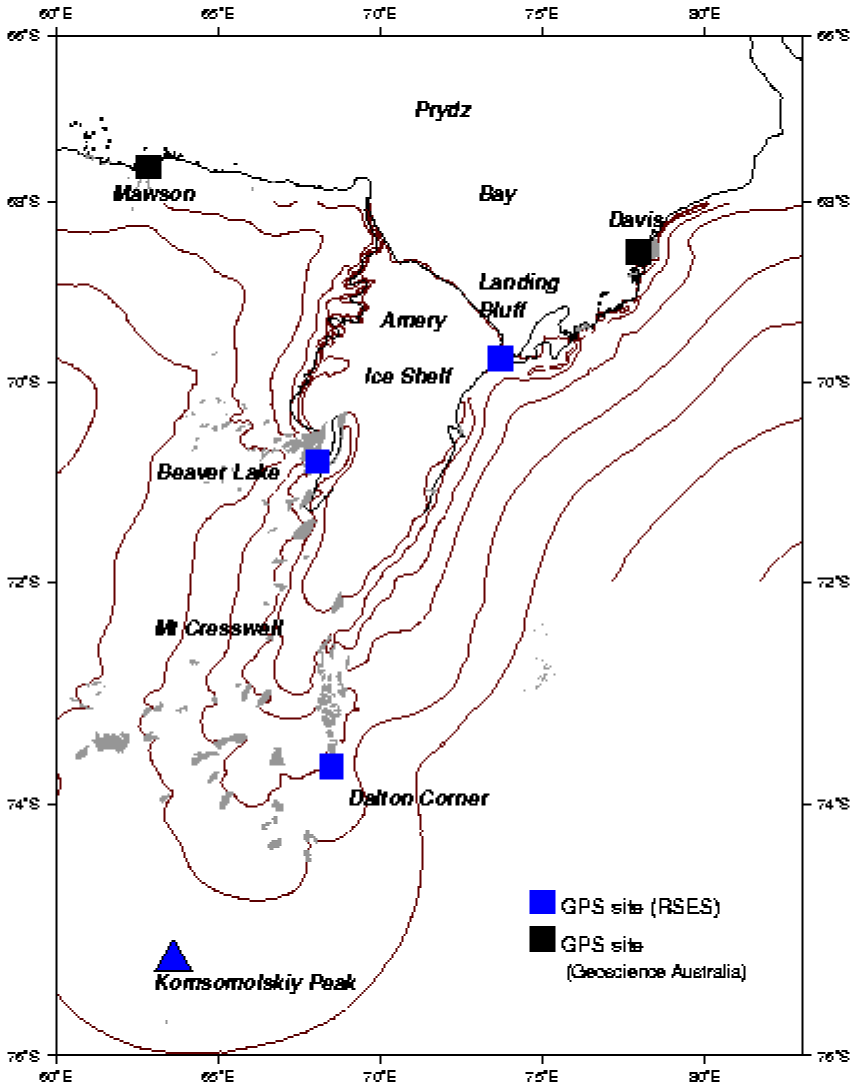

Figure 4: Location of GPS sites in the Prince Charles Mountains, Antarctica.

Sea level, ice sheets and climate during marine isotope sub-stages 5a and 5c

E.-K. Potter, K. Lambeck and T. Esat

The timing and magnitude of marine isotope sub-stage (MIS) 5a and 5c sea-level oscillations have been determined by U-Th dating of more than 80 coral samples from the uplifted reef terraces at Barbados. At least three distinct periods of coral growth during sub-stages 5a and 5c have been identified and are associated with morphologically distinct reef deposits. The `classic' sub-stage 5c and 5a deposits were found to have ages of ~101 ka and ~84 ka respectively. An additional period of coral growth during sub-stage 5a was found to occur at ~77 ka BP. This is the first time a distinct sea-level feature of this age has been clearly established. The extensive U-Th data set has also enabled an examination of the processes influencing the reliability of U-Th dating, including the possibility of changes in oceanic $\delta^{234}U$ and the effects of diagenetic alteration on a coral's U-Th system.

The sea levels associated with the classic sub-stage 5c and 5a deposits and the additional 5a feature at Barbados are -15±4 m, -19±4 m and -19±4 m respectively. Further estimates of sub-stage 5a sea level at sites throughout the Caribbean range from -19 m at Barbados to above present sea level on the US East Coast. These estimates are reconciled in the current study by taking into account the effects of glacio-hydro-isostasy. The comparison of sea-level observations with glacio-hydro-isostatic model predictions provides constraints on both the melting history of the Laurentide Ice Sheet (LIS) during MIS 5 and on the effective viscoelastic rheology of the Earth. In particular, the modelling results suggest that the LIS may have been centred further north and that it contributed a smaller proportion to the global ice volume during MIS 5 compared to MIS 3 or the last glacial maximum. The results also point to a high viscosity for the upper mantle beneath the LIS and surrounding region ($>4\times10^{20}$ Pa s) and a high viscosity for the lower mantle ($>1\times10^{22}$ Pa s).

The new Barbados sea-level record implies that the sea-level change during sub-stages 5a and 5c is more complex than suggested by some previous studies. A similar complexity is also implied by the MIS 5 uplifted coral reefs at Huon Peninsula, PNG. A comparison of these sea-level observations with other proxy records of climate change indicates that climate variability during MIS 5 is the result of a complex interplay between insolation forcing and intrinsic climate instability.

Sea-level change and vertical tectonics of the Mediterranean

K. Lambeck, F. Antonioli [4], D. Sivan [5] and A. Purcell

Studies of sea-level change have been conducted in recent years for several areas of the Mediterranean, including tectonically stable and tectonically active regions. These have included Greece and Turkey, France, Israel and, most recently, Italy. The objectives have been several: to test the global models of sea-level change developed at RSES; to establish the extent of lateral variability in earth rheology; to provide a reference for estimating rates of vertical movements and to provide maps of shoreline evolution for archaeological and pre-history studies.

The Tyrrhenian coast of Italy has yielded a number of quality records of sea-level change at locations where the Last Interglacial shorelines can also be identified. Thus these sites serve to establish whether the areas have been tectonically stable and provide tests of the predictive glacio-hydro-isostatic models for sea-level change. The results confirm earlier outcomes that ocean volumes have continued to increase over the past 6000-7000 years. Elsewhere the comparisons of observed sea levels with model predictions have revealed evidence for non-uniform rates of uplift over the last few glacial cycles.

New results from wells in Caesarea, Israel, for the past 2000 years have also contributed to the development of the sea-level model for the eastern Mediterranean and, together with the data from earlier analysis, are providing a comprehensive model for sea-level change and shoreline evolution in the Mediterranean since the time of the last Glacial Maximum.

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[1] Visitor to the school in 1998, now at Department of Earth Sciences, University of Perugia, Italy
[2] Visitor to the School in 1999; now at the Universite de Liege, Belgium
[3] Universite Joseph Fourier, Grenoble, France
[4] ENEA Centro Casaccia, Rome, Italy
[5] University of Haifa, Israel

Seismology

This report is no longer available.

PRISE

This report is no longer available.

Annual Report 2002 Research Support

ELECTRONICS Workshop

Demand for Electronics support remained strong during the year. Maintenance activities accounted for 18.0% of human resources, administration and group support/ renovations planning 15.3%, with the remaining 66.7% devoted to development activity.

Notable developments undertaken included:

· Design of 2 “Filament Degassers” to support the renovated 61 and NG61 Mass Spectrometers . (D Corrigan).

· Design and fabrication of 4 “Traverser Driver” units for stepper motor stage applications in Geophysical Fluid Dynamics. (A. Welsh and J . Arnold).

· Fabrication of 4 “AntPAC 2002” instrument modules, incorporating a revised data storage computer and Iridium satellite modem support for Geodynamics and the University of Tasmania, for GPS data collection in Antarctica. (A Welsh, J Arnold, N Schram, A Forster).

· Refurbishment, safety interlocking and furnace control development for the “Rig 3” high pressure apparatus within the Petrophysics group. (A Forster).

· Development and commissioning of LabVIEW data acquisition software for the “Rig 1” high pressure apparatus within the Petrophysics Group. (J. Lanc).

· Commencement of design of updated control electronics for early SHRIMP II instruments. (A Welsh).

· Completion of 3 ‘FC3’ Field Controller Units, for application to SHRIMP II, SHRIMP RG, and the NG61 Mass Spectrometer. Commissioning of the SHRIMP RG FC3. (N. Schram and J Lanc).

· Detailed design and partial implementation of fibre-optically controlled High Voltage systems and test software for the renovated 61 and NG61 Mass Spectrometers (N Schram, J Arnold, A Latimore, A Forster).

· Design, manufacture and commissioning of automation-compatible HV Control, Magnet Pole-piece positioning and LN_2 trap ‘auto-top-up’ for the VG5400 Mass Spectrometer used by the Noble Gas Group. (A Latimore).

· The wiring and commissioning of valve controllers and furnace for the Helium extraction line and Mass Spectrometer built by the Noble Gas group. (J Arnold) .

· The wiring of 4 furnaces and control systems for the Geology Department, (J Arnold) .

Staffing:

The group comprises 7 permanent Technical Officers. D Corrigan specialises in Electro-mechanical design, working closely with both Engineering and Electronics staff. His primary focus remains ancilliary equipment for the NG61 Mass Spectrometer. J Lanc retired in December. The group initiated recruitment proceedings for 2 Trainee Technical Officers, for appointment early in 2003, as part of the school's succession planning strategy.

Outlook:

2003 promises to be an interesting year, as we turn our attention to SHRIMP updates, and further development for the NG61 Mass Spectrometer project. The profound changes to costing and accounting introduced in 2002 are yet to affect our workflow, as many projects undertaken in 2002 were 'brought forward' to avoid higher recharges anticipated from 2003 onwards. We remain concerned that the recharge system may constrain development initiatives in the longer term. The Group's accommodation will be extensively refurbished during the first half of 2003. Client service will continue through the renovation period, although some development activities are expected to experience delays. We look forward to occupying the renovated accommodation, which will enhance our efficiency and professionalism.

Mechanical Workshop

It was another busy year for the Mechanical Workshop with several major projects continuing from 2001.

External work took up more of our time than usual (21%). A significant part of this work was the quadrupole lens modifications to the SHRIMP RG at Stanford University. This job commenced in August and all workshop staff including David Hall, who was contracted for three months, have made excellent progress. The modifications will be completed in January 2003. Administration, Training and general workshop maintenance required 19% of human resources, with the remaining 60% committed to jobs for RSES.

The SHRIMP multi-collector redesign was finished in June with all workshop staff making a significant contribution.

Early in the year David Thomson and Geoff Woodward worked on the filament degasser for Earth Environment.

Valther Baek-Hansen and David Thomson made steady progress on the NG61 Electrometers with Geoff Woodward and Andrew Wilson involved later in the year.

Andrew Wilson continued with the broadband lens for OSL (Optically Stimulated Luminescence). Iain McCulloch designed this system to significantly extend the capabilities of OSL dating. The lens system, completed in November will be tested soon. More work on this project is expected in 2003.

Roger Willison built a new vacuum chamber for Dr Dunlap's Helium line. Roger carried out many repairs to coring equipment, built a new clay corer and a Lithium reactor all for Earth Environment.

Late in the year work commenced on degasser units for the NG61 mass spectrometer.

Other projects included

- various refinements made to SHRIMP;
- new solar panel frames for use in Antarctica;
- two new valve assemblies designed by Derek Corrigan and built for the Finnigan Triton and Neptune mass spectrometers.

We carried out regular tasks such as

- refurbishing pressure vessels;
- general repairs to vacuum components;
- grinding of synthetic samples;
- grinding high-pressure ceramic and tungsten carbide pistons.

Staffing

The group consists of 6 Technical Officers. Bob Waterford and Roger Willison (both of whom are due for retirement in April of 2003). Valther Baek-Hansen (part time 3 days per week), David Thomson, Geoff Woodward and Andrew Wilson. We are very pleased to have Brendan Taylor who began his apprenticeship in November. It has been a privilege to have David Hall to help during high-workload periods. David was contracted for two separate periods of 3-months.

Outlook

With the retirement of Bob Waterford and Roger Willison, 2003 will see significant changes to staffing in the workshop. The refurbishment of electronics and extension of the mezzanine floor will provide us with a ceiling over the entire workshop. As a result we anticipate much better lighting and improved temperature consistency year round. During construction the rear section of the workshop will be closed and therefore some machines will not be operational. We will attempt to maintain services but ask for users to be patient during periods of disruption.

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NEW GRANTS for 2002

Drs A.J. Berry and J. Hermann received an ARC Discovery Project grant for 2003–2004; "Water storage in the earth's mantle — understanding the process of OH incorporation in olivine."

Dr A.J. Berry in collaboration with Dr H.StC. O'Neill received a grant from the Australian Synchrotron Research Program to continue their work on oxidation states in silicate glasses and melts at the Australian National Beamline Facility, Tsukuba, Japan.

Dr A.J. Berry was an investigator in a successful ARC LIEF bid; "Fluorescence detector for the Australian National Beamline Facility".

Drs A.J. Berry, J. Mavrogenes and Mr A. Hack received a grant from the Access to Major Research Facilities Fund to study synthetic fluid inclusions at GSECARS, Advanced Photon Source, Argonne National Laboratory, USA.

Dr J. Braun was awarded a Discovery grant ($385 000) for 2003-2005 on "Constraining landform response to tectonic and climate changes in an active orogen: a multi-disciplinary approach". He and Dr Malcolm Sambridge were awarded a LIEF grant (See Malcolm Sambridge's annual report contribution for more details). Dr Jean Braun is Partner Investigator on a large AIF/ACOA research grant funding the development of a large-scale three-dimensional numerical model of the Earth's mantle and crust. The purpose of the model is to understand the complex interactions between the Earth's crust, the underlying mantle and the hydrosphere. The Chief Investigator is Prof. Beaumont of Dalhousie University. Funding is $3,767,690 over 5 years.

Drs. Braun and Sambridge were awarded a grant from the ARC Discovery Linkage Infrastructure Equipment fund for construction of a Beowulf cluster of 130 PCs (Total value \$372,000). The computational facility is designed for solving nonlinear inverse problems using parallel computation. Partner institutions in the project entitled `Geowulf: An inference engine for complex Earth systems' were; Univ. of Melbourne, Univ. of Macquarie, Univ. of Western Australia, Univ. of Dalhousie, Geoscience Australia and Cougar Computers Pty.

Professor J. Chappell was awarded a three year ARC Discovery grant DP0342689 "Production and transport of soil and sediments, determined by cosmogenic radionuclides and noble gases" with co-investigators Dr M Honda, Dr D Fabel, Dr LK Fifield. He was also awarded ARC Discovery grant DP0343908 "Millenial-scale instability of sea level and the climate system: new analyses of coral terraces in Papua New Guinea" with co-investigator Dr T Esat. The grant will enable drilling on 30,000 year to 60,000 year old terraces for U-series and accelerator based radiocarbon dating to investigate ice age climate and sea-levels.

Professor S.F. Cox was successful in gaining an ARC Linkage grant of $270,000 to support research on the development of lode gold systems in the Eastern Goldfields of WA for two years.

Dr. W.J. Dunlap and Dr. S. McLaren were named investigators on an ARC Discovery Grant (2003-2005) with Dr. P. Rey, University of Sydney, and others entitled "From synchrotron characterization of single fluid inclusions to Archaean geodynamics: An integrated study of fluid-rock interactions in the primitive crust"

Dr D. Fabel was awarded two ARC Discovery Grants: DP0342704 “Looking back to see the future: Change in the Lambert Glacier and the East Antarctic Ice Sheet” with K. Lambeck, P. Tregoning, R. Coleman and D. Fink.

Dr M. Gagan was awarded the ARC Discovery Grant “*Quantifying the El Niño-Indian Ocean Dipole system using high-resolution coral palaeoclimate archives”* with W. Hantoro, J. Lough and G. Meyers. Dr M. Gagan was also awarded an Alan Cox Visiting Fellowship to Stanford University, USA.

Professor R. W. Griffiths and Dr R. C. Kerr were awarded a new Discovery Grant (ARC) for 2003-2005 for work on “The fluid dynamics of lava flows: Silicic domes and basaltic channels”.

Professor R. Grun was awarded the ARC Discovery Grant “*Stable isotopes in marsupials: reconstruction of environmental change in Australia”* with M. Gagan, D. Bowman and R. Wells.

Professor T.M. Harrison, Dr T.R. Ireland and Dr V.C. Bennett were awarded a grant from the Australian Research Council (ARC) for the project titled “A Mission to Very Early Earth: When Did Conditions Suitable for Life to Emerge on Earth?”

Professor Harrison also received an ARC grant for the project titled “Tectonic Reconstruction of the Evolution of the Alpine-Himalayan Orogenic Chain.”

Dr T.R. Ireland was awarded an ARC grant to support research on Lithic Astronomy: The age and origin of the elements and their incorporation in the solar nebula.

Dr I. Jackson was awarded an ARC discovery grant of $184,000 for studies of the influence of partial melting on seismic wave attenuation.

Professor Kurt Lambeck and Drs Derek Fabel, Paul Tregoning, Richard Coleman (University of Tasmania) and D Finko (ANSTO) were awarded an ARC Discovery Grant ($530 000) for 2003-2006 for the study of the glacial history of the Lambert Glacier in Antarctica. …

Professor M.T. McCulloch was awarded two new ARC Discovery Project Grants in 2002. They were:"Sea Levels, Sea Surface Temperatures and El Nino Variability During Warm Interglaciations" with Dr Paul Hearty of James Cook University in Queensland and Professor Alexander Halliday of ETH Zürich and "The Coral Record of Environmental Impacts in the Great Barrier Reef: Quantification of Anthropogenic Fluxes" with Dr Janice Lough of the Australian Institute of Marine Science.

Professor I. McDougall was awarded a grant from the Australian Institute of Nuclear Science and Engineering to facilitate fast neutron irradiations of geological samples in the HIFAR nuclear reactor, operated by the Australian Nuclear Science and Technology Organization, in relation to the isotopic dating of rocks by the 40Ar/39Ar method.

Ms H. McGregor was given a Goldschmidt 2002 Organising Committee Grant to attend the Goldschmidt 2002 Geochemical Conference, Davos, Switzerland, August 2002.

Dr. S. McLaren was awarded an ARC Discovery Grant, including Australian Postdoctoral Fellowship, (2002-2004) entitled “Argon thermochronometers and the effects of recrystallization”

Ms A. Müller won travel support from the Australian Coral Reef Society to attend their annual conference.

Drs H.StC. O’Neill, J. Hermann, J. Mavrogenes and Professor R. Arculus received an ARC-discovery grant for 2003–2005; “Properties of hydrous fluids and silicate melts at very high temperatures and pressures”.

Drs H.StC. O’Neill, S. Kesson and M. Gagan were successful with a major equipment proposal to purchase a new powder X-ray diffractometer

Dr C. Pelejero was awarded the grant “Uptake of atmospheric CO_2 in the oceans and implications for global change: New proxy developments” (DP0342702).

Dr P. Tregoning was awarded an ARC Linkage-Infrastructure grant ($353K)- in collaboration with Dr Coleman (University of Tasmania), Prof. Lambeck and Dr McQueen (RSES) – to purchase 6 new GPS receivers and to build 4 new electronics systems for deployment in Antarctica. The equipment was deployed in December 2002 to measure long-term glacial isostatic adjustment of the crust as well as to monitor the tidal movement of the Amery Ice Shelf. Dr Tregoning was also awarded an ARC Discovery grant ($380K over 5 years) for a project titled “Caught in a vice: Modelling crustal deformation in Papua New Guinea.

Dr J.G. Wynn was awarded the Cooperative Research Centre for Greenhouse Accounting “Program B2(c) Continuation of Soil Organic Carbon Inventory Techniques” with $7800 funding for 2002. He was also awarded the Cooperative Research Centre for Greenhouse Accounting “Program B2(c) Soil Organic Carbon Inventory Techniques, Applied to Soil Texture” with $60,000 in funding for 2002-2003.

ARMSTRONG, Dr. R. has participated in a number of collaborative projects with a number of scientists from the Geological Surveys of Britain, 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.

BERRY, Dr. A. J. collaborated with FORAN, Dr. G. J., ANSTO, on X-ray absorption spectroscopy of metal ions in crystals and glasses.

BRAUN, Dr. J. was an invited speaker at a workshop on "Defining a New Seismic Risk Map of Australia" organized by Geoscience Australia in Adelaide (November 2002).

CALVO, Dr. E. and PELEJERO, Dr. C. are involved in co-operative research with LOGAN, Dr. G.A., Geoscience Australia, on molecular biomarker analysis from marine sediments and the setting up of carbon and nitrogen isotopes analysis.

CAMPBELL, Dr. I.H. and STOLTZE, Ms. A. collaborated with Placer Granny Smith Pty Ltd to study ore-fluid pathways around the mesothermal gold deposits in the Laverton region, WA using alkali elements and stable isotopes. The project is supported by a SPIRT grant from ARC.

FABEL, Dr. D. established a cooperative agreement (AMS-02-14) with the Australian Nuclear Science and Technology Organisation (ANSTO) to measure in situ produced Be-10 and Al-26 in quartz samples.

FANNING, Mr. C.M. continued collaborations with the Geological Surveys of South Australia and Queensland. He collaborated with TEALE, Mr. G., Teale and Associates and a number of mineral and petroleum exploration companies.

FITZ GERALD, Dr. J.D. collaborated with DEVRIES, M of CSIRO Division of Minerals in a project to characterise reaction microstructures in reduced ilmenite polycrystals.

GLIKSON, Dr. A. collaborated with GORTER, Dr. J., AGIP Australia, on lamproites of the Bonaparte Basin, Timor Sea.

GLIKSON, Dr. A. collaborated with HICKMAN, Dr. A., WILLIAMS, Dr. I. and VAN KRANENDONK, Dr. M., GSWA, on the Archaean asteroid impact fallout units, Pilbara craton, Western Australia. He also collaborated with PIRAJNO, Dr. F. GSWA, on the origin of the Shoemaker Impact Structure, Nabberu Basin, Western Australia and with IASKY, Dr. R. GSWA, on new Western Australian impact structures.

GREEN, Emeritus Prof. D.H. was appointed as a 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.

GRIFFITHS, Prof. R.W. continued collaboration with Australian Scientific Instruments on marketing of the Geophysical Flows Rotating Table. ASI delivered the latest unit to the Courant Institute of Mathematical Sciences, New York, in September.

HARRISON, Prof. T.M. is a Member of the National Committee for Earth Science. The committee is currently developing a strategic plan for Earth sciences in Australia (due June 2003). Professor Harrison is also a Member of the Board of the Australian National Seismic Imaging Resource (ANSIR), a Major National Research Facility operated as a joint venture of GA and RSES. Professor Harrison developed a joint appointment structure for fixed term academic positions with CSIRO Exploration and Mining. Professor Harrison also gave a Seminar for Geoscience Australia, 19 June, entitled "A Mission to Really Early Earth: When did the Earth Become Suitable for Habitation?"

HEATH, Mr. C. continued his study of the "Origin and composition of Ore-forming fluids in the giant Golden Mile gold deposit, Kalgoorlie in collaboration with Kalgoorlie Consolidated Gold Mines. The project is being supported through an ARC SPIRT grant to Campbell, Dr. I.

HENDY, Ms. E., GAGAN, Dr. M. and MCCULLOCH, Prof. M. continued collaborative work with LOUGH, Dr. J., ISDALE, Dr. P. and BARNES, Dr. D. of the Australian Institute of Marine Science. Ms Hendy's PhD research is a core project of the AUSCORE (AUStralian COral REcords) initiative and is designed to document decadal-to-centennial climate variability in the Great Barrier Reef region over the last 400 years. New AUSCORE collaborative work is underway with Honours student, LILLY, Ms. K.

KENNETT**,** Prof. B.L.N**.** has continued to provide support to the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organisation in Vienna through the operation of the Warramunga Seismic and Infrasound Research Station near Tennant Creek in the Northern Territory. The seismic and infrasound arrays have been very effectively managed by John Grant with assistance from Peter Biggs. Very high reliability has been achieved with data transmitted continuously to the International Data Centre in Vienna via satellite link.

KENNETT, Prof. B.L.N. took on the position of Director of the Australian National Seismic Imaging Resource (ANSIR) from July 1, having previously been Deputy Director. ANSIR is a Major National Research Facility operated as a joint venture by the Australian National University and Geoscience Australia.

KENNETT, Prof. B.L.N. is Chair of the Academy Committees for Postdoctoral Opportunities in Japan and exchange arrangements with N.E. Asia (China, Japan, Korea, Taiwan). Australian Academy of Science

KENNETT, Prof. B.L.N is chair of the Committee for the Frederick White Conference Series. Australian Academy of Science

LAMBECK, Prof. K**.** is Chair of the Antarctic Science Advisory Committee and a member of an AUSAID Technical advisory Group.

LAMBECK, Prof. K. is currently Foreign Secretary of the Australian Academy of Science and a member of its Council. He is also a member of the Executive Committee of the International Inter-Academy Panel.

MCCULLOCH, Prof. M.T. is undertaking a collaborative study with DE CAVITAT, Dr.P. from Geoscience Australia on the use of isotopic signatures to decipher basement signatures through sedimentary basin cover. Collaborative research on the Great Barrier Reef is continuing with BARNES, Dr. D. and LOUGH, Dr. J. from the Australian Institute of Marine Sciences.

MCGREGOR, Ms. H. and GAGAN, Dr. M. continued collaborative research with BRUNSKILL, Dr. G., LOUGH, Dr. G. J. and BARNES, Dr. D. of the 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.

MCQUEEN, Dr. H. collaborated with staff of the CSIRO Division of Exploration and Mining and with the National Mapping Division of Geoscience Australia on absolute gravity measurements and instrument calibrations at the Mt Stromlo Gravity Station in support of the Superconducting Gravimeter installation.

MÜLLER, Ms. A. co-operates with the Australian Institute of Marine Science (AIMS).

MÜLLER, Dr. W. cooperated with WESTAWAY, Mr. M. National Museum of Australia, on provenancing Aboriginal human skeletal remains from Victoria using stable and radiogenic isotope analysis.

NORMAN, Dr. M. is collaborating with several gold exploration companies as well as being involved in projects with CSIRO and Geoscience Australia.

NUTMAN, Dr. A. P. is working with GIBSON, Dr. G. of Australian Geological Survey Organization (AGSO) on the tectonothermal evolution of the Broken Hill area.

PILLANS, Dr. B. undertook site investigation and hazard assessment at the Lucas Heights nuclear reactor site, Sydney, for the Australian Nuclear Science and Technology Organisation (ANSTO). He also completed a geological investigation and report on a Pleistocene paleontological site near Canberra, for Environment ACT. Dr B. Pillans completed his 12 month term as Assistant Director of the CRC for Landscape Environments & Mineral Exploration, and continued collaborative research on paleomagnetic dating of regolith with CRC personnel from CSIRO, Geoscience Australia, University of Canberra, and a number of mining companies including St Barbara Mines, Newmount, Perilya and Kalgoorlie Consolidated Gold Mines.

ROHRLACH, Mr. B. and CAMPBELL, Dr. I. H., LOUCKS, Dr. R. R., PALIN, Dr. J. M. and MCDOUGALL, Prof. I. have completed their collaboration with WMC Resources Ltd on the study of the Tampakan Cu-Au deposit in southern Mindanao, Philippines.

SAMBRIDGE, Dr. M. took part in a CSIRO sponsored gathering of Australian scientists (in Nice, France) interested in potential field inversion studies. Flowing from this a new specialist group was organized to foster collaborative projects in the area between Australian Industry, CSIRO and universities.

SAMBRIDGE, Dr. M. began a collaboration with CUMMINS, Dr. P. (Geoscience Australia) in the area of nonlinear inversion applied to source studies in the Australian continent.

SOMMACAL, Mr. S. (PhD student) is a founding member of the Association For Research Between Italy and Australasia (ARIA)-Canberra, a non-profit association which aims to promote scientific and technological cooperation between Italy and Australasia.

TURNER, Prof. J. S. chaired an evaluation of Australia's Antarctic Science Program in the fields of Glaciology, Geosciences and Oceanography. The Review Committee heard submissions during meetings held at the Antarctic Division in Hobart in November.

WILLIAMS, Dr. I. S. continued his longstanding collaboration with Australian Scientific Instruments Pty. Ltd. (a subsidiary of ANUTECH Pty Ltd) in the manufacture and marketing of SHRIMP ion microprobes, taking up a 25% appointment as Applications Scientist for the company in February. April through October he worked with ASI on the development of stable isotope and multiple collector analysis on, and the final tuning of, the SHRIMP II purchased by the All-Russian Geological Research Institute, St Petersburg. This included three weeks in October training three scientists from VSEGEI in SHRIMP analytical procedures. In August Dr Williams assisted ASI with SHRIMP marketing at Goldschmidt 2002, Davos.

WYNN, Dr. J.G. is a member of the Cooperative Research Centre for Greenhouse Accounting, Programs B and A.

YAXLEY, Dr. G. is involved in projects with a number of Australian and international diamond exploration companies.

COLLABORATION WITH AUSTRALIAN UNIVERSITIES

A Mission to Very Early Earth: When Did Conditions Suitable for Life Emerge on Earth? by Prof. T. M. HARRISON in collaboration with Prof. R.T. Pidgeon, Curtin University in research for ARC grant.

A new stable-isotope microanalytical facility by Dr. M. GAGAN with Prof. P. De Deckker and Dr. B. Opdyke, Geology Department, ANU, Drs I. Goodwin and R. Drysdale, University of Newcastle, and Prof. R. Henderson, James Cook University.

Application of x-ray tomography facilities to characterise fracture and pore geometries in deformed rocks by Prof. S.F. COX and Dr. E. Tenthorey with Mr. K Ruming, University of Newcastle, and Dr. M. Knackstedt, RSPhysS&E, ANU.

Appointed as an Emeritus Prof. D.H. GREEN continued collaborative research with Dr. T.J. Falloon and Prof. A.J. Crawford.

^{40}Ar-^{38}Ar dating by Ms. L. GLASS with Dr. D. Phillips, University of Melbourne.

Aspects of Proterozoic crustal evolution in Australia and the evolution of the Mount Painter province, South Australia by Dr. S. MCLAREN with Drs. R. Powell and M. Sandiford, University of Melbourne.

Comparison of different proxies of past ocean chemistry by Drs. E. CALVO and C. Pelejero with Dr. W. Howard from the Cooperative Research Centre for the Southern Ocean Environment, University of Tasmania.

Coral reconstructions of the Holocene climate of the equatorial central Pacific by Dr. M. GAGAN with Prof. C. Woodroffe, University of Wollongong.

Dating intrusions from the Antapaccay porphyry copper-gold deposit in southern Peru by laser ICP-MS by Drs. I. H. CAMPBELL and C. Allen with Mr. B. Jones, University of Tasmania.

Determining Fe oxidation states by Mössbauer spectroscopy by Drs A.J. BERRY and H.StC. O'Neill with Drs. S.J. Campbell and K.D. Jayasuriya, University of New South Wales.

Determining the trace element and isotopic compositions of melt inclusions by Dr. V.BENNETT with Dr. V. S. Kamenentsky, University of Tasmania.

Dr. M. NORMAN is involved in collaborative studies with Prof. John Foden, Adelaide University**,** Dr. V. Kamenetsky, Dr. G. Davidson, Dr. A. Rae, Prof. R. Large and Mr. P. Robinson, University of Tasmania**,** Dr. J. Webb and Mr. C. Ihlenfeld, La Trobe University and Dr. D. Belton and students, University of Melbourne**.**

Development of stable isotopic studies on biomarkers by Drs. E. CALVO and C. Pelejero with Dr. K. Grice from Petroleum and Environmental Organic Geochemistry Centre, Curtin University, Perth.

Development of large-scale numerical models of the Earth's crust, mantle and hydrosphere by Dr. J. BRAUN with collaborators at the University of Melbourne and the RMIT.

Environmental context of megafaunal extinction in Australia by Prof. R. GRÜN with Dr. J.Magee, Department of Geology, ANU.

Fluid inclusion analysis by Dr. J. MAVROGENES with Drs. P. Williams and T. Baker, James Cook University.

Geochronology of Fiordland, New Zealand by Dr. T. IRELAND with Prof. G. Clarke and Dr. J Hollis, Sydney University.

Improved Sr thermal ionisation strategies by Dr. W. MÜLLER with Dr. R. Maas, La Trobe University.

Late Quaternary sea levels: the South Australian Gulf regions in a global context by Professors M.T. McCULLOCH and R. Grün and Dr N. Spooner with Dr. C. Murray-Wallace, University of Wollongong.

Mantle melting by Prof. D.H. GREEN with Dr. T.J. Falloon and Prof. A.J. Crawford, University of Tasmania.

Marine electromagnetic studies by Dr. T. LILLEY with Dr. A. White, Flinders University and Dr. G. Heinson, Adelaide University.

Metamorphism in central Australia and South Africa by Dr. I. S. WILLIAMS with Dr. I. Buick, La Trobe University, and Dr. M. Hand, Adelaide University.

New insights into mantle evolution from complementary microbeam studies of melt inclusions by Dr. S. EGGINS with J. Woodhead, University of Melbourne.

Noble gas studies in diamonds by Dr. M. HONDA with Dr. D. Phillips, University of Melbourne.

Prof. T.M. HARRISON is a Member of the Advisory Committee of the Australian Crustal Research Centre, School of Geosciences, Monash University and a member of the Science Advisory Council of the Tectonics Special Research Centre, The University of Western Australia.

Rb-Sr microsampling dating of fibrous minerals in strain shadows around pyrite by Dr. W. MÜLLER with Dr. D. Durney, Macquarie University.

Reconstruction of past oceanic and climatic conditions south of Tasmania by Drs. E. CALVO and C. Pelejero with Prof. P. DeDeckker, Department of Geology, ANU.

Regolith dating by Dr. B. PILLANS with Prof. A. Chivas, University of Wollongong and Prof. R. Bourman, University of South Australia.

Research projects in Oman and Namibia by Dr. R. ARMSTRONG with Prof. D. Gray, University of Melbourne and Dr. B. Goscombe, University of Adelaide.

Sea level changes during interglacial periods by Prof. M.T. MCCULLOCH with Dr. P. Hearty, James Cook University.

Single-grain IR laser $^{40}Ar/^{39}Ar$ dating of white micas from the Iceman's intestine by Dr. W. MÜLLER with Dr. J. Wartho, Curtin University.

Stable isotopic studies on biomarkers by Drs. E. CALVO and C. Pelejero with Dr. W. Howard, University of Tasmania and Dr. K. Grice, Curtin University.

Stable isotope systematics of cassowary eggshell from Papua New Guinea by Dr. M. GAGAN with Prof. C. Murray-Wallace, University of Wollongong.

Stable isotope and trace element ratios in Late Pleistocene tufa deposits from northwestern Queensland by Dr. M. GAGAN with Dr. R. Maas, La Trobe University.

Stable isotope ratios in the Tower Hill lacustrine sediments by Dr. M. GAGAN with Prof. P. Kershaw, Monash University.

Stable isotopes in marsupials: reconstruction of environmental change in Australia by Prof. R. GRÜN and Dr. M. Gagan with Dr. R. Wells, Flinders University and Dr. D. Bowman, Northern Territory University.

Systematics in arc volcanic glasses and melt inclusions by Mr. SUN with Prof. R.J Arculus, Department of Geology, ANU and Dr. V.S. Kamenetsky, University of Tasmania.

The age of the Cuddie Springs site by Prof. R. GRÜN with Drs. P. White and J. Field, University of Sydney.

The age of South Australian sites with faunal remains including Naracoorte Cave and the Rocky River Site on Kangaroo Island by Prof. R. GRÜN with Dr. R. Wells, Flinders University.

The geochemistry, classification and petrogenesis of granites from the New England Batholith, Eastern Australia by Dr. C. BRYANT with Prof. B. Chappell Macquarie University.

Tectonic Reconstruction of the evolution of the Alpine-Himalayan Orogenic Chain

by Prof. T.M. HARRISON with Prof. G. Lister, Monash University.

The age of detrital zircons from sandstone collected from the Stawell gold mine in Victoria by Drs. I. H. CAMPBELL and C. Allen with Dr. Richard Squire, Melbourne University.

Tectonics of the Neoproterozoic – Early Palaeozoic margin in eastern Australia by Dr. C.M. FANNING with Associate Prof. C. Fergusson, University of Wollongong and Prof. R. Henderson, James Cook University.

The environmental effects of the late Devonian Woodleigh impact event by Dr. A. GLIKSON with Dr. M.V. Glikson, University of Queensland.

The environmental context of megafaunal extinction in Australia by Prof. M.T. MCCULLOCH and Prof. R. Grün with Dr. N. Spooner and Dr. J. Magee, Department of Geology.

The evolution of the Lachlan Fold Belt as recorded in zircon preserved in igneous and sedimentary rocks by Dr. I. S. WILLIAMS and Prof. B.W. Chappell, Macquarie University, with Prof.A.J.R. White, formerly Victorian Institute of Earth and Planetary Sciences.

The onset of dune formation in the Stretzlecki Desert by Prof. R. GRÜN with Prof. R. Twidale, University of Adelaide.

The palaeobiology and geochemistry of early Proterozoic black shales, Hamersley Basin, Western Australia by Dr. A. GLIKSON with Dr P. Haines, University of Tasmania**.**

The petrology and geochemistry of the Woodleigh impact structure, Western Australia by Dr. A. GLIKSON with Drs. S. Golding and T. Uysal, University of Queensland.

Testing of the hypothesis of active neotectonism through quantifying bedrock erosion rates in the Mt. Painter region of the Flinders Ranges, South Australia, using cosmogenic nuclides by Dr. D. FABEL with Prof. M. Sandiford, University of Melbourne.

The thermal stability of paramagnetic centres from cores of the Otway basin by Prof. R. GRÜN with Prof. A. Gleadow, University of Melbourne.

The timing and extent of Palaeozoic reactivation in the western Arunta block, by Drs. S. MCLAREN and W.J. Dunlap with Dr. M. Sandiford, University of Melbourne, and Drs. I. Scrimgeour, D. Close and C. Edgoose, Northern Territory Geological Survey.

The timing of Carboniferous-Permian volcanic rocks in the Tamworth belt NSW by Mr. C.M. FANNING with Prof. J. Roberts, University of New South Wales.

The timing of magmatic events in Bolivia by Mr. C.M. FANNING with Dr. S. Boger, Monash University.

Trace element distribution in high temperature metamorphic minerals present during partial melting by Dr. J. HERMANN with Mr. I. Buick, La Trobe University.

Trace element geochemistry of fish otoliths by Prof. M.T. MCCULLOCH with Prof. M. Kingsford, James Cook University.

Using granites to date deformation in the Wyangla region by Dr. I. S. WILLIAMS with Dr. P. Lennox, University of New South Wales.

Using Hf isotopes in zircon to study magma genesis in south-eastern Australia by Dr. I. S. WILLIAMS with Prof. J. Hergt, Dr. J. Woodhead, and Mr. R. Kemp, Melbourne University.

Using melt inclusions in flood volcanic picrites to constrain the nature of mantle processes leading to flood volcanism by Dr. G. YAXLEY with Dr. V. Kamenetsky, University of Tasmania.

Using stable isotope ratios in foraminifera and corals to reconstruct the palaeoceanography and carbon budget of Australasian marginal seas by Dr. M. GAGAN with Ms A. Müller, Ms H. Bostok, Ms K. Lilly and Dr. B. Opdyke, Geology Department, ANU.

International Collaboration

Age and origin of the lunar crust by Dr. M.D. NORMAN with Dr. L. Borg, University of New Mexico, USA.

Age and origin of lunar impact melts by Dr. M.D. NORMAN with Dr. G. Ryder, Lunar and Planetary Institute, USA (deceased).

Age and origin of the lunar crust and meteorite parent bodies by Dr. M.D. NORMAN with Dr. L. Nyquist, Dr. D. Bogard, Dr. D. Mittlefehldt, Dr. A. Brandon, NASA Johnson Space Center, Houston, USA.

Age and origin of the lunar crust by Dr. M.D. NORMAN with Dr. L. Borg, University of New Mexico, USA.

Age and origin of lunar impact melts by Dr. M.D. NORMAN with Prof. R. Duncan, Oregon State University, USA.

A Mission to Very Early Earth: When Did Conditions Suitable for Life Emerge on Earth? by Prof. T.M. HARRISON with Drs T.R. Ireland and V. Bennett, Prof. S.J. Mojzsis Dept. of Geological Sciences, University of Colorado, Dr. F.J. Ryerson, Lawrence Livermore National Laboratory, Prof. G. Turner University of Manchester, Prof. K.D. McKeegan Dept. of Earth and Space Sciences, UCLA, Prof. B.P. Bourdon Institut de Physique du Globe, Universite de

Paris, Prof. J.L. Kirschvink, Division of Geological and Planetary Sciences, Caltech and Dr. Y. Amelin, Geological Survey of Canada.

A new study began on the dynamics of the emplacement of large andesitic lava flows on Tongariro volcano, New Zealand by Prof. R. W. GRIFFITHS and Dr. R.C. Kerr with Dr. N. Stevens, Institute of Geological and Nuclear Sciences, New Zealand.

A new study on patterns of circulation and thermal evolution in the mantle wedge above subduction zones was started by Prof. R. GRIFFITHS with Prof. C. Kincaid, Graduate School of Oceanography, University of Rhode Island, USA.

An exploration of the influence of double-diffusive processes on the melting of ice in the Arctic Ocean was conducted by Prof. J.S. TURNER with Prof. G. Veronis, Yale University. During a period of leave Prof. Veronis spent in RSES they carried out a series of laboratory experiments. The work on the production of vortex rings, previously published with Prof. P.F. Linden, University of California, San Diego, has led to insights in to the mechanisms of swimming of aquatic organisms, and it is being extended with a view to publication in the biological literature.

A project on uncertainty estimation in reservoir simulation by Dr. M. SAMBRIDGE with Prof. M. Christie and Dr. Sam Subbey of Heriot Watt Uni. UK. Prof. Christie visited the school briefly during the year.

Archaean crustal evolution in Greenland by Dr. A.P. NUTMAN with Dr. C.R.L. Friend, Oxford Brookes University, U.K.

Archaean crustal evolution in India by Dr. A.P. NUTMAN with Dr. B. Chadwick, University of Exeter, U.K.

Archaean gold mineralisation in the Nuuk district, Western Greenland by Dr. A.P. NUTMAN with Nunaminerals A/S associated with the Greenland Homerule Government.

As President of the International Association for Seismology and the Physics of the Earth's Interior IASPEI Prof. B.L.N. KENNETT is also a member of the Executive Committee of the International Union of Geodesy and Geophysics IUGG.

A study into the aspects of surface wave tomography is being conducted by Prof.B.L.N. KENNETT and Mr. S. Fishwick with Dr. E. Debayle, University of Strasbourg, France and Dr. K. Yoshizawa, University of Hokkaido, Japan.

A study of the geochronology and geochemistry of the alkali intrusion along the Jinshajiang Ailaoshan Red River fault zone in China by Drs I. H. CAMPBELL and C. Allen with Prof. Liang Hua-Ying, Chinese Academy of Science.

Busidima-Dikika Paleoanthropology Research Project, lower Awash Valley, Ethiopia by Dr. J.G. WYNN, Project Geologist, with scientists from Ethiopia, France, the United States, Canada, Chile and Australia.

Calibration of amino acid racemisation in bones, cave bear evolution and dating human material from Sidron by Prof. R. GRÜN with Prof. Trinidad de Torres, Escuela Tecnica Superior de Ingenieros de Minas de Madrid.

Carrying out research into the glacial history, sea-level change and crustal rebound in Sweden Prof. K. LAMBECK served as the Tage Erlander Guest Professor of the Swedish Research Council from May until October.

Changes in provenance of sandstones in the Snake River plain and environs with the passing of the Yellowstone hot spot, by Mr. C.M. FANNING with Prof. P. K. Link, Idaho State University, USA.

Collaborative studies of Quaternary sedimentary sequences in the North Island, New Zealand by Dr. B. PILLANS, as Research Associate of the New Zealand Institute of Geological & Nuclear Sciences IGNS, with Drs T. Naish, A. Beu and B. Alloway.

Constraints on subduction zone fluids from high pressure ultramafic rocks by Dr. J. HERMANN with Prof. M. Scambelluri, University of Genova, Italy.

Continuous research on aspects of global heterogeneity and its influence on seismic travel times is conducted by Dr. SAMBRIDGE and Ph.D. student Todd Nicholson with Dr. O. Gudmundsson, of the Danish Lithospheric Centre.

Coral bleaching in the southern Pacific, National Geographic sponsored project, by Prof. M.T. MCCULLOCH with Dr. L. Ingram, from the University of California.

Coral bomb pulse ^{14}C records from the eastern Indian Ocean by Ms. N. ABRAM and Dr. M. Gagan with W. Beck from the University of Arizona and N. Grumet and R. Dunbar from Stanford University. As part of this collaboration Nerilie Abram spent three months working at the NSF-AMS Facility at the University of Arizona in early 2002.

Core-mantle interaction in the Hawaiian plume by Dr. M. D. NORMAN with Dr. A. SCHERSTEN, University of Bristol, UK.

Cosmogenic nuclide-base boundary conditions for numerical ice sheet models: a simulation of the Fennoscandian Ice Sheet through a glacial cycle, NSF project OPP-0138486 by Dr. D. FABEL with co-investigators J. Harbor and A. Stroeven.

Cosmogenic nuclide-based boundary conditions for numerical ice sheet models: a simulation of the Fennoscandian Ice Sheet through a glacial cycle, Vetenskapsradet, Sweden project G-AA/GU 12034-301 by Dr. D. FABEL with co investigators A. Stroeven, J. Harbor, A. Hubbard, Prof. K. Lambeck, C. Hättestrand and J.O. Näslund.

Cretaceous thermotectonism along the Livingstone Fault region, Otago and Northern Southland, New Zealand by Drs W.J. DUNLAP and S. McLaren with Dr. N. Mortimer, Institute of Geological and Nuclear Sciences, Dunedin, New Zealand.

Culturing diatoms and coccolitophorae algae by Drs. E. CALVO and C. Pelejero with Dr. R. Simó, Marine Sciences Institute CMIMA-CSIC, Barcelona, Spain.

Dating igneous and metasedimentary rocks of the Transantarctic Mountains, southern Victoria Land, using the laser ICP-MS, by Drs. I. H. CAMPBELL and C. Allen with Prof. A. Cooper, University of Otago.

Dating of a range of sites in South Africa, including the newly discovered human site of Cornelia by Prof. R. GRÜN with Dr. J. Brink, Bloemfontein.

Dating of Quaternary age coral samples from Barbados to determine past variations in climate and sea level by Dr. T. ESAT with Prof. U. Radtke, Geographisches Institut Universitaet zu Koeln, Germany.

Dating Sturtian-aged glacial events in central Africaby Dr. R.A. ARMSTRONG with Dr. R. Key, British Geological Survey, UK.

Dating zircons from the two youngest caldera-forming ignimbrites of the Yellowstone volcanic field, using the laser ICP-MS, by Drs. I. H. CAMPBELL and C. Allen with Dr. M. Palin, University of Otago.

Deducing the composition of the Earth and its implications Dr. H.STC. O'NEILL with Prof. H. Palme, University of Köln

Deciphering the glacial history of Northern Victoria land in Antarctica with Dr. P. Augustinus, Department of Geology, University of Auckland, Auckland, New Zealand.

Detailed zircon U-Pb dating of a complex granite batholiths, Japan by Dr. R.A ARMSTRONG with Dr. R. Anma, University of Tsukuba, Japan.

Determining Ar diffusion rates in mica at high pressure by Dr. G. YAXLEY with Drs. J. Lee and A. Camacho, Queens University, Canada.

Detrital zircon provenance studies in central Australia by Dr. R.A. ARMSTRONG with Dr A. Camacho, Kingston University, Canada.

Detrital zircon provenance of North Sea and Papua New Guinea sandstones by Mr. C.M. FANNING with Dr. A. Morton, HM Associates, UK.

Detrital zircon provenance of some Chilean sandstones by Mr. C.M. FANNING with Dr. H. Bahlburg and Ms C. Augustsson, Westfälische Wilhelms-Universität, Germany.

Documenting the ages of Neoproterozoic glaciations by Dr. R.A. ARMSTRONG with K. Hoffmann, Geological Survey of Namibia.

Dr. D. FABEL collaborated on the burial dating of marine sediment in South Gippsland, Victoria with Dr. T. Gardiner, Herndon Professor of Geology, Department of Geosciences, Trinity University, San Antonio, Texas, U.S.

Evidence for carbonatite and silicate melt involvement in the genesis of micro-diamonds in subducted continental crust by Dr. J. HERMANN with Dr. A. Korsakov, United Institute of Geology, Geophysics and Mineralogy, Novosibirsk, Russia.

Evolution and extent of a Caledonian eclogite province in East Greenland by Dr. A.P. NUTMAN with Dr. J.A. Gilotti, University of Iowa, USA.

Evolution of the southern Patagonian batholiths and outboard accreted terranes by Mr. C.M. FANNING with Prof. F. Hervé, University of Chile, Santiago, Chile

Evolution of fluid flow patterns in the Mont Blanc and Aar Massifs in the European Alps by Prof. S.J. COX with Drs. Boullier, Universite Joseph Fourier, Grenoble, N Mancktelow ETH, Zurich and G. Pennachioni, University of Padova. The collaboration forms part of an ARC Large Grant project, held in the Geology Department, ANU.

Evolution of the Antarctic Peninsula by Mr. C.M. FANNING with Dr. I. Millar, British Antarctic Survey, UK.

Evolution of the Colorado Front Range by Mr C.M. FANNING with Mr W.V. Premo, US Geological Survey, Denver USA

Evolution of Corsica and beyond by Mr. C.M. FANNING with Dr. A. Cocherie and Dr. P. Rossi, BRGM, Orleans, France.

Evolution of the Terre Adelie Craton, Antarctica by Mr. C.M. FANNING with Dr. J.J. Peucat, Geosciences, Rennes, France.

Experimental determination of garnet-zircon-monazite-melt trace element partitioning and on relating zircon and monazite domains to garnet growth zones using trace elements by Dr. J. HERMANN with Dr. D. Rubatto, Geology Department, ANU.

Experimental studies of the genesis of island arc magmas under the influence of melt-fluxing by CO_2 + H_2O by Emeritus Prof. D.H. GREEN with Prof. M.W. Schmidt, ETH, Zürich.

Extraction of late Quaternary climatic histories from raised coral terraces in Indonesia by Dr. M. GAGAN, Ms. N. Abram and Mr. D. Qu with Dr. W. Hantoro, Indonesian Institute of Sciences.

Fabrication of polycrystalline samples of magnesium oxide by Dr. I. JACKSON with S. Moricca, ANSTO and K. Itatani, Sophia University, Tokyo.

For the study of present-day tectonic motion in the region of Papua New Guinea Dr. P. TREGONING has continued cooperation with Drs. R. King, T. Herring and S. McClusky of the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology in the maintenance and development of the GAMIT GPS analysis software.

Geochemistry of early Archean terranes of Greenland by Dr. V. BENNETT with Dr. C. Friend, Oxford-Brookes University.

Geochemistry and geochronology of the Bushmanland Sequence, South Africa by Dr. R.A. ARMSTRONG with Prof. D. Reid, R. Baillie, University of Cape Town, RSA.

Geochemistry of melt inclusions from basaltic magma systems by Dr. M.D. NORMAN with Prof. R. Nielsen and Dr. A. Kent, Oregon State University, USA.

Geochronological studies in Botswana by Dr. R.A. ARMSTRONG with Prof. A.B. Kampunzu and Dr. R. Mapeo, University of Botswana

Geochronology, magmatism and tectonics associated with the Cape Granites, South Africa by Dr. R.A. ARMSTRONG with Prof. A. Kisters and Prof. R. Scheepers, Stellenbosch University, RSA.

Geochronology of the Sierras Pampenas - PAMPRE by Mr. C.M. FANNING with Dr. R.J. Pankhurst, British Geological Survey & the NERC Isotope Geosciences Laboratory, UK.

Geochronology, stratigraphy and tectonics of critical lithologies in Namaqualand by Dr. R.A. ARMSTRONG with Dr. B. Eglington, Dr. R.H. Harmer, Dr. G. Grantham, P. Macey, G. Moen and Dr B. Thomas, Council for Geoscience, RSA.

Geochronology and stratigraphy of critical sequences on the Korean peninsula by Dr. R.A. ARMSTRONG with Dr. D.L. Cho, Korea institute of Geology, Mining and Materials.

Geochronology of high-grade metasediments (of the Anápolis-Itauçu Complex) and granitoids between metasediments of the Araxá Group; dating the Brasiliano mafic magmatism in the Brasiliano Belt by Dr. R.A. ARMSTRONG with Drs. M. Pimentel, D. Fischel, M.H. de Hollanda, University of Brazilia, Brazil.

Geochronology and provenance studies on various sequences in Brazil and Namibia by Dr. R.A. ARMSTRONG with Prof. F. Chemale, Rio Grande do Sul University, Brazil.

Geochronology of Cretaceous tuffs in South Island, New Zealand by Dr. R.A. ARMSTRONG with Prof. S. Weaver, University of Canterbury, New Zealand.

Geology and geochronology of the SW Pacific Gondwana margin by Dr. T.R. IRELAND with Prof. S. Weaver and Prof. J. Bradshaw, Canterbury University, New Zealand.

Geochronology of the Vredefort impact structure by Dr. R.A ARMSTRONG with Drs. R. Gibson, C. Lana, C. Rainaud, and Prof. W.U. Reimold, University of the Witwatersrand, RSA.

Geological investigations and hazard assessment from faulting at the Lucas Heights replacement nuclear reactor site in Sydney by Dr. B. PILLANS with the New Zealand Institute of Geological & Nuclear Sciences IGNS.

Granites from Marie Byrd Land and the Ross Sea by Mr. C.M. FANNING with Dr. C. Smith-Siddoway, Colorado College, Colorado Springs, USA.

Heavy mineral provenance of the Richards Bay Minerals deposit by Dr. R.A. ARMSTRONG with Dr. G. Whitmore, University of Natal, RSA.

High pressure experimental projects to examine the role of upper mantle heterogeneities in intraplate magmatism, a collaborative study involving Dr. G. YAXLEY and Dr Alex Sobolev, Max Planck Institut für Chemie, Mainz, Germany.

High-resolution AMS measurements of nuclear bomb- test C-14 in eastern Indian Ocean corals by Dr. M. GAGAN with Dr. W. Beck, University of Arizona, and Dr. R. Dunbar, Stanford University.

Iceman stable isotopes research by Dr. W. MÜLLER with Dr. H. Fricke, Colorado College, USA. Dr. W. MÜLLER also collaborated with Prof. A. Halliday, ETH Zürich, Switzerland, Dr. P. Tropper, University of Innsbruck, Austria and Dr. E. Egarter-Vigl, Bolzano, Italy, on various aspects of Iceman work.

In laboratory modeling of the surface solidification in shear flows and long basaltic lava flows Prof. R. W. GRIFFITHS and Dr. R.C. Kerr continued collaborations with Prof. K.V. Cashman, Department of Geological Sciences, University of Oregon.

In modelling of the role of internal gravity waves in ocean outflows from gulfs and marginal seas Prof. R. GRIFFITHS continued collaboration with Dr. A.A Bidokhti, Department of Geophysics, University of Tehran, Iran

In the area of surface waveform inversion with variable parameterizations Dr. M SAMBRIDGE worked with Dr. E. DeBayle, CNRS and Universite Louis Pasteur, Strasbourg, France.

Investigation of the geochemistry of foraminifera in deep-sea cores by Dr. M. GAGAN with Prof. H. Spero, University of California at Davis, and Prof. D. Lea, University of California at Santa Barbara.

Isotopic systematics of presolar grains and refractory inclusions in meteorites by Dr. T.R. IRELAND with Prof. E. Zinner, Washington University and Prof. K. McKeegan, UCLA.

Isotopic and elemental analysis of siliceous sponges by Dr. S. EGGINS with Dr. M. Ellwood, National Institute of Water, Hamilton, New Zealand.

Luminescence dating of New Zealand loess by Dr. B. PILLANS with Prof. G. Berger, Desert Research Institute, Reno.

Measurement of elastic wave speeds by Dr. I. JACKSON with Prof. Liebermann Stony Brook University in New York state – ARC Linkage International proposal pending.

Modelling of the role of internal gravity waves in ocean outflows from gulfs and marginal seas Prof. R. GRIFFITHS continued collaboration with Dr. A.A. Bidokhti, Department of Geophysics, University of Tehran, Iran.

Monitoring of local deformation at Rabaul and in the surrounding region by Dr. P. TREGONING with the Papua New Guinea University of Technology, Lae and with the Rabaul Volcano Observatory, with staff at the observatory using RSES equipment.

Ms. P. TREBLE collaborated with Prof. K. McKeegan and Dr. M. Grove, Department of Earth and Space Sciences, University of California, Los Angeles, USA.

Noble gas studies in diamonds by Dr. M. HONDA with Dr J.W. Harris University of Glasgow and Dr P. Cartigny, University of Paris.

On a large AIF/ACOA research grant funding the development of a large-scale three-dimensional numerical model of the Earth's mantle and crust Dr. J. BRAUN is Partner Investigator. The purpose of the model is to understand the complex interactions between the Earth's crust, the underlying mantle and the hydrosphere. The Chief Investigator is Prof. Beaumont of Dalhousie University.

On an ARC Discovery grant to study the complex interactions between landform evolution and tectonics in the Southern Alps of New Zealand Dr. J. BRAUN is Chief Investigator, partner investigators are Prof. Beaumont of Dalhousie University, Prof. Whipple of MIT and Dr. Batt of Royal Holloway, London.

On a research project aiming to constrain the age of the large-scale relief in the European Alps using thermochronological data and numerical models Dr. J.BRAUN is also Co-investigator with Dr. van der Beek of the Universite Joseph Fourier of Grenoble France.

On receiver function inversion Dr. M. SAMBRIDGE worked with Dr. Honn Kao Academia Sinica, Taiwan.

Onset of dune formation in the Stretzlecki Desert by Prof. R. GRÜN with Prof. Helmut Wopfner and Dr. A. Hilgers, Universität zu Köln.

^{17}O nuclear magnetic resonance studies of wadsleyite by Dr. A. BERRY with Drs. S. Wimperis and S.E. Ashbrook, University of Exeter, UK.

On tomography in irregular parameterisations and visualization by Dr. M. SAMBRIDGE with Dr. A. Gorbatov, JAMSTEC, Japan.

On zircon metasomatism in a subduction zone garnet peridotite by Dr. J. HERMANN with Prof. V. Trommsdorff, ETH, Zürich.

Operating and analysing a Superconducting Gravimeter at Mt Stromlo to monitor dynamic processes in the Earth by Dr. H. MCQUEEN and Prof. K. Lambeck with Prof. T. Sato of the National Astronomical Observatory of Japan.

Oxygen isotopes in zircon by Dr.I. WILLIAMS with Dr. S. Claesson and Dr. M. Whitehouse Naturhistoriska Riksmuseet, Stockholm.

Oxidation state of the upper mantle by Dr. M.D. NORMAN with Dr. C.T. Lee, Rice University, Houston, USA.

Paleoceanographic studies along the Northern South China Sea by Dr. C. PELEJERO with Dr. T.J.J. Hanebuth, Department of Geosciences, University of Bremen, Germany, Dr. M.Kienast, Department of Earth and Ocean Sciences, University of British Columbia, Canada, Dr. S. Steinke, Institute of Applied Geophysics, National Taiwan Ocean University, Taiwan and Dr. L. Shao, Department of Marine Geology, Tongji University, China.

Petrology and geochemistry of Hawaiian volcanoes and mantle plumes by Dr. M.D. NORMAN with Prof. M. Garcia, University of Hawaii, USA.

Petrology and geochemistry of Hawaiian volcanoes and mantle plumes by Dr. M.D. NORMAN with Prof. M. Rhodes, University of Massachusetts, USA.

Precambrian evolution of South America by Dr. A.P. NUTMAN with Prof. U.G. Cordani and Dr. M. Basei, University of São Paulo, Brazil.

Primary melt inclusions in andalusite from anatectic graphitic metapelites: implications for the Al_2SiO_5 triple point by Dr. J. HERMANN with Prof. B. Cesare, University of Padova, Italy.

Problems in Patagonia and PAMPRE by Mr. C.M. FANNING with Dr. C.W. Rapela, Universidad de la Plata, Argentina.

Quaternary climatic change research by Prof. J. CHAPPELL with Prof. W. Pinxian, Laboratory of Marine Geology Togji University, Shanghai. During 2002, analysis of long-period climate cycles in South China Sea was completed.

Reconstruction of Australian palaeoclimates using isotopic signatures in emu and Genyornis eggshell by Dr. M. GAGAN with Prof. G. Miller, University of Colorado.

Reconstruction of tropical palaeoclimates in the southwestern Pacific by Dr. M. GAGAN with Drs. T. Correge and G. Cabioch, Institute for Research and Development, New Caledonia.

Regional geochronology of Brazil and the completion of a new geological/chronostratigraphic map of Brazil by Dr. R.A. ARMSTRONG with Dr. L. da Silva, Geological Survey of Brazil.

Research into methods for the analysis of magnetotelluric data by Dr. T. LILLEY with Prof. J.T. Weaver of the University of Victoria, Canada.

Research on a variety of issues in seismic wave propagation ranging from strong ground motion in western Japan to the influence of changes in crustal thickness on regional seismic wave propagation is being conducted by Prof. B. KENNETT with Dr. T. Furumura at the Earthquake Research Institute, University of Tokyo, Japan.

Research on coral reefs from Barbados by Prof. M.T. McCULLOCH with Prof. U. Radtke from Köln University.

SHRIMP geochronological projects in Greenland by Dr. A.P. NUTMAN with Drs. F. Kalsbeek, A.A. Garde and P.R. Dawes, Geological Survey of Denmark and Greenland.

SHRIMP U-Pb geochronology of various sequences in Brazil by Dr. R.A ARMSTRONG with Dr. E. Paiva, Instituto de Geosciencias – Unicamp, Brazil.

SHRIMP U-Pb dating of ash beds within the Karoo basin, South Africa by Dr. R.A. ARMSTRONG with M. Werner, University of Würzburg, Germany.

SHRIMP U-Pb geochronology of the Limpopo Belt and other areas of Botswana by Dr. R.A. ARMSTRONG with T. Majaule, B.K. Paya, Geological Survey of Botswana.

SHRIMP U-Pb zircon dating of Late Proterozoic magmatism and mineralisation in the Zambian Copper Belt by Dr. R.A. ARMSTRONG with J. W. Barron, Colorado School of Mines, USA.

Sierras Pampeanas and the evolution of the Argentine PreCordillera by Mr. C.M. FANNING with Prof. C. Casquet and Dr. C. Galindo, Universidad Complutense, Madrid, Spain.

Soil production and erosion research by Prof. J. CHAPPELL with Dr. A. Heimsath, Dartmouth University, Hanover NH. During 2002, two main outcomes were achieved: (i) established sampling strategies for determining erosion rates on rough rocky terrain using cosmogenic nuclides, March 28-April 3 at Hanover and (ii) obtained drill-core samples through deep saprolite Profile for geochemical mass balance analysis, Dec 14-20, Bega Valley NSW.

Sr isotope analysis of garnet and clinopyroxene from mantle xenoliths by Dr. W. MÜLLER with Dr. D. Jacob, University of Greifswald, Germany.

Studies on siderophile element systematics of the Hawaiian plume by Dr. V. BENNETT with Prof. M. Garcia University of Hawaii.

Study and development of potential isotopic studies on siliceous sponges from Antarctica by Drs. E. CALVO and C. Pelejero with Prof. J. Maria Gili, Marine Sciences Institute CMIMA-CSIC, Barcelona, Spain.

Sulphide partial melting by Dr. J. MAVROGENES with Dr. R. Frost, University of Wyoming, US.

Tectonic evolution of Dronning Maud Land, sensu lato by Mr. C.M. FANNING with Dr. J. Jacobs, University of Bremen, Germany.

The archaean to early Proterozoic impacts, Pilbara Craton, Western Australia by Dr. A. GLIKSON with Professors B.M. Simonson, Oberlin College, Ohio, USA, G.R. Byerly, State University of Louisiana, Baton Rouge, USA, and D. Lowe, Stanford University, California, USA.

The Baja-BC conundrum by Mr. C.M. FANNING with Dr B.J. Mahoney, University of Wisconsin-Eau Claire, USA.

The daily analysis of the REGAL Reseau GPS dans les Alpes network GPS data in the southern french Alpes is directed by Dr. P. TREGONING with Dr. J. Virieux Geosciences Azur, Nice and Dr. A. Walpersdorf LGIT, Grenoble.

The East Antarctic Craton in the Transantarctic Mountains by Mr. C.M. FANNING with Dr. J. Goodge, Southern Methodist University, USA.

The evolution of the Cape Fold Belt by Dr. R.A. ARMSTRONG with Prof. M. de Wit, University of Cape Town, RSA.

The evolution of the Lurio Belt, Mozambique by Dr. R.A. ARMSTRONG with D. Jamal, Eduardo Mondlane University, Mozambique.

The genesis of highly undersaturated, intraplate magmas by Emeritus 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. This research has been supported by the Humboldt Foundation, Germany.

The Geological Evolution of the Himalayan-Tibetan Orogenic System by Prof. T.M. HARRISON with Professors An Yin, Dept. of Earth and Space Sciences, UCLA and G. Lister, Monash University.

The Horoman Peridotite, Hokkaido — particularly on evidence for complex mantle recycling of the peridotite and late-stage channelling by volatile-rich magmas by Emeritus Prof. D.H. GREEN with Associate Prof. K. Niida, University of Hokkaido and Dr. T. Morishita, Kanazawa University.

The Neoproterozoic to Early Cambrian tectonism in the Gjelsvikfjella, Maud Belt, Antarctica by Dr. R.A. ARMSTRONG with Professors H Frimmel, A. Bisnath, University of Cape Town, RSA.

The petrology and geochemistry of the Woodleigh impact structure, Western Australia by Dr. A. GLICKSON with Dr. J. Whitehead, University of New Brunswick, Canada.

The provenance of late Proterozoic and early Palaeozoic Gondwanan sediments of Antarctica and India by Dr. I.S. WILLIAMS with Dr. J. Goodge Southern Methodist University, Dallas and Prof. P. Myrow, The Colorado College, Colorado Springs.

The role of carbonated recycled oceanic crust in petrogenesis of carbonatites and related rocks by Dr. G. YAXLEY in collaboration with Prof. Dr. G. Brey, Universität Frankfurt, Germany.

The role of carbonated recycled oceanic crust in petrogenesis of carbonatites and related rocks by Dr. G.YAXLEY with Prof. G. Brey at the Universitat Frankfurt, Germany and Drs A. Woodland and M. Seitz at the Universität Frankfurt, Germany.

The role of upper mantle heterogeneities in intraplate magmatism by Dr. M. YAXLEY with Dr. A. Sobolev, Max Planck Institut für Chemie, Mainz, Germany and to determine Ar diffusion rates in mica at high pressure with Drs. J. Lee and A. Camacho, Queens University, Canada.

The role of Li abundances in upper mantle minerals as a petrogenetic indicator by Dr. G. YAXLEY with Drs. A. Woodland and M. Seitz, Universität Frankfurt, Germany.

The Subcommission on Quaternary Stratigraphy (SQS) and the Working Group on the Lower-Middle Pleistocene Boundary, involvement by Dr. B Pillans both for the International Commission on Stratigraphy ICS.

The tectonic evolution of the Tugela Belt by Dr. R.A. ARMSTRONG with Prof. S. McCourt, University of Durban-Westville, RSA.

The trace element distribution in high temperature metamorphic minerals present during partial melting by Dr. J. HERMANN with Mr. I. Buick, La Trobe University, Melbourne.

The Zhangbaling metamorphic belt adjacent the Tan-Lu Fault in China by Dr. W.J. DUNLAP with C. Teyssier and Q. Zhang, University of Minnesota.

The zircon geochronology of the Merensky Reef, Bushveld Complex by Dr. R.A. ARMSTRONG with Prof. A. Wilson, University of Natal, RSA.

Thickness and composition of the lunar crust by Dr. M.D. NORMAN with Prof. I. McCallum, University of Washington, USA.

Timing of events in the New England region, North America by Mr. C.M. FANNING with Dr. J.A Aleinikoff, US Geological Survey, Denver USA.

Timing of modern human evolution by Prof. R. GRÜN with many international scholars. Prof. R. Grün has collected hominid samples from the anthropological sites Cave of Hearths, Hutjiespunt, Swartkrans, and Border Cave - South Africa, Prof. V.A. Tobias, Dr. L. Berger, Department of Anatomy, Medical School, University of the Witwatersrand, Prof. J. Parkington, Department 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, Department of Anthropology, Harvard University, Tabun Prof. C.B. Stringer, Natural History Museum, London and Atapuerca, Spain Prof. J.L. Arsuaga, Department of Palaeontology, Universidad Compultense, Madrid and Prof. J. Bermudes de Castro, Museo de Ciencias Naturales, Madrid.

Tracing the Sr isotopic evolution of the Archean and Proterozoic mantle by Dr. V. BENNETT with Prof. D. DePaolo, University of California, Berkeley.

Tropical river research by Prof. J. CHAPPELL with Prof. W. Dietrich, UC Berkeley. During March 14-25, Prof. J Chappell completed research on geomorphologic and sedimentary evolution of the Fly River, PNG.

U-Pb geochronology and provenance studies in eastern Namaqualand, the Limpopo Belt, the Pongola basin and various Proterozoic sediments by Dr. R.A. ARMSTRONG with Professors N. Beukes, R. Boshoff, H. Dorland, J. Mukhopadhyay, N. Nhleko and H. van Niekerk, Rand Afrikaans University, RSA.

U-Pb reference zircons by Mr. C.M. FANNING with Dr. K. Shiraishi and Dr. K. Misawa, National Institute for Polar Research, Tokyo, Japan.

Uranium isotope variations in Quaternary oceans by Dr. T. ESAT with Dr. L. Ayliffe, Department of Geology and Geophysics, University of Utah.

Uranium uptake of bones by Prof. R. GRÜN with Dr. A. Pike, Research Laboratory for Archaeology and the History of Art, Oxford University, UK.

U-series dating of cave bear teeth by Dr. W. MÜLLER with Prof. G. Rabeder, University of Vienna, Austria.

U-series dating of cyclic seismogenic fault cements to establish earthquake recurrence intervals by Dr. W. MÜLLER with Dr. P. Eichhubl, Stanford University, USA.

U-series of dating fossil corals from the uplifted coral terraces at Henderson Island by Prof. M.T. McCULLOCH with Dr. C. Stirling and Prof. A. Halliday, ETH Zürich.

Using XANES and EXAFS to determine the specification of ore-forming metals in natural and synthetic fluid inclusions by Dr. A.BERRY and Dr .J. MAVROGENES with Drs. S. Sutton and M. Newville, University of Chicago and Argonne National Laboratory, USA.

Variations in sea-levels, uranium isotopes and radiocarbon during the last glacial period by Dr. T. ESAT with Dr. Y. Yokoyama, Graduate School of Science, University of Tokyo.

Zircons from Alpine eclogites by Mr. C.M. FANNING with Prof. D. Gebauer and Dr. A. Liati, ETH Zürich, Switzerland.

Dr C. Allen attended the Geological Society of America meeting in Denver where she presented a poster on the ages of detrital zircons from the Klamath River, N. California.

Dr R.A. Armstrong attended the final meeting of the Kaapvaal Craton Project, held in Cape Town, South Africa, where he presented a paper and co-authored a number of others. He also presented papers at the 11th Quadrennial IAGOD Symposium and Geocongress, Windhoek, Namibia, and at Gondwana XI in Christchurch, New Zealand. He participated in a meeting of the IGCP 418 Working Group held in Namibia.

Dr V. Bennett attended the Geological Society of Australia meeting in Adelaide in July where she presented papers on "Constraints on early Earth processes from geochemical investigations of the oldest (≥3800 Ma) abyssal periodotites" and "Combined osmium and isotopic and seismic evidence for orphaned early Proterozoic mantle beneath Phanerozoic crust in the New England Fold Belt, Eastern Australia". In December, Dr. Bennett attended the American Geophysical Union meeting in San Francisco where she gave a talk on "New Estimates of Rhenium in the Crust: Implications for Mantle Re-Os Budgets".

Mr J.P. Bernal attended the Goldschmidt Conference, August 2002, Davos, Switzerland, where he presented "Strategies for the determination of the isotopic composition of natural Uranium".

Dr A.J. Berry presented work on Fe oxidation states in silicate glasses at the Goldschmidt Conference, Davos, Switzerland, 18 to 23 August. He also attended the workshop "Neutrons for the Earth Sciences", Sydney, 12 to 13 December.

Dr J. Braun was invited Professor at the Universite Joseph Fourier in Grenoble in Decmber 2001 and January 2002, where he taught a course on quantitative thermochronology to Honours and Graduate students. He also presented seminars at the Department of Earth Sciences and Engineering at Imperial College in London, January 2002; the Department of Geology, Royal Holloway, University of London, January 2002; and Yale University on his recent work in quantifying landform evolution from thermochronological data (April 2002).

Dr J. Braun visited Dalhousie University (Canada) to collaborate with Prof. Beaumont and his group on developing a large-scale three-dimensional numerical model of the Earth's mantle and crust. (April and November 2002); and attended a workshop organized by the Earth System Evolution Program of the Canadian Institute for Advanced Research, of which he is a member since 1993. (November 2002)

Dr C. Bryant co-authored a poster presentation on "Lithium Isotopes; a Potential Aid to Understanding Granite Petrogenesis" at the American Geophysical Union Meeting, San Francisco in December. She also presented a seminar on "The geochemical evolution of the Late Oligocene – Recent Izu-Bonin-Mariana arc; sediment recycling and implications for crustal evolution models" at Macquarie University in November 2002.

Dr E. Calvo gave a seminar entitled "Reconstruction of past oceanic chemistry: Development of new techniques" in the Marine Sciences Institute (CMIMA-CSIC) in Barcelona, Spain, 20th September.

Dr I.H Campbell attended the Australian Geological Congress in Adelaide where he presented a paper on the Chuquicamata porphyry copper deposit. He also attended the International Mineralogical Meeting in Edinburgh.

Professor J. Chappell was invited speaker at Rice-Exxon-Mobil "Vail Symposium", Houston Texas, 7-8 March, where he gave the talk "Downstepping reef cycles, Late Quaternary sea level changes, ice-cycles and isotopes". Professor J. Chappell was plenary speaker at the Australia-New Zealand Geomorphology Association conference, Kalgoorlie, September 30-October 4, where he gave a presentation entitled "Erosion, soil production and sustainability: assessment using cosmogenic nuclides". Professor J. Chappell presented a paper jointly with Dr B.J. Pillans at the Australian Regolith conference, University of Canberra, November 21-22 entitled "The dynamics of soils in North Queensland: rates of mixing by termite determined by single grain luminescence dating". He was also an invited speaker at the Australian Academies, National Conference "Living with Climate Change", Canberra December 18-19, where he gave the talk "Living with climate change: can we take lessons from history ?".

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Professor S.F. Cox co-convened the theme “Plate Boundary Fault Mechanics and the Interaction of Stress, Strain and Fluid Pressure Regimes” at the Western Pacific AGU meeting in Wellington, New Zealand, in July. He also presented a paper at that meeting.

Professor S.F. Cox also presented a paper on “Application of stress transfer modelling for area selection in mesothermal gold systems” at the conference on “Applied Structural Geology for Mineral Exploration and Mining” in Kalgoorlie, WA in September. The conference was held under the auspices of the Australian Institute of Geoscientists.

Professor S.F. Cox co-authored a paper with Dr Y. Rolland (ANU Geology) at the Goldschmidt conference in Switzerland in August.

Dr G. F. Davies attended the symposium “The Living Earth”, which was part of the centenary celebrations of the Carnegie Institution of Washington in September, and he presented an invited lecture on the emergence and dynamics of plate tectonics.

Dr G. F. Davies was invited to present a lecture in September on the emergence and dynamics of plate tectonics at the symposium “The Living Earth”, which was part of the centenary celebrations of the Carnegie Institution of Washington.

Dr S. Eggins gave the following presentations and abstracts as invited speaker at the 3rd International Conference on High-Resolution ICPMS, Atlanta, Georgia October 3-5 2002: “In-situ U-series analysis by laser ablation-MC-ICPMS", Eggins S, Bernal J-P, Shelley JMG, McCulloch MT, Kinsley L; "Laser ablation sampling: Watts going on?", Steve Eggins, Les Kinsley. Michael Shelley and "Laser ablation-ICP-MS compositional Professoriling of chamber walls in planktonic Foraminifera; implications for Mg/Ca thermometry", Eggins S, De Deckker P, Marshall J. He also presented the following talks at the 12th Annual V.M. Goldschmidt 2002 Conference, Davos, Switzerland: Geochim Cosmochim Acta 66 (15A): A207; Volatile elements in pillow lava glasses from the Kermadec Arc – Havre Trough and offshore Taupo Vaolcanic Zone, southwest Pacific. Wysoczanski RJ, Hauri EH, Gamble JA, Luhr JF, Eggins SM, Wright IC, 12th Annual V.M. Goldschmitt Conference, Davos, Switzerland. Geochimica et Cosmochimica Acta 66 (15A): A848; Rhenium systematics in submarine MORB, arc and back-arc basin glasses by laser ablation ICP-MS. Sun W, Bennett VC, Eggins SM, Arculus RJ, Kamenetsky VS, Falloon TJ., 12th Annual V.M. Goldschmitt Conference, Davos, Switzerland. Geochimica et Cosmochimica Acta 66 (15A): A754.

Dr T. Esat gave the invited presentation at the Goldschmidt 2002 Conference, Davos, Switzerland, 2002: T.M. Esat and Y. Yokoyama, rapid sea-level, ice-volume and radiocarbon excursions during a Heinrich event at Huon Peninsula, *Geochim. Cosmochim. Acta* 66 (2002) 216.

Dr D. Fabel attended the the 12th Annual V.M. Goldschmidt Conference in Davos, Switzerland, August 18-23, 2002, and presented the abstract "Landscape preservation under ice sheets". He also attended the 10th Australian and New Zealand Geomorphology Group Conference, Kalgoorlie, 30 September – 4 October, 2002 and presented the abstract "Surviving glaciation: complex exposure modelling and the preservation of glacial landscapes".

Mr C.M. Fanning co-convened a session on Antarctica and presented a paper at the Australian Geological convention in Adelaide in July. He presented a paper at a Symposium on the "Amalgamation of Precambrian Blocks and the role of the Palaeozoic Orogens in Asia" in Sapporo, Japan in September. He carried out field work in Utah and Idaho and then attended the Annual meeting of the Geological Society of America in Denver in October. He was an invited visiting researcher at the National Institute for Polar Research, Tokyo in June.

Dr U. Faul attended the 2002 Goldschmidt conference in Davos, Switzerland, from 18 to 23 August and gave an invited paper entitled "Systematics in the seismic wave attenuation of partially molten olivine aggregates". Dr Faul also attended the 2002 Channel Users Meeting in Sydney from 18 to 19 November 2002 and gave an invited presentation entitled "EBSD Mapping of Silicates".

Dr J.D. Fitz Gerald attended the 17th Australian Conference on Electron Microscopy in Adelaide in February and coauthored a presentation "TEM Investigation of Aluminium-containing precipitates in high-Aluminium doped Silicon Carbide". He also attended a workship on Nanomaterials run in October by ANU's Centre for Science and Engineering of Materials.

Dr M. Gagan presented invited talks at the Goldschmidt 2002 Conference special session: *Ocean Paleotemperatures*, held in Davos, Switzerland, 18-23 August and the U.S. National Oceanic and Atmospheric Administration Conference: *The Hadley Circulation: Present, Past, and Future*, held at the University of Hawaii, USA (12-15 November).

Professor R.W. Griffiths attended the 9th National Conference of the Australian Meteorological and Oceanographic Society held at the University of Melbourne in February, where he presented an invited keynote address on processes governing the ocean thermohaline circulation.

Professor R. W. Griffiths was invited to present a keynote lecture at the 9th National Conference of the Australian Meteorological and Oceanographic Society held at the University of Melbourne in February.

Professor R. Grün was invited by the session organisers “Abrupt climatic fluctuations: a context for hominid and human development” to present *Dating modern human evolution* at the European Geophysical Society, 22-26 April 2002, Nice, France. He was invited by the Max Planck Institut für Evolutionäre Anthropologie, Leipzig, to present *Direct dating of hominids using ESR and U-series dating* at the meeting on Palaeontological and Archaeological Insights into Human Evolution. 2-3 June 2002, Leipzig, Germany. In September, Professor R. Grün was invited by the Korean Basic Science Institute to present two lectures at the 3rd Korean Basic Science Institute Symposium on Age Determination on *Dating methods for the Quaternary* and *Dating of modern human evolution.* He also presented a lecture at the Korean Institute on Nuclear Safety on Quaternary Geochronology. Professor R. Grün attended the 10th International Conference on Luminescence and Electron Spin Resonance Dating. 24-28 June where he presented with S. Eggins, M. Shelley and A. Pike *Laser ablation ICP-MS analysis for the determination of U-concentration Profiles and in situ U-series dating.* He was member of the Scientific Organising Committee, chaired the session “ESR Dating” and is the editor for the proceedings in Quaternary Science Reviews.

Dr A. Glikson gave a number of seminars: “The search for Australian impact structures, with particular reference to the Woodleigh impact structure, Carnarvon Basin, Western Australia”, Curtin University, April 2002; “The search for early Precambrian impact signatures”, Geological Survey of Western Australia, April 2002; “The oldest asteroid impacts, Pilbara Craton, Western Australia”, Curtin University, December 2002 and “Asteroids and early crustal evolution”, University of Queensland, December 2002.

Professor D.H. Green attended the 16th Australian Geological Convention “Geoscience 2002: Expanding Horizons” in Adelaide from 1 to 5 July and presented an invited paper “Island Arc Ankaramites: primary magmas from refractory lherzolite fluxed by CO_2 and H_2O”. He attended the 14th International Workshop on Orogenic lherzolites and Mantle Processes, held at Samani in Hokkaido from August 26 to September 3 and presented an invited paper “Island Arc Ankaramites: products of (CO_2 + H_2O)-fluxed melting of refractory lherzolites”. This meeting was followed by the “International Symposium on the Amalgamation of Precambrian Rocks in Asia” (PPO/Asia) at University of Hokkaido, Sapporo at which Professor Green was a keynote speaker on “Convergent Margin Magmatism”. Professor Green was also an invited speaker at the Australian Mars Exploration Society conference “Exploring the Red Planet” held at Sydney University, 12 to 14 July and presented a paper “Martian Volcanoes: Gateways to the Martian Interior”.

Mr A. Hack presented an abstract on copper solubility in mineral-buffered, near-magmatic supercritical fluids: insights from LA-ICP-MS, PIXE and EXAFS of synthetic fluid inclusion experiments, at the Australian Geological Convention in Adelaide, 1 to 5 July.

Professor T.M. Harrison travelled to California USA 3-17 January to give seminars at UC Santa Cruz and the Lawrence Livermore National Laboratory; he also undertook lead isotope multicollector measurements at UCLA. The Director visited Los Angeles, USA 19-25 April to undertake lead isotope multicollector measurements at UCLA and to give seminars. From 26 April to 13 May he was engaged in fieldwork in Tibet.

Professor T.M. Harrison attended the 16th AGC Conference in Adelaide 30 June to 4 July where he gave a keynote address entitled "75 Years of Indo-Asian Collision Models". He then attended the IAU Symposium 213 "Bioastronomy 2002: Life Among the Stars" and Fulbright Symposium 2002: "Science Eduction in Partnership" at Hamilton Island, Great Barrier Reef 5-12 July, presenting a talk entitled "A Mission to Really Early Earth". He also visited Lawrence Livermore National Laboratory in San Francisco 14-16 August and then travelled to Davos, Switzerland for the Goldschmidt Conference 18-23 August.

Professor T.M. Harrison visited Los Angeles 29 September to 15 November and then 22 November to 7 December during which time he supervised a graduate student in the completion phase of her theses and administered existing contracts and grants at UCLA. During a brief return to Australia he attended the Australian Crustal Research Centre Research Symposium 2002 at Monash University in Melbourne 19-21 November presenting a talk entitled "Testing the Extrusion Hypothesis". The Director also attended a one-day workshop at ANSTO, Sydney on 13 December to address how the needs of neutron beam users are to be met by the replacement reactor.

Dr J. Hermann attended the IX International Symposium on Experimental Mineralogy, Petrology and Geochemistry in Zürich, Switzerland, from 24 to 27 March where he gave an oral presentation on the interaction of hydrous granitic melts with carbonates: implications for devolatilisation in subduction zones. He also presented a poster entitled "Experimental determination of zircon-garnet-melt trace element partitioning and its application to dating". Dr Hermann attended the 18th International Mineralogical Association in Edinburgh, from 1 to 6 September where he gave a keynote lecture on phase relations, melt properties and crust-mantle interactions in subduction zones. He also attended the 81st Riunione della Società Geologica Italiana in Turin, Italy, 10 to 12 September where he gave an oral presentation entitled "Contrasting features of subducted oceanic and continental crust". Dr Hermann was invited to present seminars in Italy: Turin: (4 April), Mailand (8 April), Genua (11 April) and Padua (15 April) entitled "Eclogiti e petrologia sperimentale: una finestra sui processi di subduzione".

Dr M. Honda attended the 16th Australian Geological Congress held in Adelaide in July where he presented a paper entitled "Unusual noble gas compositions in polycrystalline diamonds: preliminary results from Jwaneng, Botswana".

Dr G.O. Hughes attended the 9th National Conference of the Australian Meteorological and Oceanographic Society held at the University of Melbourne in February, where he presented a talk entitled "Damping of internal gravity waves in stratified fluids".

Dr T.R. Ireland attended the Lunar and Planetary Science Conference XXIII in Houston, USA in March, where he presented a paper. From 11-18 April, Dr T.R. Ireland visited New Zealand, attending a function in honour of Dr A. Reay and presenting a seminar at Otago University. He also collaborated with Professor Steve Weaver at Canterbury University and presented a seminar.

Dr T.R. Ireland travelled to New Zealand 13-20 June where he was invited to present a seminar to the Geology Department at the Canterbury University. He also conferred on papers with Professor Steve Weaver at Canterbury University and with Dr A. Reay at Otago University. From 29 June to 6 July, Dr Ireland travelled to Adelaide for the 16th Australian Geological Convention, where he presented a paper for the Robin Oliver Memorial Symposium.

Dr T.R. Ireland attended the 65th Annual Meeting of the Meteoritical Society at the University of California in Los Angeles, USA from 19-29 July where he presented a paper concerning trace element abundances in CAIs. He also attended a meeting of the Council of the Meteorical Society, to which he has been elected. Dr Ireland travelled to Christchurch, New Zealand in August to attend the Gondwana Symposium, at which he presented a paper and also participated in a fieldtrip to the Chatham Islands. Dr Ireland also attended the 6th Torino Workshop in Nuclear Astrophysics, held in Melbourne from 9-13 December, and presented a paper.

Dr I. Jackson travelled to Washington, D.C. in February to serve on a US National Science Foundation special panel and during the same trip, visited Stony Brook University and lectured at the California Institute of Technology. During the same month he attended the Condensed Matter Physics Meeting of the Australian Institute of Physics in Wagga Wagga NSW and presented a poster paper. A poster paper describing an experimental study of seismic wave attenuation in partially molten olivine aggregates was presented at the fall annual meeting of the American Geophysical Union in San Francisco in December.

Professor B.L.N. Kennett attended the Superplume Project Symposium in Tokyo in January giving a paper on the strong S wave signature associated with deep subduction zones.

In April he attended the European Geophysical Society meeting in Nice with a presentation on surface wave velocities and anisotropy under Australia, as well as the Bureau meeting of IASPEI.

In June he was a keynote speaker at the annual workshop of IRIS (Incorporated Research Institutions in Seismology) in Hawaii, and gave a presentation on the development of a continental array of portable seismic instruments in Australia.

He gave a paper on seismic heterogeneity in the mantle at the Australian Crustal Research Centre Symposium in Melbourne in November. In December he attended the Fall AGU meeting in San Francisco with a poster on the influence of anisotropy on seismic tomography

Dr A.E. Kiss attended the 9th National Conference of the Australian Meteorological and Oceanographic Society held at the University of Melbourne in February, where he presented a talk entitled "The influence of continental slopes and boundary conditions on western boundary current separation in mid-latitude wind-driven gyres"

Professor Kurt Lambeck attended

(i) the meeting of the Earth Science Evolution Program (ESEP) of CIAR (10-14 June) followed by the all-programs meeting from 14-17 June in Victoria, British Columbia, Canada;

(ii) the final Stage III Workshop (concerned with modelling climate and environment during the interval leading into the Last Glacial Maximum for northern Europe), Cambridge (18-22 June);

(iii) the INTIMATE Conference in Tromso, Norway, (22-28 June);

(iv) Crafoord Symposium at the royal Swedish Academy in conjunction with the Crafoord Prize Ceremony.

Dr Lilley participated in the 12th Australian Geological Convention held in Adelaide in July, contributing a paper co-authored with colleagues at Geoscience Australia, Flinders University, and the University of Manitoba, Canada.

Dr Lilley attended the Edgeworth David Day Symposium and Dinner at the University of Sydney on 6 September, on the topic of "Climate Change: Myth or Reality?

Mr. X. Liu took part in the IX International Symposium on Experimental Mineralogy, Petrology and Geochemistry, Zürich, Switzerland, from 24 to 27 March 2002 where he gave an oral presentation on Cr_2O_3: the unforgettable but forgotten oxide in mantle partial melting process, and presented a poster on the accurate determination of the solidus of simplified spinel lherzolite in the system CaO-MgO-Al_2O_3-SiO_2 (CMAS) at 11 kbar: traditional and new experimental techniques.

Dr J. Mavrogenes presented a seminar at the Geology Department, Melbourne University, entitled “Sulfide partial melting at Broken Hill, NSW”.

Professor M.T. McCulloch attended several conferences during 2002. They include: Living with Climate Change, National Academies Forum, 18-19 December, Canberra; American Geological University Fall Meeting 2002, 6-10 December, San Francisco, at which he presented the poster “A 250 year coral record of environmental change in the Great Barrier Reef, Australia”; Australian Coral Reef Society Conference 2002, 8-10 November, Brisbane, at which he delivered the paper “Impact of drought on sediment fluxes entering the Great Barrier Reef”; Goldschmidt 2002, 18-23 August, Davos, Switzerland, at which he presented the abstract “Geochemical tracing of human impacts on coral reefs” and also chaired the session “Geochemistry of Pollution”; European Meeting of the International Society for Reef Studies, 4-7 September, Cambridge, England; First International Palaeolontological Congress, 6-10 July, Sydney; 2002.

Professor I. McDougall participated in an international conference on Lipari in the Aeolian Islands, north of Sicily, Italy, in late September. The meeting, run under the auspices of the Italian National Committee for UNESCO, was to celebrate the inclusion of the Aeolian Islands in the World Heritage List. The Aeolian Islands are the summits of youthful volcanoes built up from the floor of the Tyrrhenian Sea, and include the islands of Vulcano, Stromboli and Lipari as well as several others. McDougall presented a paper at the meeting on Lord Howe Island, which is an oceanic island that was included on the World Heritage List some 20 years ago.

Ms H. McGregor attended the NCCR Swiss International Climate Summer School, Grindelwald, Switzerland, September 2002. She also attended the Goldschmidt 2002 Geochemical Conference, Davos, Switzerland, August 2002.

Ms Julia Mullarney attended the 9th National Conference of the Australian Meteorological and Oceanographic Society held at the University of Melbourne in February.

Ms A. Müller presented papers at the following conferences: Müller, A., Gagan, M.K. & Lough, J.M., Effect of early marine diagenesis on coral reconstructions of 20th century changes in surface-ocean carbonate saturation state. Australian Coral Reef Society, Annual meeting, Stradbroke, November 2002; Müller, A., Gagan, M.K. & Lough, J.M., Early marine diagenesis in corals and consequences for paleo-reconstructions of carbonate saturation state in coral reefs and atmospheric CO_2. European Meeting of the International Society for Reef Studies, Cambridge, September 2002; Müller, A., Holocene sea-level change in the southwestern Baltic Sea. DEUQUA (German Quaternary Association), Annual conference, Potsdam, August 2002; Müller, A. & Gagan, M.K., Geochemical expressions of early marine diagenesis in corals–implications for paleoceanographic reconstructions. 12th Goldschmidt conference, Davos, August 2002; Dewi, K.T., Müller, A. & Frenzel, P., Ostracoda (micro-crustacea) from the Timor Sea, and their relations to paleoenvironments. International Symposium on Crustacean Fisheries 2002: Biology, Technology and Management, Bogor, August, 2002; Müller, A. & Gagan, M.K., Sea surface temperature reconstructions in the eastern Indian Ocean. Australian Marine Sciences Association, Fremantle, July 2002; Müller, A. & Gagan, M.K., Early marine diagenesis in corals and geochemical consequences for sea surface temperature reconstructions. European Geophysical University, XVII. General Assembly, Nice, April 2002; Müller, A. & Gagan, M.K., Validity of paleoceanographic reconstructions from corals for the last interglacial. Stage 5 deposits in Europe in the context of global climate evolution. First Workshop of the DEKLIM-EEM project: Climate Change at the Very End of a Warm Stage, Leipzig, March 2002; Müller, A. & Gagan, M.K., Past sea surface temperature reconstructions from massive coral: Important tracers and potential errors. Australian Meteorological and Oceanographic Society, Annual Conference, Melbourne, February 2002.

Dr W. Müller, gave the following invited talks: Goldschmidt 2002 conference, Davos, Switzerland: Müller, W., Fricke, H., Halliday, A.N., McCulloch, M.T., 2002: *Combined Sr, Pb and O isotopic tracing of origin and migration of the Neolithic Alpine Iceman*. Geochimica et Cosmochimica Acta, 66/15A, A531, August 2002; 14th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications (EMIS-14), Victoria (CAN): Kutschera, W. Müller, W., 2002: *Isotope Language of the Alpine Iceman investigated with MS and AMS.* Abstract vol. 14th EMIS-14, May 2002; International Conference on Archaeometry, Amsterdam (NL): Müller, W., Fricke, H., Halliday, A.N., 2002: *Isotopic tracing of the Neolithic Alpine Iceman – clues to his origin and migration.* Abstract vol., Int. Conf. on Archaeometry, Amsterdam, p. 161, April 2002. Dr W. Müller was co-convenor of the special session "Linking geochronology with textures and petrology" at 12th Goldschmidt Conference, Davos, Switzerland (August 2002). He was also co-chair of the task group "Geochronology", International Goldschmidt Program Committee, for the Organization of scientific sessions at Goldschmidt Conferences.

Dr Marc Norman attended the Lunar and Planetary Science Conference held during March in Houston, U.S.A. and the 16th Australian Geological Convention in Adelaide in July. During September he travelled to Taos, New Mexico for "The Moon Beyond 2002: Next Steps in Lunar Science and Exploration" and in December attended the Lunar and Planetary Institute Workshop run by the American Geophysical Union in San Francisco

Dr A.P. Nutman attended and gave two talks at the 16th Australian Geological Congress held in July in Adelaide.

Dr H.StC. O'Neill presented a keynote talk on "The Composition of the Earth" at the IX International Symposium on Experimental Mineralogy, Petrology and Geochemistry in Zürich, Switzerland, 24 to 27 March. He also attended the Goldschmidt Conference in Davos, Switzerland from 18 to 23 August where he presented a paper on "An electrochemical cell across the core-mantle boundary" with Dr S.A.T. Redfern, and the 4th Orogenic Lherzolite Conference in Samani, Japan from 27 August to 3 September where he presented work on the origin and significance of Cr-diopside suite segregations in mantle peridotites. He spent July-August visiting Professor H. Palme in Cologne, continuing their collaboration on deducing the composition of the Earth and its implications.

Dr C. Pelejero gave a seminar entitled “Combined application of isotopic analysis by MC-ICP-MS and molecular biomarkers in paleoceanographic studies” in the Centre of Environmental Studies (CEA), Autonomic University of Barcelona, 18th September.

Dr Pillans presented papers at the following conferences: Australian Geological Convention, Adelaide, 1-5 July; 10th Australia & New Zealand Geomorphology Group Conference, Kalgoorlie, 30 September to 4 October and Regolith and Landscapes in Eastern Australia, Canberra, 21-23 November.

Ms Emma-Kate Potter attended the Goldschmidt conference in Davos, Switzerland, and the Quaternary Sea-Levels conference in Barbados.

Dr Anthony Purcell was on attachment to the Quaternary Geology Department of the University of Lund, Sweden, (May to September). The primary purpose of this visit was to compare theoretical and observed values of relative sea-level change during late- and post-glacial time. This process began with a comprehensive review of the available Scandinavian field data and the methodology applied to its interpretation. The numerical model for the Fennoscandian ice sheet was then refined in time and space to improve agreement with the extended observational data set. Finally, a search of the rheological parameters was performed to determine the earth and ice model combination of best fit. In cooperation with Dr Nils-Olov Svensson the observational data-set was expanded to include shoreline transgression, highest shoreline, and Baltic ice-lake data. Preliminary comparisons between these observations and the numerical results indicate that further refinement of ice and earth models may be possible and that numerical results may be used to identify suspect observational data whose interpretation may need to be re-evaluated. Some of this period was spent at Durham University working with Dr. Glenn Milne on bench-marking of the codes used by the ANU and Toronto groups for the calculation of sea-level change. This collaboration is ongoing but has already yielded several improvements to the code used by both groups.

Dr Nick Rawlinson attended the 2002 Fall Meeting of AGU in San Francisco 6-10 December.

Mr B. Rohrlach presented a paper co-authored with Dr R. Loucks and Dr J. Palin at the 16th Australian Geological Convention in Adelaide in July 2002 on the link between intra-arc compressive stress and metallogenic fertility based on a study of the Tampakan Cu-Au deposit in the southern Philippines.

Dr M. Sambridge attended the European Geophysical Society meeting during April in Nice, France, where he gave a presentation on `Fast marching methods for evolution of seismic wavefronts'.

Dr M. Sambridge was an invited speaker in August at the first international meeting on `Inverse problems, modelling and simulation' held in Fethiye, Turkey.

Mr S. Sommacal attended the Australian Geological Convention in Adelaide, 1 to 5 July and the Goldschmidt Conference in Davos, Switzerland, 18 to 24 August where he presented a paper on computational petrology and pyroxene thermodynamics.

Mr W. Sun attended the Goldschmidt Conference (18-24 Sept. 2002) in Davos, Switzerland and presented a paper "Rhenium systematics in volcanic glasses and melt inclusions by laser ablation ICP-MS". He also participated in "Highly Siderophile Element Workshop" (25-28, Sept. 2002) in Nancy, France and presented a paper "Rhenium Geochemistry: laser ablation ICP-MS results". He attended several Chinese conferences in December 2001 in Hong Kong, Guanzhou, Xi'an and Beijing and gave talks on the Qinling Dabie orogenic belt.

Dr E. Tenthorey attended the AGU Annual Meeting in San Francisco, USA in December 2002 where he presented the paper - Evolution of strength recovery and permeability during fluid-rock reaction in experimental fault zones.

Ms P. Treble attended the Goldschmidt 2002 Conference, Davos, Switzerland.

Dr P. Tregoning attended the European Geophysical Society meeting in Nice in April 2002. He spent 6 months at Geosciences Azur, Nice, working with seismologists on developing software for analysing slip distribution patterns of large earthquakes. He also presented a seminar at Ecole Normale Superieure, Paris in June, titled "Geodetic Research at The Australian National University.".

Ms J. Trotter attended the First International Palaeontological Congress at Macquarie University, Sydney, 6-10 July, 2002, where she presented a poster entitled "Conodont Geochemistry – in-situ chemical profiling of single conodont elements using LA-ICPMS".

Dr I.S. Williams attended the 16th Australian Geological Convention, Adelaide, June 30–July 5, where he presented a paper on large-scale sediment transport along the coast of early Paleozoic Gondwana. He also attended Goldschmidt 2002, Davos, August 16–21, where he presented a paper on the response of zircon and monazite to high-grade metamorphism. In February he spent a week at the Naturhistoriska Riksmuseet, Stockholm, experimenting with oxygen isotope analysis on the Cameca IMS1270.

Dr J.G. Wynn attended the following conferences: April 2002, Annual Science Meeting, Cooperative Research Centre for Greenhouse Accounting, Adelaide, South Australia; August 2002, Biogeochemistry of the Continental Carbon Cycle, Cooperative Research Centre for Greenhouse Accounting Program B2. Brisbane, Queensland; November 2002, Below Ground Carbon Accounting Workshop, Cooperative Research Centre for Greenhouse Accounting, Canberra, ACT and December 2002, American Geophysical University Fall Meeting, San Francisco, California.

Dr G. Yaxley attended the 16th Australian Geological Convention, held in Adelaide in July, where he presented a poster entitled "The Link Between Subduction and Carbonatites". He also presented a talk entitled "A Melt Inclusion Study of Baffin Bay Picrites" at Goldschmidt

2002, held in Davos, Switzerland in August and a keynote talk entitled "The Petrological Behaviour of Eclogitic Heterogeneities in the Mantle" at the 4th International Workshop on Orogenic Lherzolites and Mantle Processes, held in Samani, Japan in September. At the Australian Diamond Conference, held in Perth during December, he held discussions with personnel from a number of Australian and international diamond exploration companies

EDITORIAL RESPONSIBILIES

Dr C. Allen is a member of the editorial board of the Australian Journal of Earth Sciences.

Dr. V. Bennett became an Associate Editor for the *Journal of Geophysical Research.* She was also co-editor of a special volume of *Chemical Geology*, "Highly Siderophile Elements in the Earth and Meteorites".

Professor J. Chappell is a member of the editorial board of *Quaternary Research.*

Prof S.F. Cox continued as a member of the editorial advisory boards of *Journal of Structural Geology*, and *Geofluids*

Dr D. Fabel was guest editor of the article "Inceptions: mechanisms, patterns and timing of ice sheet inception" in *Quaternary International*, 95-96, pp. 137.

Professor R. Grün is Editor of *Quaternary Geochronology (Quaternary Science Reviews*), associate editor of the *Journal of human Evolution*, member of the Editorial Boards of *Quaternary International* and *Radiation Measurements*, and Member of reviewers' panel of *Ancient TL.* He is also a standing member of the scientific committee and editor of the proceedings of the *International Conferences on Luminescence and Electron Spin Resonance Dating*. The next conference in this series will be held in Cologne in July 2005.

Professor T.M. Harrison is an associate editor of *Geochimica Cosmochimica Acta* and serves on the editorial board for *Earth and Planetary Science Letters*.

Dr I. Jackson continued to serve as an Associate Editor of the Journal of Geophysical Research and as a member of the Editorial Advisory Boards of the journals *Physics and Chemistry of Minerals* and *Physics of the Earth and Planetary Interiors.*

Professor B.L.N. Kennett is an associate editor for *Physics of the Earth and Planetary Interiors* and *Earth and Planetary Science Letters.*

Professor Kurt Lambeck is an Editorial Advisory Board Member for *Quaternary Science Reviews* and for *Earth and Planetary Science Letters*.

Dr Jean Braun is Associate Editor for the *Journal of Geophysical Research* of the American Geophysical Union.

Professor M.T. McCulloch is a member of the editorial board of *Quaternary Geochronology (Quaternary Science Reviews)* and a council member of the *International Association of Geochemistry and Cosmochemistry*.

Dr A.P. Nutman is a member of the editorial board of Precambrian Research.

Dr. Sambridge continued to serve on the editorial board of Geophysical Journal International. He handles papers through the Pacific Region Office.

Outreach and Workshops

Mr J.P. Bernal gave the following presentations: “Aplicación de LA-ICP-MS a la geoquímica y geocronología de procesos de intemperismo”, Instituto de Geología, Universityversityversidad Nacional Autónoma de México, 3rd September 2002; “Geoquímica de procesos de intemperismo”, Instituto Mexicano del Petróleo, 4th September 2002; “U-series analysis of weathering minerals by LA-MC-ICP-MS: A new tool for weathering geochronology?”, 23rd October 2002, Geoscience Australia, CRC-LEME Bimonthly Seminar and CRC-LEME Weathering Geochronology Workshop, 20th November 2002, Australian National University.

Dr A. Berry was an invited speaker at the workshop "The Australian Synchroton: New Opportunities for Soil and Environmental Science", Melbourne, 3 to 4 October.

Dr J. Braun taught Geophysics to Year 10 students at Telopea Park School for 3 weeks in October 2002. He has also organized several visits by secondary students of Telopea Park School to RSES, and organized the visit to RSES by secondary students from various parts of the country taking part in the Siemens Science Experience in October 2002.

Professor J. Chappell was involved in "Factor of Ten — A Future Worth Having", a major ANU environmental event held through October. His personal contributions included a public lecture "The burning bush - a short environmental history of humans", two floor talks at the Art School gallery, and a sculpture on the theme of water stress in Australia. Professor J. Chappell also gave seminars at a number of institutions in the United States, including University of California, Berkeley, University of California, Santa Barbara and Dartmouth University, New Hampshire.

Professor S.F. Cox joined with Professor Rick Sibson (University of Otago) in presenting a two day course on structural controls on faulting, fracturing and fluid flow in ore systems for the University of Western Australia and the Geological Survey of Western Australia in September.

Professor S.F. Cox presented a seminar to geological staff at AurionGold in Kalgoorlie in October.

Professor S.F. Cox is a member of the committee of the ACT Board of Senior Secondary Studies which oversees Year 11/12 curricula in Earth Sciences.

Dr S. Eggins gave the following presentations during 2002: Primary magma and melt inclusion compositions in SW Pacific island arcs at the Smithsonian Institution, Washington DC, 9th October 2002; *In-situ* U-series analysis and dating by LA-ICPMS at the University of Maryland, 8th October 2002 and Compositional Profiling using Laser ablation ICPMS: application to environmental materials at the University of Victoria, British Columbia, 16th October 2002.

Professor Kurt Lambeck conducted a short course to graduate students at the University of Stockholm.

Dr J. Mavrogenes attended the workshop "The Australian Synchroton: New Opportunities for Soil and Environmental Science", Melbourne, 3 to 4 October.

Dr W. Müller featured in The Bulletin, Australia's weekly political magazine: 26. 6. 2002, p.32-33: Cheryl Jones: *Ice breakers – the secret life of Ötzi the Iceman is being revealed thanks to the efforts of an Australian scientist.*

Dr M. Norman conducted presentations to National Youth Science Forum visitors to RSES

Dr H.StC. O'Neill attended the Neutron Scattering workshop from 12 to 13 December at Lucas Heights. He also visited the Australian National Beamline Facility (ANBF), Tsukuba, Japan from 27 October to 5 November to undertake XANES spectroscopy experiments.

Dr I.S. Williams completed the CPAS graduate course in scientific communication.

Dr G. Yaxley liaised on the School's behalf with website design consultants to progress an upgrade of the School web-site. He also attended a half-day seminar on supervision of graduate students held at ANU in May.

TEACHING ACTIVITIES

Dr J. Braun has taught an Honours course while Invited Professor at the Universite Joseph Fourier of Grenoble, in late 2002.

Professor J. Chappell gave 3 lectures and associated laboratory classes at the Department of Geology, The Faculties. He also gave a 2-day short course on radiocarbon dating at the Centre for Archaeologic Research.

Professor Cox as part of his joint appointment at RSES and the Department of Geology (The Faculties), taught the one semester GEOL 3002 Structural Geology and Tectonics course, half of GEOL 2012 Introduction to Structural and Field Geology and part of the GEOL3001 Field Geology courses in the Geology Department.

Professor R.W. Griffiths was lecturer for half of a third year unit (Physics 3034: Physics of Fluid Flows) within the undergraduate physics curriculum. He and Dr G. O. Hughes also supervised a short research project of a student taking the third year course Research Projects in Physics.

Professor R. Grün gave a lecture series on topics of Quaternary geochronology to students of the Department of Archaeology and Anthropology, The Faculties.

Professor Harrison taught the geological time portion of Earth Science (GEOL 1002) in the Department of Geology, ANU. He also taught a graduate course, Geochemical Kinetics (ESS 210) while on leave at UCLA and guest lectured in the course Deformation and Metamorphism of the Crust (ESC3201) in the School of Geosciences, Monash University.

Professor B.L.N Kennett - Honours Course 2002 (18 lectures):

Seismology and the Earth's Interior (for Physics and Geology students).

Dr J. Mavrogenes taught the third year Economic Geology course and first year Earth Science course in the Geology Department, Australian National University.

Dr W. Müller was invited lecturer at the Summer School *"Ore minerals and metallurgical techniques between Past and Present"*, Auronzo, Italy, June 2002.

Dr B. Pillans gave lectures in regolith geology courses in Geology Department, ANU and School of Applied Science, University of Canberra.

Mr N.G. Ware taught the Microanalysis component of the 2002 workshop series conducted by the Australian National University Electron Microscope Unit. He also gave a master class on X-ray microanalysis at the Australian and New Zealand Forensic Science Society Conference held in Canberra in May.

Dr Williams assisted several students with SHRIMP analyses, including Ms H. Degeling and Mrs L. Bean, PhD and Honours students respectively from the ANU Geology Department, Ms A. Storkey, PhD student from La Trobe University, and Mr R. Kemp, PhD student from Melbourne University.

Other Matters

Dr I.H. Campbell is a member of the Commission for Igneous and Metamorphic Petrogenesis, a subcommission of the International Union of Geological Sciences. He is also a councillor of the International Mineralogical Association and has recently been appointed co-leader of the Commission for Large Igneous Provinces (LIP).

Professor S.F. Cox was a member of the external review committee which reviewed the Monash University School of Geoscience in October.

Dr D. Fabel was a consultant on setting up a quartz separation facility for cosmogenic isotope analysis at Stockholm University, Stockholm, Sweden. He was also a consultant on setting up a Be and Al extraction laboratory at the University of Canterbury, Christchurch, New Zealand

Dr J.D. Fitz Gerald continues to serve on the advisory board of Physics and Chemistry of Minerals.

Dr J.D. Fitz Gerald continues on the advisory committee for the ANU's Centre for Science and Engineering of Materials

Professor R. W. Griffiths served as a member of the Advisory Board, Centre for Complex Systems, ANU. He was also a member of the Sir Frederick White Prize Committee, Australian Academy of Science, a member of the Academy's Section Committee 4 (Earth Sciences), and a member of the Fellows Committee, VGP Section, American Geophysical Union.

Dr T.R. Ireland is a Senior Fellow at Canterbury University, New Zealand. He was also elected to the Council of the Meteoritical Society.

Mr A. Lyman joined the GFD Group in July as a PhD scholar, after completing his MSc at Arizona State University, Tempe, USA.

Professor I. McDougall participated in an expedition to the Kibish area, southern Ethiopia, in January-February, 2002, in relation to further exploration of this area for youthful hominid fossils, the predecessors of modern humans. His role was mainly to explore the area for volcanic deposits in order to collect material for isotopic dating by the 40Ar/39Ar method. The work is being supported by the US National Science Foundation through a grant to Dr. J. Fleagle, State University of New York, Stony Brook, New York.

Dr C. Mériaux Departed

Dr Nick Rawlinson acted as Secretary of ACT branch of Society of Exploration Geophysics.

Software development for Infrasound processing for CTBTO, Vienna (US$100K).

Co-investigators Dr D.J. Brown and Professor. B.L.N. Kennett with support from Dr C. Tarlowski.

Dr I.S. Williams was convener of the RSES Thursday seminar series for 2002.

GROUP: *PRISE*

CONFERENCES AND OUTSIDE STUDIES

Mr C.M. Fanning co-convened a session on Antarctica and presented a paper at the Australian Geological convention in Adelaide in July. He presented a paper at a Symposium on the "Amalgamation of Precambrian Blocks and the role of the Palaeozoic Orogens in Asia" in Sapporo, Japan in September. He carried out field work in Utah and Idaho and then attended the Annual meeting of the Geological Society of America in Denver in October. He was an invited visiting researcher at the National Institute for Polar Research, Tokyo in June.

Dr R.A. Armstrong attended the final meeting of the Kaapvaal Craton Project, held in Cape Town, South Africa, where he presented a paper and co-authored a number of others. He also presented papers at the 11th Quadrennial IAGOD Symposium and Geocongress, Windhoek, Namibia, and at Gondwana XI in Christchurch, New Zealand. He participated in a meeting of the IGCP 418 Working Group held in Namibia.

Dr G. Yaxley attended the 16th Australian Geological Convention, held in Adelaide in July, where he presented a poster entitled “The Link Between Subduction and Carbonatites”. He also presented a talk entitled “A Melt Inclusion Study of Baffin Bay Picrites” at Goldschmidt 2002, held in Davos, Switzerland in August and a keynote talk entitled “The Petrological Behaviour of Eclogitic Heterogeneities in the Mantle” at the 4th International Workshop on Orogenic Lherzolites and Mantle Processes, held in Samani, Japan in September. At the Australian Diamond Conference, held in Perth during December, he held discussions with personnel from a number of Australian and international diamond exploration companies

Dr Marc Norman attended the Lunar and Planetary Science Conference held during March in Houston, U.S.A. and the 16th Australian Geological Convention in Adelaide in July. During September he travelled to Taos, New Mexico for “The Moon Beyond 2002: Next Steps in Lunar Science and Exploration” and in December attended the Lunar and Planetary Institute Workshop run by the American Geophysical Union in San Francisco

COOPERATION WITH AUSTRALIAN UNIVERSITIES

Mr C.M. Fanning collaborated with Associate Professor C. Fergusson, **University of Wollongong** and Professor R. Henderson, **James Cook University** on Tectonics of the Neoproterozoic – Early Palaeozoic margin in eastern Australia, Dr S Boger, **Monash University** on the timing of magmatic events in Bolivia and Professor J. Roberts, **University of NSW** on the timing of Carboniferous-Permian volcanic rocks in the Tamworth belt NSW.

Dr R. Armstrong started collaborative research projects in Oman and Namibia with Professor David Gray of the **University of Melbourne** and Dr B. Goscombe of the **University of Adelaide**.

Dr G. Yaxley is collaborating with Dr Vadim Kamenetsky, **University of Tasmania** in a project using melt inclusions in flood volcanic picrites to constrain the nature of mantle processes leading to flood volcanism.

Dr M. Norman is involved in collaborative studies with Prof. John Foden, **Adelaide University,** Dr. Vadim Kamenetsky, Dr. Gary Davidson, Dr. Andrew Rae, Prof. Ross Large and Mr. Philip Robinson, **University of Tasmania,** Dr. John Webb and Mr. Chris Ihlenfeld, **La Trobe University** and Dr. David Belton and students, **University of Melbourne.**

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 participated in a number of collaborative projects with a number of scientists from the Geological Surveys of Britain, 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 is involved in projects with a number of Australian and international diamond exploration companies.
Dr M. Norman is collaborating with several gold exploration companies as well as being involved in projects with CSIRO and Geoscience Australia.

INTERNATIONAL COLLABORATION

Mark Fanning:

Changes in provenance of sandstones in the Snake River plain and environs with the passing of the Yellowstone hot-spot by Mr C.M. FANNING with Professor P. K. Link, Idaho State University, USA

The Baja-BC conundrum by Mr C.M. FANNING with Dr B.J. Mahoney, University of Wisconsin-Eau Claire, USA

Evolution of the southern Patagonian batholith and outboard accreted terranes by Mr C.M. FANNING with Professor F. Hervé, University of Chile, Santiago, Chile

Geochronology of the Sierras Pampenas - PAMPRE by Mr C.M. FANNING with Dr R.J. Pankhurst, British Geological Survey & the NERC Isotope Geosciences Laboratory, UK

Evolution of the Antarctic Peninsula by Mr C.M. FANNING with Dr I. Millar, British Antarctic Survey, UK,

Problems in Patagonia and PAMPRE by Mr C.M. FANNING with Dr C.W. Rapela, Universidad de la Plata, Argentina

Detrital zircon provenance of some Chilean sandstones by Mr C.M. FANNING with Dr H Bahlburg and Ms C. Augustsson, Westfälische Wilhelms-Universität, Germany

Evolution of Corsica and beyond by Mr C.M. FANNING with Dr A. Cocherie & Dr P. Rossi, BRGM, Orleans, France

Timing of events in the New England region, North America by Mr C.M. FANNING with Dr J.A Aleinikoff, US Geological Survey, Denver USA

Evolution of the Colorado Front Range by Mr C.M. FANNING with Mr W.V. Premo, US Geological Survey, Denver USA

Granites from Marie Byrd Land and the Ross Sea by Mr C.M. FANNING with Dr C. Smith-Siddoway, Colorado College, Colorado Springs, USA

U-Pb reference zircons by Mr C.M. FANNING with Dr K. Shiraishi and Dr K. Misawa, National Institute for Polar Research, Tokyo, Japan

The East Antarctic Craton in the Transantarctic Mountains by Mr C.M. FANNING with Dr J.

Goodge, Southern Methodist University, USA

Evolution of the Terre Adelie Craton, Antarctica by Mr C.M. FANNING with Dr J.J. Peucat, Geosciences, Rennes, France

Tectonic evolution of Dronning Maud Land, sensu lato by Mr C.M. FANNING with Dr J. Jacobs, University of Bremen, Germany

Zircons from Alpine eclogites by Mr C.M. FANNING with Professor D. Gebauer and Dr A. Liati, ETH Zürich, Switzerland

Detrital zircon provenance of North Sea and Papua New Guinea sandstones by Mr C.M. FANNING with Dr A. Morton, HM Associates, UK.

Sierras Pampeanas and the evolution of the Argentine PreCordillera by Mr C.M. FANNING with Prof. C. Casquet and Dr C.Galindo, Universidad Complutense, Madrid, Spain

Rich Armstrong:

Geochronology of the Vredefort impact structure, Dr RA ARMSTRONG with Dr R. Gibson, C. Lana, C. Rainaud, and Professor W.U. Reimold (University of the Witwatersrand, RSA)

The tectonic evolution of the Tugela Belt, Dr RA ARMSTRONG with Professor S. McCourt (University of Durban-Westville, RSA),.

The zircon geochronology of the Merensky Reef, Bushveld Complex, Dr RA ARMSTRONG with Professor A. Wilson (University of Natal, RSA)

Heavy mineral provenance of the Richards Bay Minerals deposit, Dr RA ARMSTRONG with Dr. G. Whitmore (University of Natal, RSA)

The evolution of the Cape Fold Belt, Dr RA ARMSTRONG with Professor M. de Wit (University of Cape Town, RSA)

Geochemistry and geochronology of the Bushmanland Sequence, South Africa, Dr RA ARMSTRONG with Professor D. Reid, R. Baillie, (University of Cape Town, RSA)

The Neoproterozoic to Early Cambrian tectonism in the Gjelsvikfjella, Maud Belt, Antarctica, Dr RA ARMSTRONG with Professor H Frimmel, A. Bisnath (University of Cape Town, RSA)

Geochronological studies in Botswana, Dr RA ARMSTRONG with Professor A.B. Kampunzu and Dr R. Mapeo (University of Botswana)

SHRIMP U-Pb geochronology of the Limpopo Belt and other areas of Botswana, Dr RA ARMSTRONG with T, Majaule, B.K. Paya (Geological Survey of Botswana)

Documenting the ages of Neoproterozoic glaciations, Dr RA ARMSTRONG with K. Hoffmann (Geological Survey of Namibia)

The evolution of the Lurio Belt, Mozambique, Dr RA ARMSTRONG with D. Jamal (Eduardo Mondlane University, Mozambique)

U-Pb geochronology and provenance studies in eastern Namaqualand, the Limpopo Belt, the Pongola basin and various Proterozoic sediments, Dr RA ARMSTRONG with Professor N. Beukes, R. Boshoff, H. Dorland, J. Mukhopadhyay, N. Nhleko and H. van Niekerk (Rand Afrikaans University, RSA)

Geochronology, magmatism and tectonics associated with the Cape Granites, South Africa, Dr RA ARMSTRONG with Professor A. Kisters and Professor R. Scheepers (Stellenbosch University, RSA)

Geochronology, stratigraphy and tectonics of critical lithologies in Namaqualand, Dr RA ARMSTRONG with Dr B. Eglington, Dr R.H. Harmer, Dr G. Grantham, P. Macey, G. Moen and Dr B. Thomas (Council for Geoscience, RSA)

Detailed zircon U-Pb dating of a complex granite batholith, Japan, Dr RA ARMSTRONG with Dr Ryo Anma (University of Tsukuba, Japan),.

Dating Sturtian-aged glacial events in central Africa, Dr RA ARMSTRONG with Dr R. Key (British Geological Survey, UK)

Geochronology and stratigraphy of critical sequences on the Korean peninsula, Dr RA ARMSTRONG with Dr Deung-Lyong Cho (Korea institute of Geology, Mining and Materials)

Geochronology of high-grade metasediments (of the Anápolis-Itauçu Complex) and granitoids between metasediments of the Araxá Group; dating the Brasiliano mafic magmatism in the Brasiliano Belt, Dr RA ARMSTRONG with Dr M. Pimentel, D. Fischel, M.H. de Hollanda (University of Brazilia, Brazil);

Geochronology and provenance studies on various sequences in Brazil and Namibia, Dr RA ARMSTRONG with Professor F. Chemale (Rio Grande do Sul University, Brazil)

Regional geochronology of Brazil and the completion of a new geological/chronostratigraphic map of Brazil, Dr RA ARMSTRONG with Dr L. da Silva (Geological Survey of Brazil)

SHRIMP U-Pb geochronology of various sequences in Brazil, Dr RA ARMSTRONG with Dr Elson Paiva (Instituto de Geosciencias – Unicamp, Brazil)

SHRIMP U-Pb dating of ash beds within the Karoo basin, South Africa, Dr RA ARMSTRONG with M. Werner (University of Würzburg, Germany)

Detrital zircon provenance studies in central Australia, Dr RA ARMSTRONG with Dr A. Camacho (Kingston University, Canada)

SHRIMP U-Pb zircon dating of Late Proterozoic magmatism and mineralisation in the Zambian Copper Belt, Dr RA ARMSTRONG with J. W. Barron (Colorado School of Mines, USA)

Geochronology of Cretaceous tuffs in South Island, New Zealand, Dr RA ARMSTRONG with Professor S. Weaver (University of Canterbury, New Zealand)

Greg Yaxley:

The role of carbonated recycled oceanic crust in petrogenesis of carbonatites and related rocks, Dr G. YAXLEY in collaboration with Prof Dr Gerhard Brey (Universität Frankfurt, Germany)

The role of Li abundances in upper mantle minerals as a petrogenetic indicator Dr G. YAXLEY with Drs Alan Woodland and Michael Seitz (Universität Frankfurt, Germany)

High pressure experimental projects to examine the role of upper mantle heterogeneities in intraplate magmatism, a collaborative study involving Dr G. YAXLEY and Dr Alex Sobolev (Max Planck Institut für Chemie, Mainz, Germany)

Determining Ar diffusion rates in mica at high pressure, Dr G. YAXLEY with Drs Jim Lee and Alfredo Camacho (Queens University, Canada)

Marc Norman:

Age and origin of the lunar crust and meteorite parent bodies, Dr M.D. NORMAN with Dr. Lawrence Nyquist, Dr. Don Bogard, Dr. David Mittlefehldt, Dr. Alan Brandon (NASA Johnson Space Center, Houston, USA)

Petrology and geochemistry of Hawaiian volcanoes and mantle plumes, Dr M.D. NORMAN with Prof. Michael Garcia (University of Hawaii, USA)

Age and origin of lunar impact melts, Dr M.D. NORMAN with Prof. Robert Duncan (Oregon State University, USA)

Geochemistry of melt inclusions from basaltic magma systems, Dr M.D. NORMAN with Prof. Roger Nielsen and Dr. Adam Kent (Oregon State University, USA,)

Age and origin of the lunar crust, Dr M.D. NORMAN with Dr. Lars Borg (University of New Mexico, USA)

Thickness and composition of the lunar crust, Dr M.D. NORMAN with Prof. Ian McCallum (University of Washington, USA)

Petrology and geochemistry of Hawaiian volcanoes and mantle plumes, Dr M.D. NORMAN with Prof. Michael Rhodes (University of Massachusetts, USA,)

Core-mantle interaction in the Hawaiian plume, Dr M.D. NORMAN Dr. Anders Schersten (University of Bristol, UK)

Oxidation state of the upper mantle, Dr M.D. NORMAN with Dr. Cin-Ty Lee (Rice University, Houston, USA)

Age and origin of lunar impact melts, Dr M.D. NORMAN with Dr. Graham Ryder (Lunar and Planetary Institute, USA)(deceased)

OUTREACH AND WORKSHOPS

Dr G. Yaxley liaised on the School's behalf with website design consultants to progress an upgrade of the School web-site. He also attended a half-day seminar on supervision of graduate students held at ANU in May.
Dr M. Norman conducted presentations to National Youth Science Forum visitors to RSES

PUBLICATIONS

Aleinikoff, J.N., Horton, J.W. Jr., Drake, A.A. Jr. and **Fanning, C.M**. (2002) SHRIMP and Conventional U-Pb ages of Ordovician granites and tonalites in the central Appalachian Piedmont: Implications for Paleozoic tectonic events. *American Journal of Science* **202**, 50-75.

Aleinikoff, J.N., Wintsch, R.P., **Fanning, C.M**. and Dorias, M.J. (2002) U-Pb geochronology of zircon and polygenetic titanite from the Glastonbury Complex, Connecticut, USA: an integrated SEM, EMPA, TIMS, and SHRIMP study. *Chemical Geology* **188**, 125-147.

Armstrong, R.A., Vishnevsky, S. and Koeberl, C. (2002) U-Pb analyses of zircons from the Popigai impact structure, Russia: first results. In: *Impacts in Precambrian Shields*, (eds.) Plado, J. and Pesonen, L.J. Springer-Verlag, Berlin Heidelberg, 109-116.

Bagai, Z., **Armstrong, R.** and Kampunzu, A.B. (2002) U-Pb single zircon geochronology of granitoids in the Vumba granite-greenstone terrain (NE Botswana):Implications for the evolution of the Archaean Zimbabwe craton. *Precambrian Research* **118/3-4**, 149-168.

Boger, S.D., Carson, C.J., **Fanning, C.M.**, Hergt, J.M., Wilson, C.J.L. and Woodhead, J.D. (2002) Pan-African intraplate deformation in the northern Prince Charles Mountains, east Antarctica. *Earth and Planetary Science Letters* **195**, 195-210.

Camacho, A., Hensen, B.J. and **Armstrong, R.** (2002) Isotopic test of a thermally driven intraplate orogenic model, Australia. *Geology* **30/10**, 887-890.

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Fergusson, C.L. and **Fanning, C.M.** (2002) Late Ordovician stratigraphy, zircon provenance and tectonics, Lachlan Fold Belt, southeastern Australia. *Australian Journal of Earth Sciences* **49**, 423-436.

Geslin, J.K., Link, P.K., Riesterer, J.W., Kuntz, M.A and **Fanning, C.M.** (2002) Pliocene and Quaternary stratigraphic architecture and drainage systems of the Big Lost Trough, northeastern Snake River Plain, Idaho. *In* Link, P.K. and Mink, L.L. (Eds) Geology, Hydrogeology and Environmental Remediation: Idaho National Engineering and Environmental Laboratory, Eastern Snake River Plaun, Idaho: Boulder, Colorado. *Geological Society of America Special Paper* **353**, 11-26.

Goodge, J.W. and **Fanning, C.M.** (2002) Precambrian crustal history of the Nimrod Group, central Transantarctic Mountains. *In* Gamble, J.A., Skinner, D.N.B. & Henrys, S., (Eds). Antarctica at the close of the millenium. *Royal Society of New Zealand Bulletin* **35**, 43-50.

Kelly, N.M., Clarke G.L. and **Fanning, C.M.** (2002) A two-stage evolution of the Neoproterozoic Rayner Structural Episode: new U–Pb sensitive high resolution ion microprobe constraints from the Oygarden Group, Kemp Land, East Antarctica. *Precambrian Research* **116**, 307-330.

Key, R.M., Liyungu, A.K., Njamu, F.M., Somwe, V., Banda, J., Mosley, P.N. and **Armstrong, R.A.** (2001) The western arm of the Lufilian Arc in NW Zambia and its potential for copper mineralization. *Journal of African Earth Sciences* **33**, 503-528.

Kisters, A.F.M., Belcher, R.W., **Armstrong, R.A.,** Scheepers, R., Rozendaal, A. and Jordaan, L.S. (2002) Timing and kinematics of the Colenso Fault: The Early Paleozoic shift from collisional to extensional tectonics in the Pan-African Saldania Belt, South Africa. *South African Journal of Geology* **105(3)**, 257-270.

Königer, S. Lorenz, V. Stollhofen, H. and **Armstrong, R.A.** (2002) Origin, age and stratigraphic significance of distal fallout ash tuffs from the Carboniferous-Permian continental Saar-Nahe Basin (SW Germany*). International Journal of Earth Sciences (Geol Rundsch)* **91**, 341-356.

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Norman M.D., Bennett V.C., and Ryder G. (2002) Targeting the impactors: highly siderophile element signatures of lunar impact melts from Serenitatis. *Earth and Planetary Science Letters* **202**, 217-228.

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Vaughan, A.P.M., Pankhurst, R.J. and **Fanning, C.M.** (2002) A mid-Cretaceous age for the Palmer Land event, Antarctic Peninsula: implications for terrane accretion and Gondwana palaeolatitudes. *Journal of the Geological Society, London* **159**, 113-116.

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