Australian Microscopy & Microanalysis Research Facility

2008 Profile

ENABLING WORLD-CLASS RESEARCH

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The AMMRF is funded by

An Australian Government Initiative
National Collaborative Research Infrastructure Strategy

NSW First for Business
Department of State and Regional Development

Queensland Government

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Australian
Microscopy & Microanalysis
Research Facility

"I had the opportunity this morning to assist in a review of the [HQ of the] AMMRF. Sometimes to sit on a review is a pleasure and sometimes it is a headache, depending on the quality of the institution you have to review. This morning was a great pleasure and I was very pleased to see the progress, and in particular I believe this centre is on its way to a bright future, so I think Australian science is also on a good way."

Dr Heinrich Rohrer

Nobel Laureate, IBM Research Fellow

Vice-Chancellor's Public Lecture
The University of Sydney, 14 February 2008

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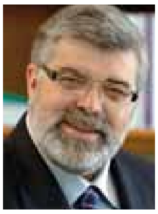
ammrf.org.au

MESSAGE FROM THE MINISTER



Senator the Hon. Kim Carr

An Australian Government Initiative

National Collaborative Research Infrastructure Strategy

Cutting-edge national research infrastructure is vital for enabling world-class science and is central to the Australian innovation system. The recent report of the review of the Australian innovation system, *Venturous Australia*, has identified the importance of research infrastructure for the future prosperity of the nation and recommends continued and sustained investment in research infrastructure.

Such investment in national facilities like the Australian Microscopy and Microanalysis Research Facility (AMMRF) is creating research capability that is the cornerstone of many fields of science and technology. This capability is actively being applied to projects related to all the national research priorities.

Established in 2007, the AMMRF is a national research facility that was funded by the National Collaborative Research Infrastructure Strategy (NCRIS). NCRIS is an initiative of the Commonwealth Government to invest over $500 million in strategic research infrastructure projects to 2011. These projects are the result of 16 priority areas identified in the 2006 NCRIS Strategic Roadmap that was developed following an extensive consultation process with the research community and other stakeholders.

Since commencing operations, the AMMRF has begun commissioning state-of-the-art flagship instruments – to complement a comprehensive suite of microscopy and microanalysis platforms – and recruiting a team of talented technical and scientific support staff. These investments are building a unique, user-focussed capability that is openly accessible to all Australian researchers. The research outputs profiled in this publication demonstrate that Australian researchers are capitalising on the availability of the facility and generating important science outcomes. These outcomes strengthen the Australian innovation system and confirm the value of NCRIS.

Senator the Hon. Kim Carr
Minister for Innovation, Industry, Science and Research

ammrf
Australian Microscopy & Microanalysis Research Facility

VISION

The AMMRF is a user-focussed, interdisciplinary organisation that employs microscopy and microanalysis to explore structure-function relationships of materials in the physical, chemical and biological sciences and their technologies. Accessible to all Australian researchers, the facility provides a quality user experience enabled through the provision of world-class research services, research training and research programs.

MISSION

The AMMRF is Australia's peak research facility for the characterisation of materials through macro, meso, nano and atomic length scales by means of advanced microscopy and microanalysis.

MESSAGE FROM THE CHAIR

The 2008 Profile of the Australian Microscopy and Microanalysis Research Facility (AMMRF) is designed to provide a broad insight into the progress of this national capability.

Until mid-2007, I was board chairman of the NANO-MNRF, the successful predecessor of the AMMRF. Now, as chair of the new AMMRF Executive Board, it is evident to me that the AMMRF is building solidly from the successes of NANO to create new capabilities in a bigger facility. A leading indicator of its development has been the speed with which it became fully operational after the award of NCRIS funding.

The AMMRF was formally launched in September 2007 by then Minister for Education, Science and Training, the Hon. Julie Bishop, MP. The facility has six nodes across Australia that are already active and productive, as are the six Linked Laboratories, which have already been welcomed into the organisation too.

To date, eight flagship instruments are in operation, with others in the pipeline. A majority of the key technical and scientific positions required for operation of, and applications development for, these instruments have been filled. The rapidity with which AMMRF has commenced operations augers well for its future success as the organisation continues to develop new initiatives.

One reason for the early success of AMMRF is its commitment to the Australia-wide user base of the facility. From the AMMRF's board, down through the entire organisation, the AMMRF has clarity that its first role is to satisfy the needs of any researcher who chooses to work with it and to offer that individual the easiest possible access to the broadest array of microscopy and microanalysis research capabilities, wherever they may reside in Australia. This genuine commitment to providing the widest range of instruments is obvious from the ongoing efforts of the staff to continue expanding their offerings. Besides the NCRIS-funded flagships – nearly $6 million worth of which has been installed to date – the nodes have installed another $3.3 million worth of other microscopes and equipment during the last 12 months. These other instruments are funded from a host of other competitive sources, such as the Australian Research Council's LIEF scheme, and are complementary to the flagships.

In addition, the AMMRF continues to develop its own research achievements. While this is quality research in its own right, it contributes significantly to the deepening and broadening of the facility's capabilities by developing additional research techniques and significant high-level applications in the field. The AMMRF views this as a crucial ingredient of the facility's ability to offer Australian researchers access to the best available tools in microscopy and microanalysis research and to the latest techniques to address scientific questions.

The Australian federal government has a strong focus on science, research and innovation as drivers of economic growth. Of course, the technology transfer of research findings and successful innovation are more than simply cash generators, as these outcomes also help us to meet pressing global issues that, across the AMMRF, reflect research in areas encompassing clean energy generation, sustainable food production, resource management and recycling, and human health.

I do hope that you find this 2008 Profile useful to help you further understand the depth, breadth and potential of the amazing tools and highly skilled people now operating in the Australian Microscopy and Microanalysis Research Facility.

Dr Gregory R. Smith
Chair of Board

We also thank Prof. David Siddle from the University of Queensland for his participation on the board.

BOARD MEMBERS

Dr Gregory Smith
Chair of Board
SciVenture Investments Pty Ltd

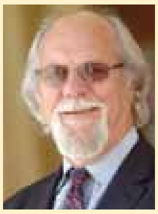
Prof. Merlin Crossley
Deputy Vice-Chancellor, Research
The University of Sydney

Prof. Doug McEachern
Deputy Vice-Chancellor, Research and Innovation
The University of Western Australia

Prof. Les Field
Deputy Vice-Chancellor, Research
The University of New South Wales

Prof. Alan Lawson
Pro-Vice-Chancellor, Research & Research Training
The University of Queensland

Prof. Simon Ringer
AMMRF Executive Director & CEO
The University of Sydney



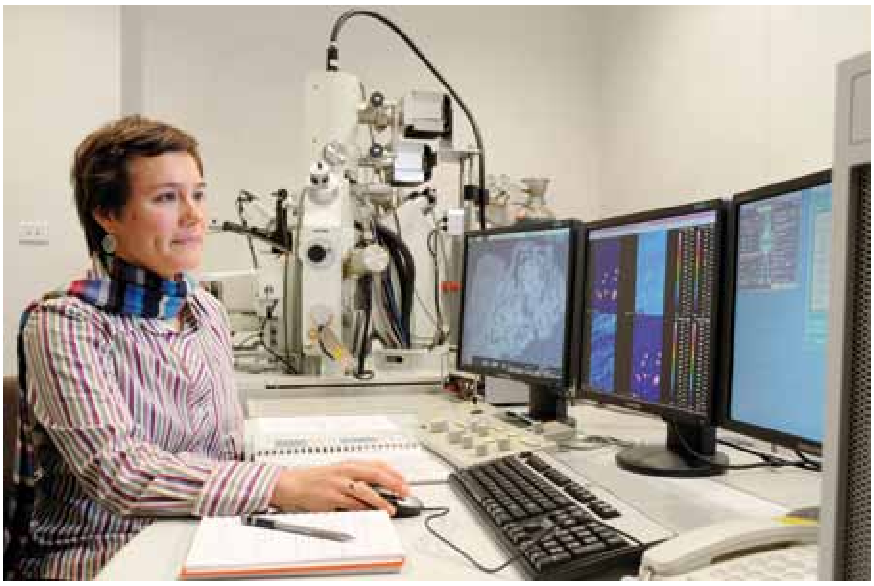
Prof. Richard Russell
Pro-Vice-Chancellor, Research
The University of Adelaide

Prof. Jim Williams
Director,
Research School of Physical Sciences & Engineering
Australian National University

MESSAGE FROM THE CEO

It is a pleasure to present the 2008 Profile for the Australian Microscopy and Microanalysis Research Facility (AMMRF). The Profile highlights some of the recent achievements of the facility and showcases its capabilities and expertise, which are openly accessible to the Australian and international research communities as they pursue research excellence.

The AMMRF provides researchers, from doctoral students through to senior professors, with advanced instruments and expert support in assorted types of microscopy and microanalysis. These tools and know-how allow insights and discovery about the structure-function relationships that are pivotal for so much of science and technology, across disciplines from agriculture to zoology and everything in between. The small selection of project summaries shown here in the 2008 Profile, though just a drop in the ocean, illustrate the diversity and quality of research enabled by the AMMRF. The facility also underpins the research efforts of major Australian research centres. For example, many of the Australian Research Council's Centres of Excellence make extensive use of our microscopes and microanalytical equipment to redefine the technology and efficiencies of photovoltaic cells, strive towards optical rectification devices, push the limits of modern fabrication science for quantum computing, and design new light alloys. These strategic interactions even extend to other NCRIS facilities, like the Australian National Fabrication Facility (ANFF) and Networked Biosecurity Framework. In 2008, the AMMRF and the ANFF signed an agreement to cooperate in achieving best practice in facility management, and the Linked Laboratory partnership with CSIRO's Australian Animal Health Laboratory (AAHL) will soon see two advanced microscopy platforms sited in its PC4 laboratories to form the Australian Biosecurity Microscopy Centre.



The AMMRF – providing cutting-edge instruments and expertise to the Australian research community.

An important, early achievement in this area was the creation and release of the AMMRF's access and pricing policy. The 2008 Profile gives an overview of how researchers can access the AMMRF and further detail is available on the AMMRF website (ammrf.org.au). I am always interested to hear of our users' experience with AMMRF access arrangements. Another key event in the implementation of facility access was the launch of the AMMRF's Travel and Access Program (TAP) in December 2007. This program provides contributions towards travel, accommodation and instrument time through peer-reviewed applications. The process is done online for speed and efficiency and is particularly directed towards helping young researchers who need to access advanced microscopy.

The success of these access arrangements is evident in the usage of the AMMRF. During the financial year 2007–2008, there were over 2400 users who accessed the national facility, across the six nodes (eight universities) and Linked Laboratories. Collectively, these users generated 136,000 hours of instrument time. What I find particularly pleasing is that these users are clearly having a productive and worthwhile experience of working in the AMMRF. While there is no shortage of personal anecdotes to support this view – a view that is also confirmed by the acknowledgements of the facility's instruments and experts that daily make their way into the peer-reviewed literature – our recent survey of the user community probably provides the best 'hard' evidence. The results of this year's survey, taking in more than 500 users (or nearly a quarter of the user community), found that 93% of respondents were satisfied or highly satisfied (about equally split) with the facilities provided by the AMMRF. More important still, over 94% were satisfied or highly satisfied with staff support, with just shy of two-thirds of those surveyed falling into the latter category. To me, this high user satisfaction with staff support is essential, because the AMMRF is as much about the people as the equipment.

Given the importance of our staff to the success of the facility, another great achievement for 2008 had been the hiring of nine new technical and scientific staff for flagship instruments. We welcome new members and all other new staff across the the facility: we value your input, expertise and hard work in the coming years as we strive to make the AMMRF still more successful. Some of these positions support flagship instruments with the latest in microscopy and microanalysis. This year saw the installation of an FEI Helios NanoLab Dual-Beam, a combined focussed ion beam and field-emission scanning electron microscope, at the SARF node, and phase one of the high-resolution scanning electron microscope facility at UNSW. These instruments are in addition to the pulsed-laser atom probe that was installed during 2007.

Welcome and congratulations are due to the Linked Laboratories, the creation of which was another major highlight of the AMMRF's operations to date. In general, the Linked Laboratories bring smaller, specialist microscopy centres into the AMMRF network, to the benefit of the national research community. As of July 2008, the Linked Laboratories are the Advanced Analytical Facility at James Cook University, the Microscopy and Microanalysis Facility at RMIT University, the Analytical Electron Microscopy Facility at Queensland University of Technology, the Optical Microcharacterisation Facility at Macquarie University, and the aforementioned laboratory at AAHL.

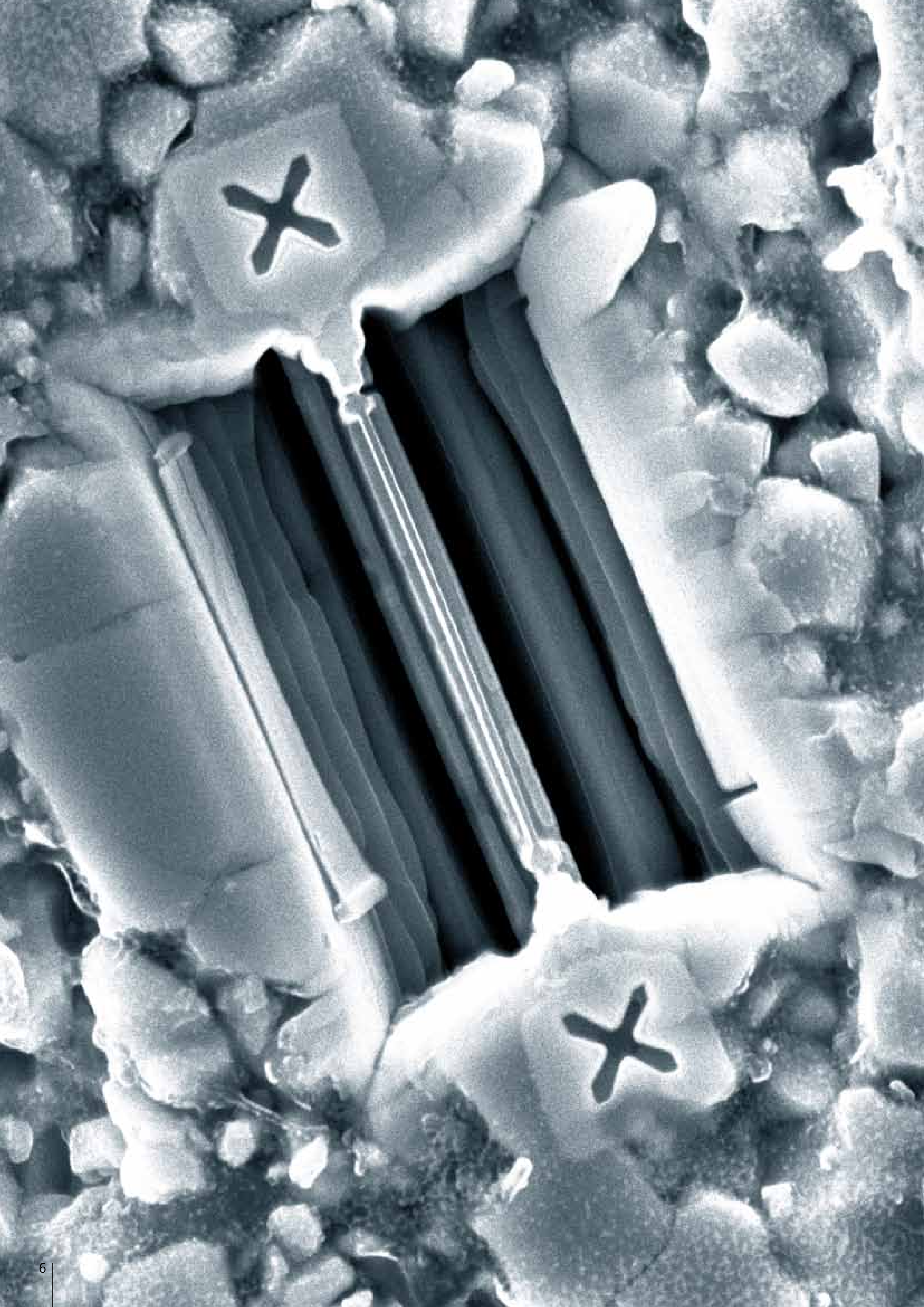
An important part of the success of the AMMRF so far is due to the dedicated efforts of the Operations Committee, which provides the day-to-day strategic leadership of the facility. The committee comprises the directors of the individual nodes and their leadership and hard work are critical to the success of the facility. The work, in recent years, of Prof. Craig Atkins from the University of Western Australia deserves particular thanks, and we welcome Craig's successor, Prof. David Sampson, who has already begun to make valuable contributions to the facility. I must also thank Dr Miles Apperley, General Manager of the AMMRF, for his fine work in getting us to where we are, and gratefully acknowledge the legal counsel at Sydney, who championed so many agreements on behalf of us all in the early days of establishing the AMMRF.

Clearly, in the first 12 months of operation, this facility has made impressive progress against all its performance targets in instruments, staff, access, linkages, organisation and promotion, and the Operations Committee and I wish to thank all staff for getting the facility off to such a tremendous start.

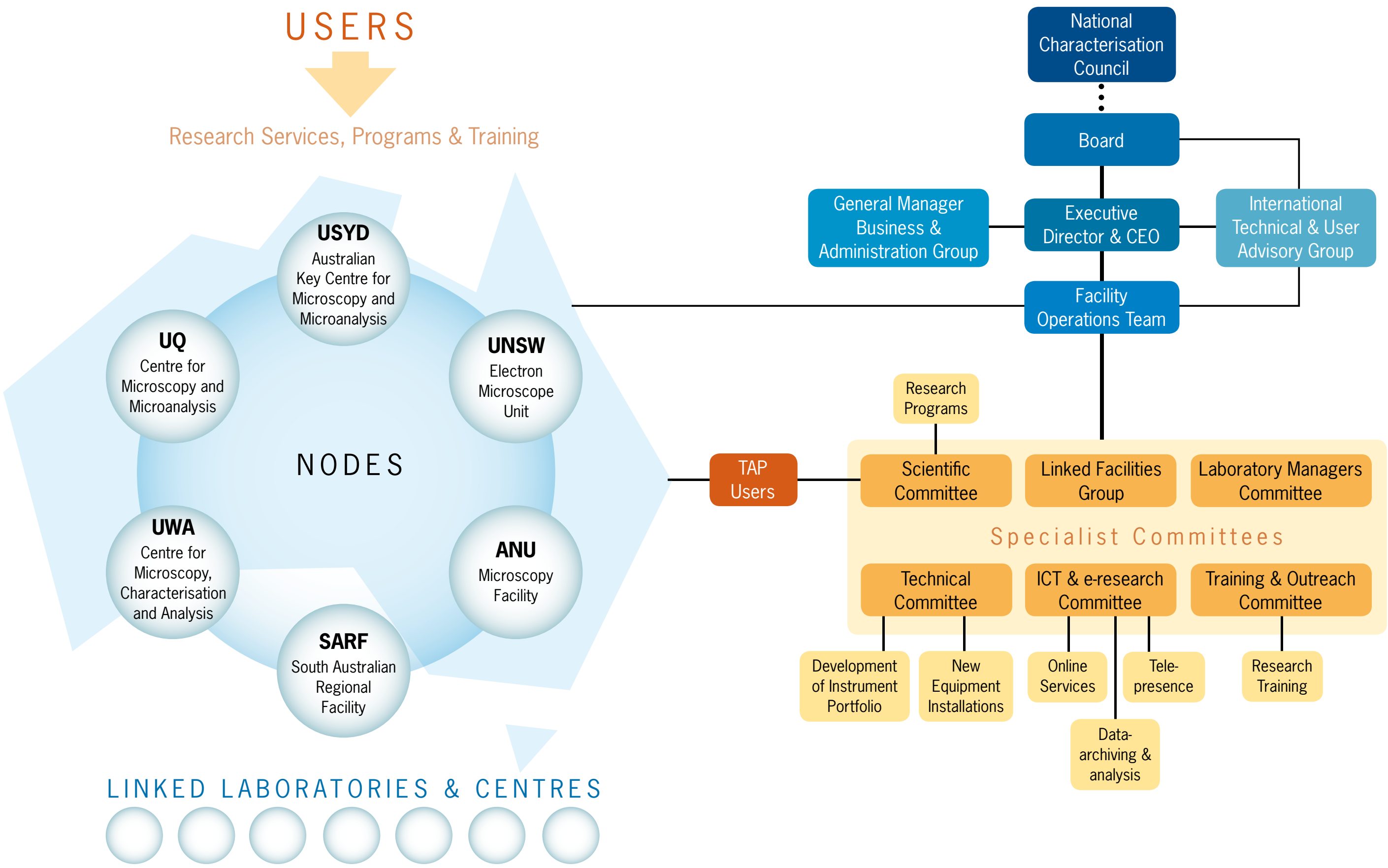
What can the AMMRF do for you? I would urge you to contact me or a local node or Linked Laboratory of the AMMRF to discuss how microscopy and microanalysis can play a role in your research and development.

Prof. Simon P. Ringer
Executive Director & CEO

Staff at the 2008 AMMRF Strategic Planning Workshop, held on 14 and 15 May in Sydney. Deep into its first year of operation, the theme was 'Building the Community', reflecting the current stage of the AMMRF, growing in staff numbers, commissioning new flagship instruments, and supporting researchers around Australia.



ORGANISATIONAL STRUCTURE



AMMRF Node Directors

The University of Sydney (AMMRF Headquarters)
Australian Key Centre for Microscopy and Microanalysis
Director: Prof. Simon P. Ringer

The University of New South Wales
Electron Microscope Unit
Director: Prof. Paul Munroe

The University of Queensland
Centre for Microscopy and Microanalysis
Director: Prof. John Drennan

Australian National University
Electron Microscopy Unit
Director: A/Prof. Tim Senden

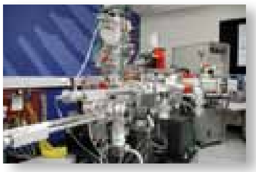
The University of Western Australia
Centre for Microscopy, Characterisation and Analysis
Director: Prof. David Sampson

We also thank Prof. Craig Atkins for his directorship.

South Australian Regional Facility (SARF)
Ian Wark Research Institute
(University of South Australia);
Adelaide Microscopy
(The University of Adelaide);
Flinders University Nanotechnology
(Flinders University of South Australia)
Director: Prof. Hans Griesser

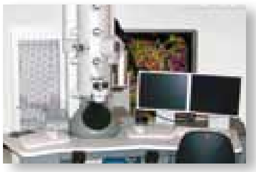
Secondary electron image of a TEM cross-section from a copper-alumina nanocomposite prepared by focussed ion beam milling. Image by Dr Charlie Kong and Prof. Paul Munroe from the University of New South Wales.

FLAGSHIP INSTRUMENTS



Cameca NanoSIMS 50 @ UWA

The scanning ion microprobe is designed for chemical and isotopic analysis of solids with unprecedented probe resolution and elemental sensitivity. This unique instrument can be used to document dopant concentrations within synthetic materials, locate isotopically labelled compounds within cell structures, and quantify natural isotopic variability within minerals. Applications are diverse, encompassing materials science, biology and biomedicine, and geology.



FEI Tecnai F30 High-Throughput CryoTEM @ UQ

A platform for high-throughput molecular biology at the nanoscale, with capabilities for automated electron tomography, electron crystallography and single particle analysis. Capable of the high output essential to make genuine inroads into key questions in molecular biology, medicine and biotechnology.

Imago Local Electrode Atom Probe and the Wide-Field-Of-View Laser Atom Probe @ USYD

Atom probe tomography is without peer as a tool for 3-D mapping of the location and chemistry of elements of the periodic table. The atom probe suite comprises two local electrode atom probes. The most recent acquisition is a laser-based platform that greatly expands the types of materials that can be characterised to include ceramics, semiconductors, organics, glasses and oxide layers.

FEI Nova Nanolab 200 DualBeam FIB @ UNSW

The Nova Nanolab 200 is an advanced microscopy platform with dual high-resolution electron and ion columns. It provides a unique characterisation facility for advanced materials and nanoscience, nanomachining and fabrication, TEM specimen preparation, 2-D and 3-D microscopy, and microanalytical investigations.

JEOL JXA-8500F Electron Probe Micro Analyzer (EPMA) @ UNSW

The platform includes four wavelength-dispersive X-ray spectrometers, and a silicon drift detector for energy-dispersive analysis. It also operates as a field-emission SEM, collecting images from backscattered or secondary electrons, to combine high-resolution topographic details with sensitive, spatially-resolved elemental information. The instrument is particularly suited for geosciences, nanotechnology and advanced materials research.

JEOL 7001F SEM @ UNSW

This field-emission SEM is designed for high-resolution imaging and for advanced analysis with its wide range of detectors: a secondary electron detector for topographic studies, a backscattered electron detector for compositional contrast, an electron backscattered diffraction (EBSD) detector for crystallographic studies, a silicon-drift detector for chemical analysis, and a cathodoluminescence (CL) detector for analysing defect structures in device materials.

FEI Helios NanoLab DualBeam FIB/FESEM @ SARF

This instrument combines nanoscale milling and deposition with an imaging system capable of nanometre-resolution for diverse applications in nanotechnology, advanced materials and environmental sciences. It can be used for both 2-D and 3-D microscopy and nano-fabrication of a wide range of materials including metals, semiconductors, ceramics, minerals, polymers and composite materials.

To come online in 2009:

PHI TRIFT V nanoToF ToF-SIMS @ SARF
Cameca IMS 1280 Ion Microprobe @ UWA

CAPABILITIES

Your partner of choice for microscopy, microanalysis, and image analysis at the atomic, molecular and cellular scale

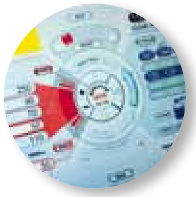
The AMMRF has a huge variety of instruments under its umbrella, which are operated and maintained for the benefit of the Australian research community.

The instruments can be used to address scientific problems across a broad spectrum of research disciplines from materials science to geology and from cell biology to archaeology and beyond.

The instruments, however, are only one part of the AMMRF; the expert staff are also central to facilitating the experience for users. Through the provision of advice on experimental design, training, interpretation of results and preparation of any resulting publications, AMMRF staff support the user from beginning to end.

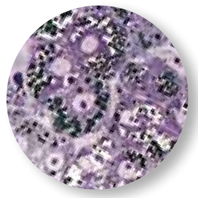
Structure and composition are two of the fundamental properties that impact on the behaviour and function of matter, be it a rock or a cell. The various specialised instruments are designed to analyse these properties in different types of samples from the sub-nanometre to the centimetre scale. A common feature of many of the AMMRF instruments is the ability to pinpoint the locations of elements and molecules in three dimensions under different experimental conditions.

The AMMRF flagship instruments are often unique within Australia and, by virtue of this, provide something extremely valuable to the research community. Alongside these there are also many more commonly available, but highly advanced and in demand, instruments, forming the basis for an extensive array of scientific enquiry. Confocal microscopes for fluorescence work and scanning and transmission electron microscopes, usually fitted for spectroscopy to map the location of elements, are available in most nodes.



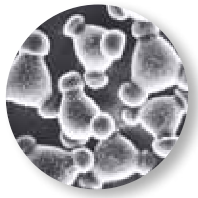
Specimen Preparation

Biological
Materials
Cell Culturing and Molecular Preparation
Thermomechanical Processing



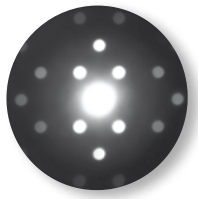
Light and Laser Optics

Confocal and Fluorescence Microscopy
Optical Microscopy
Flow Cytometry and Cell Sorting
Live-cell Imaging
Vibrational and Laser Spectroscopy
Laser Microdissection



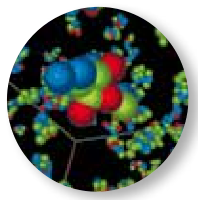
Scanning Electron Microscopy

Analytical Spectroscopy
In situ Imaging and Testing
Metrology



Transmission Electron Microscopy

Analytical Spectroscopy
Diffraction
Phase and Z-contrast Imaging
Cryo Techniques and Tomography



Advanced Ion Platforms

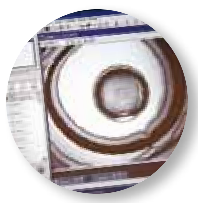
Nanoscale Mass Spectroscopy
Atom Probe Tomography
Ion Milling and Machining
Ion Implantation

Scanned Probe Techniques

Atomic Force Microscopy
Scanning Tunneling Microscopy
Raman Spectroscopy

X-ray Technologies

X-ray Diffraction
X-ray Fluorescence
X-ray Microtomography



Visualisation and Simulation

Computed Spectroscopy
Computed Diffraction
Image Simulation, Analysis and Data Mining

ACCESS

World-class instrumentation accessible to all Australian researchers

The AMMRF is a user-focussed facility, and all Australian researchers are able to access any of the AMMRF instruments wherever they are in Australia. When a user has identified the node that houses the instruments they wish to use, they can contact that node directly to discuss their project and register as a user. The project is then assessed by the node director and the relevant technical staff. Assessment is based on scientific merit and feasibility, along with the availability of the instrument and associated technical expertise. Once a project is approved, there is a typical lead-time of around three weeks although many of the instruments, especially the flagships, are proving to be very much in demand.

If you wish to use specific AMMRF infrastructure, please contact the relevant node to discuss the project and arrange access.

Contact details on page 36.

AMMRF Travel and Access Program

When the AMMRF facilities are in a different city from the researcher, the Travel and Access Program (TAP) is available to contribute towards the cost of accessing the desired instruments. A TAP award often provides an excellent route for a researcher to get enough preliminary results to form the basis of a more substantial grant application.

The Travel and Access Program has been running since December 2007, and the guidelines and application form are available on the AMMRF website (ammrf.org.au). The online application has proved easy to use and manage. Typical turnaround time from the application being received to the formal letter of offer is in the order of two weeks.

TAP applications have been received from a wide range of institutes across the country. Grants have been made to many scientists from institutions like the University of Newcastle, Central Queensland University, Curtin University, the University of Western Australia, Deakin University, the University of New England, the University of Queensland, RMIT University, Monash University, Murdoch University and the Peter MacCallum Institute in Victoria. The range of topics is wide, covering the physical, biological and environmental sciences; examples include research into the characterisation of polyurethane nanocomposites through to the analysis of corrosion products of stainless steel and the design of healthy foods.

The TAP has proved very popular and is crucial to enabling the AMMRF to be a truly national facility, providing a way for researchers to develop their projects by using the widest array of state-of the-art instruments.

The following list provides the titles of accepted and pending proposals to illustrate the diverse topics that are catered for by the AMMRF.

HOW TO APPLY

All Australian researchers are eligible to apply online to the TAP through the AMMRF website at

ammrf.org.au

Applications are assessed rapidly by the Scientific Committee and funding decisions are based on the scientific quality of the proposed research.

Examples of funded TAP projects

- Virtual testing of geomaterials
- Atom probe tomography study of boride/boron clusters in a new superalloy
- Pseudo-micro truss intermetallic structure effects on the strength of hpdc Mg-Al and Mg-Zn alloys
- FIB preparation of fly ash particles for TEM profiling
- Crystal-plastic deformation of zircon – constraints from EBSD-TEM via FIB milling
- Analysis of the relationship between blood vessels, bone and transplanted hemopoietic stem cells
- Polyurethane nanocomposites
- Core-shell silica nanofibres
- Development and evaluation of functional food pasta
- Effect of pasteurisation and centrifugation on human milk
- Lithium niobate using standard Ti diffusion technique
- Using copolymer micro-domains to control the orientation of multi-walled carbon nanotubes in a uniformly distributed thin film
- Resolving the structure of CO_2 corrosion inhibitors in elevated salt
- Structure/property relationships in high-strength nanostructural spinodal alloys
- Electron-probe microanalysis study of ilmenite pre-reduction
- Dopant and elemental distribution mapping in III-V
- FIB sectioning and polishing of Hadean zircon and & ISE and RBI yields from Ga ion beams
- Respirable micro-particles of aminoglicosidic antibiotics for pulmonary administration
- Imaging mitochondrial outer membrane permeabilisation during apoptosis
- Titanium laser welding for medical devices
- FIB tomography meets X-ray micro-tomography: a 3-D approach to aid enhanced oil recovery
- Why does stainless steel corrode? An exploration of the significance of composition
- Switchable interfaces
- Oxidation state of cobalt and manganese in a mixed metal hydroxide intermediate
- New approaches to understanding grain boundary chemistry

Sarah Ellis

Head of the Microscopy Core at the Peter MacCallum Cancer Centre in Melbourne

"The TAP grant enabled me to visit the University of Sydney where I accessed a micro-computed tomography instrument and associated software. Micro-CT enabled me to capture images of the murine femur that could be reconstructed into a 3-D model to accurately visualise and analyse various parameters. The only other way to carry out this histomorphometric analysis was through serial sectioning, a laborious and less accurate procedure. Without the TAP grant, this work would not have been possible."

Richard D Metcalfe

Senior Lecturer at Central Queensland University in Rockhampton

"I'm a physics lecturer at Central Queensland University, a small institution with limited facilities for research. For the last couple of years I have been investigating the composition and morphology of the fly ash that escapes from power stations into the atmosphere. With the help of funding from TAP, I was able to visit the University of New South Wales and, with the very expert help of Charlie Kong and the UNSW FIB machine, obtain sectioned samples of fly ash particles that clearly showed the distribution of crystalline phases in the glassy matrix that makes up most of the particles. I am very grateful to TAP for the support that made this possible."

Nisha Aravind

PhD student at the University of New England in Armidale

"I express my sincere gratitude to Australian Microscopy and Microanalysis Research Facility for providing me the TAP award, which proved to be of immense help towards my PhD research program. The award was given for studying the starch protein matrix in pasta at the micro level. After this award, I got appropriate technical support from scientific staff throughout the program. It enabled me to do a novel investigation at the University of Sydney to study pasta structure using confocal scanning laser microscopy."

AMMRF LINKED LABORATORIES

Extending the capability

The AMMRF Linked Laboratories, or 'Linked Labs' are partner facilities that provide access to specialist instruments at their institution. These specialist instruments broaden the capabilities of the AMMRF, and access arrangements and pricing are the same as those for a node of the AMMRF.

A feature of the linked labs is the availability of infrastructure support engineers. These experts facilitate access to the nominated specialist equipment and act as the principal point of contact for researchers seeking to access the facilities. They provide support and advice to users throughout the planning, measurement and analysis phases of their experiments.

Partnerships with six Linked Labs have been established, and the capabilities they provide are coming progressively online as support engineers are appointed and new equipment is installed.

Photo: CSIRO Livestock Industries, Frank Filippi

NCRIS funding is allowing the development of additional PC3 and PC4 (pictured) laboratory space and the establishment of the CSIRO's Australian Biosecurity Research Laboratory. The Australian Biosecurity Microscopy Centre, incorporated in these PC4 facilities, is a Linked Laboratory of the AMMRF.

RMIT University: Microscopy and Microanalysis Facility

Provides advanced electron microscopy facilities, including high resolution and environmental scanning electron microscopes (SEM), transmission electron microscopes (TEM), scanning auger nanoprobe, X-ray photoelectron spectroscopy, and dynamic light scattering spectroscopy systems.

Australian Animal Health Laboratory, CSIRO, Geelong: Australian Biosecurity Microscopy Centre

Offers a live-cell and cryo-TEM imaging facility within PC3/PC4 bio-containment environment. This is a unique capability, enabling fundamental research with biological agents that need the highest level of containment.

Macquarie University: Optical Microcharacterisation Facility

Combines technologies in Raman microscopy, fluorescence excitation and lifetime spectroscopy, surface-enhanced Raman microscopy and near-field scanning microscopy.

Queensland University of Technology: Analytical Electron Microscopy Facility

Offers advanced SEM platforms, including a dual-beam focussed ion beam with mineral liberation analysis software, and an analytical environmental SEM complete with a cooling and heating stage.

James Cook University: Advanced Analytical Centre (AAC)

Provides specialist microanalysis capabilities, including electron-probe microanalysis, low-vacuum chamber SEM, confocal laser scanning microscope and atomic force microscope fitted with a nano-indentor.

Curtin University of Technology: John de Laeter Centre of Mass Spectrometry

Houses single and multicollector sensitive high-resolution ion microprobes (SHRIMP) for quantitative isotopic and elemental analysis.

The Linked Lab partnerships are already yielding results:

"The new AMMRF affiliation [Linked Laboratory], combined with the option of multiple-week EPMA sessions that made travel to Townsville worthwhile, also made the AAC very attractive as an analytical facility. I was familiar with the strong geological and technical EPMA experience at the ACC, and as a first-time user of the JEOL 8200 was very happy with the user-friendly computer software and exceptional backscatter image. Kevin and his team provided first-rate support in a friendly atmosphere."
Dr Tony Roache, CSIRO

The support engineer at RMIT University, Peter Rummel, has been facilitating sample preparation and training for users from a commercial client, Sutton Tools, as well as assisting with microscopy. *"I'm delighted with Peter's help in microstructural characterisation of high-speed steel tooling. It's been invaluable."*
Prof. Derry Doyle, Sutton Tools Professorial Chair in Materials and Surface Engineering

Supporting Australia's priority research

Advanced microscopy and microanalysis underpin scientific discovery, and the emergence of new technologies, in research across all fields of science, engineering and medicine. This is illustrated particularly well by way the AMMRF supports major centres of research in Australia.

The nodes of the AMMRF support users from a broad range of research centres including Co-operative Research Centres, ARC Centres of Excellence and institutes of medical research. Many of the AMMRF's users work in these centres and, therefore, the facility is playing a significant role in the performance and outcomes of these organisations.

Researchers from these centres and institutes are able to access the full range of AMMRF research services, programs and training, all of which are delivered under a common user experience. This experience is about achieving value-added research outcomes rather than just collecting data. The AMMRF considers the full cycle of the research process, from the initial idea, to user training, data collection and scientific interpretation, and finally presentation and publication of outcomes.

Some centres have partnered strategically with the AMMRF nodes for reasons such as research synergies or geographical proximity. These institutional level partnerships open-up significant characterisation capability to the partner centre, allowing the researchers to focus on their experiments and research outcomes without being limited by the availability of equipment or funds to access it.

Partnerships between the research staff within the AMMRF and those at major centres strengthen proposals for competitive grant applications. In the past, many ARC and NHMRC grants have been awarded to researchers working collaboratively with AMMRF research staff.

The AMMRF supports researchers from major research centres and institutes every day, as highlighted by this sample of the centres:

- CSIRO
- DSTO
- ANSTO
- National Measurement Institute
- University of Wollongong
- Australian Institute of Bioengineering and Nanotechnology
- Centre for Exploration Targeting
- The Centre for Expertise in Photonics
- Centre for Strategic Nano-Fabrication
- The Australian Wine Research Institute
- Research Institute for Climate Change and Sustainability
- The Ian Wark Research Institute
- Australian Centre for Plant Functional Genomics

Co-operative Research Centres

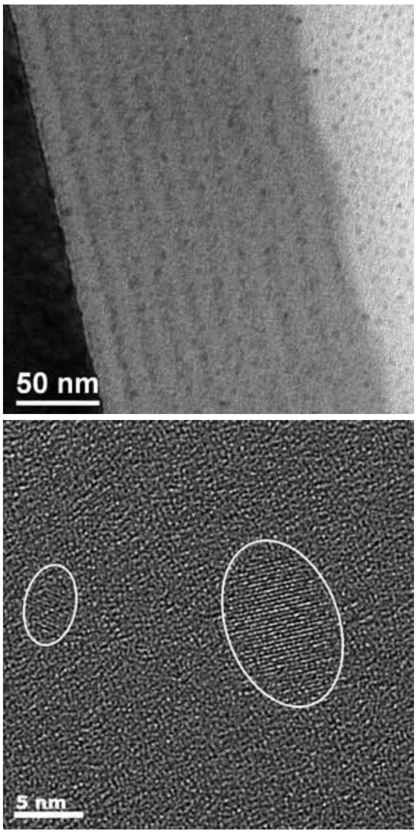
- CRC for Hearing
- CAST CRC (Alloy and Solidification Technology)
- CRC for Polymers
- Parker CRC for Integrated Hydrometallurgy Solutions
- CRC for Beef Genetic Technologies
- CRC for Landscape Environment and Mineral Exploration
- CRC for Greenhouse Gas Technologies
- Molecular Plant Breeding CRC
- CRC for Advanced Composite Structures
- CRC for Coal in Sustainable Development

ARC Centres of Excellence

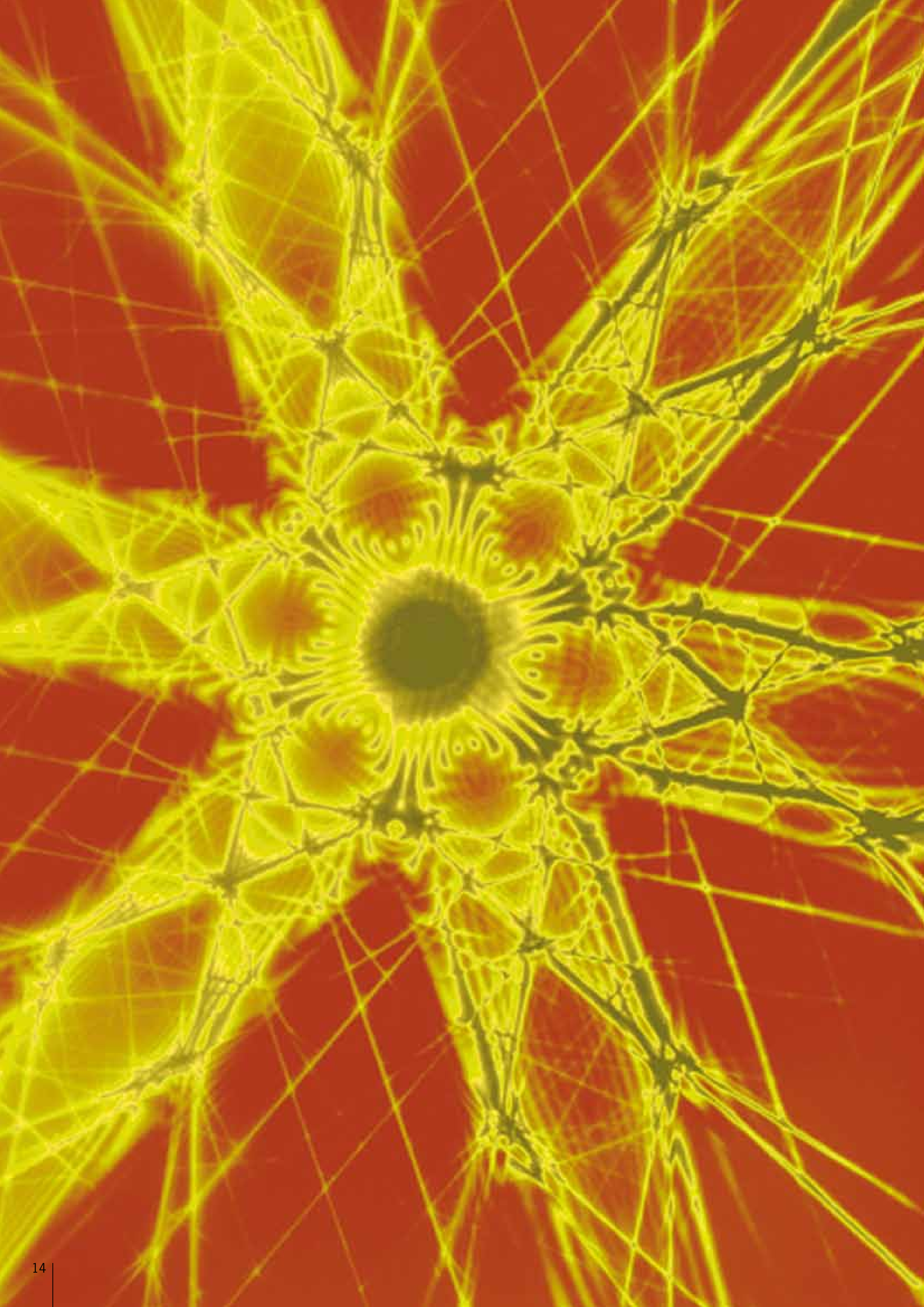
- Design in Light Metals
- Functional Nanomaterials
- Quantum Computer Technology
- Ultrahigh Bandwith Devices for Optical Systems
- Photovoltaics
- Integrative Legume Research
- Electromaterials Science
- Plant Energy Biology

Health and medical research

- Institute for Molecular Bioscience
- Queensland Brain Institute
- Queensland Institute of Medical Research
- Western Australian Institute of Medical Research
- Telethon Institute for Child Health Research
- Lung Institute of Western Australia
- Special Research Centre for the Molecular Genetics of Development
- National Centre for Stem Cell Research
- The Hanson Institute
- Garvan Institute
- Centre for Vascular Research
- Victor Chang Cardiac Research Institute
- Prince of Wales Medical Research Institute



Strategic research: high-resolution TEM imaging of nanostructured silicon for third-generation solar cells. Top: quantum dots formed in a silicon-based multilayer structure. Bottom: atomic lattice of quantum dots (circled) in the amorphous matrix. Images are courtesy of Prof. Martin Green, Dr Gavin Conibeer and Yidan Huang from the ARC Photovoltaics Centre of Excellence at UNSW.



THE AMMRF – FUNDAMENTAL TO AUSTRALIAN RESEARCH

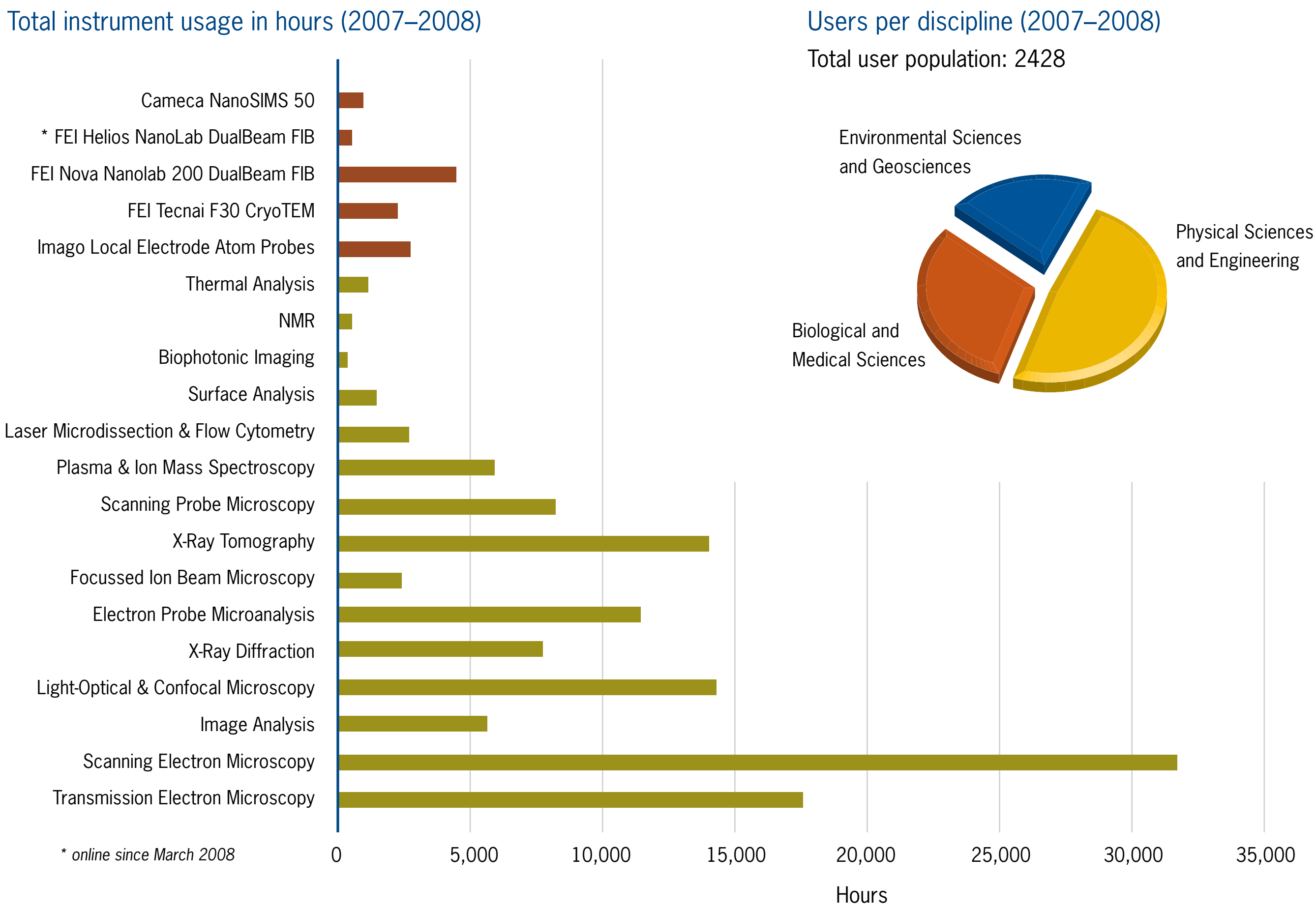
The aim of the AMMRF is to enable Australian researchers to carry out world-class research by using state-of-the-art microscopy and microanalysis in a well-managed and accessible facility. The research outputs of AMMRF users are already demonstrating the value added by this capability. The following reports highlight just a handful of the projects undertaken using the AMMRF facilities over the past year. They are at different stages along their individual pathways, but show the quality and diversity of the research done on the range of instruments available.

Some of the flagship instruments are unique in Australia and have already hosted top-flight projects. Throughout the facility, projects are resulting in publications in highly regarded journals such as *Nature* and *Science* along with presentations at international conferences and symposia.

Access to the AMMRF instruments has also contributed to grant successes for Australian researchers, allowing them to address questions with new techniques that previously would have not have been available to them.

The facility's world-class instruments are managed by specialist teams that provide expertise and training to the user community. This supportive environment offers researchers the full 'research facility' package: leading instruments, technical know-how and practical understanding of how to apply these tools to best effect.

Research itself is always pushing the bounds of possibility, trying to solve ever more challenging problems. In this way, it directly helps push forward developments of the instruments' technical applications and further extends the opportunities for Australian researchers.



* *online since March 2008*

Convergent beam pattern of a silicon crystal (110).
Image by Dr John Fitz Gerald from the Australian National University.

ISOTOPES AND ORAL HISTORIES

The Tuamotu Archipelago consists of coral atolls, yet late prehistoric basalt adzes have been collected from locations throughout the archipelago. These finds, along with oral histories, indicate that trade and travel were occurring widely. The use of basalt, a rock of volcanic origin, has led A/Prof. Marshall Weisler, an expert on Polynesia, and his colleague Prof. Ken Collerson to examine patterns of trade based on the source of this rock. By using the Radiogenic Isotope Laboratory in the Centre for Microscopy and Microanalysis at the University of Queensland, they created a database of isotopic ratios for a large number of basalts throughout the Polynesian archipelagos. These distinctive and complex fingerprints in the rocks allowed them to pinpoint the origin of a particular adze to Kaho'olawe Island within the Hawaiian archipelago, 4040 km from where it was found. The style of the adze itself is not typical of those made in Hawaii and it is likely that the rock rather than the crafted adzes travelled across the Pacific.

The importance of this find clearly indicates that prehistoric trading by Polynesians occurred over prodigious distances in open vessels and suggests a sophistication in navigation and sea-faring that was always thought to have occurred but, until now, was only recorded in oral histories.

Basalt adze found in the Tuamotu Archipelago.

This work was published in *Science* in November 2007.

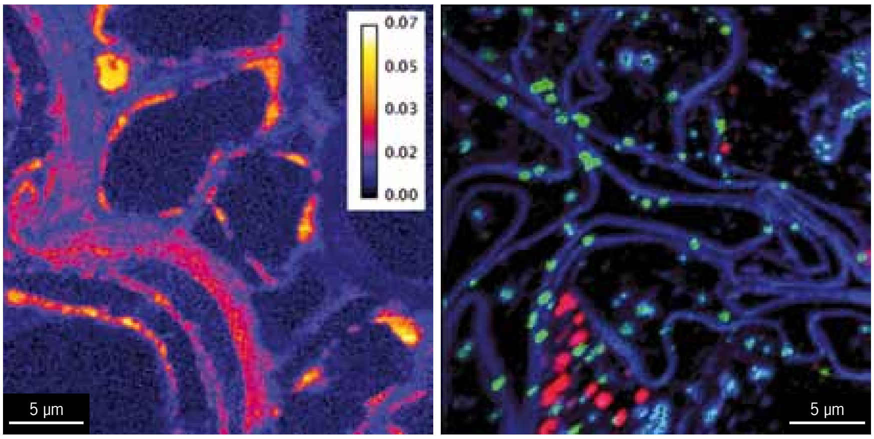
GOING UNDERGROUND WITH NANOSIMS

FLAGSHIP

Soil is a complex multi-component system comprising mineral grains, organic debris, plant roots, soil fauna, microorganisms and pore space. The rhizosphere is that region inhabited by plant roots and a proliferation of bacteria and fungi that compete with one another for available nutrients. Nitrogen (N) is the primary nutrient that limits plant growth and is consequently a major regulator of ecosystem functioning. Understanding the link between the heterogeneity of the soil's physical environment and its impact on biological processes marks the current frontier in soil science. However, knowledge has been limited by the lack of suitable methods for reliably detecting, imaging and measuring nutrients in biological systems at the sub-micron scale – the scale at which the important interactions occur.

Dr Daniel Murphy from the soil biology group at the University of Western Australia has addressed this and devised a novel experimental system coupled with NanoSIMS analysis to follow the transfer of the isotopic tracer ^{15}N from the soil to the bacteria and plant roots at the sub-micrometre scale. Samples were prepared at different time intervals and isotopic imaging carried out on the NanoSIMS. The right picture shows ion maps of a 40 µm section of the rhizosphere. Bacteria have clearly taken up a lot of ^{15}N, and show up as intense red blobs sitting among the outermost cells of the root (seen in blue). There are also silica grains from the soil shown in green. The left image shows that it is possible to resolve the sub-cellular location of the labelled nitrogen at a resolution of about 50 nm, showing accumulation of the ^{15}N in the cytoplasm and cell walls where yellow shows the regions of highest ^{15}N concentration.

For the first time, this novel technique allows imaging and measurement of ^{15}N accumulation within individual microorganisms competing within the root, on the root surface and in the external soil. It had not previously been possible to measure all these components separately, let alone visually locate them. Furthermore, this method uses natural systems, where all the components are *in situ* at a given time, providing a temporospatial map of nitrogen transport in a real context.



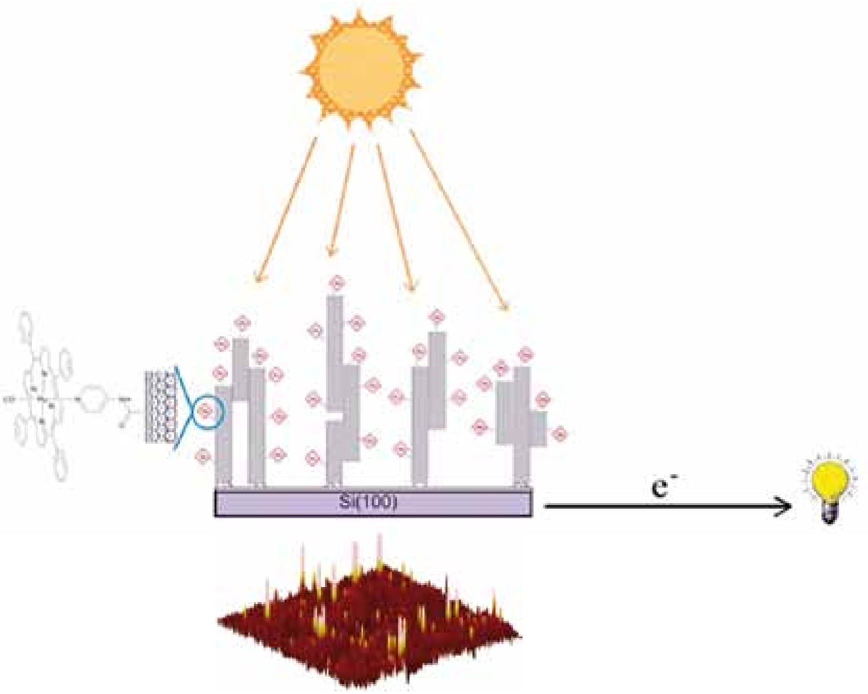
Left: NanoSIMS image of root cells with high levels of ^{15}N in yellow.
Right: NanoSIMS ion map of the rhizosphere showing bacteria in red.

SOLAR CELLS GO NANO

Although solar cells in their current form are often touted as being able to solve many climate-related energy issues, the energy cost of production is very high, meaning it takes many years of service before any gains are made. Accordingly, the development of new forms of solar cells using low energy for their production is important. As a step in this direction, Jingxian Yu, and colleagues from the School of Chemistry, Physics and Earth Sciences at Flinders University have set about creating nanoscale solar cells.

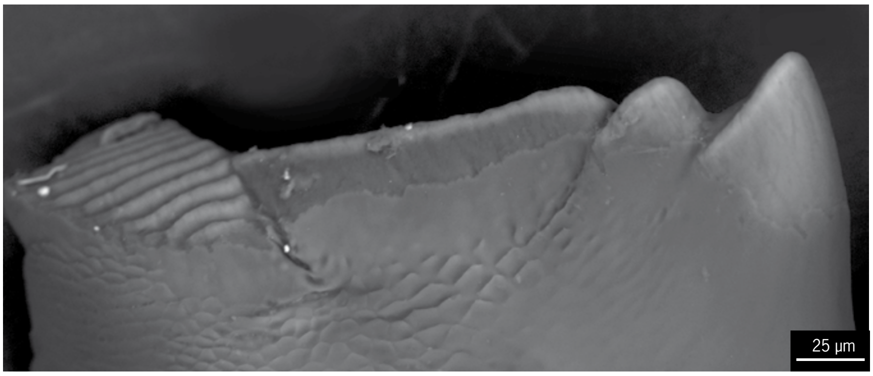
The Flinders' researchers have chemically attached single-walled carbon nanotubes directly to silicon substrates through the surface oxide layer, rather than through the intermediate linkers used previously. Despite the use of the oxide layer, the resultant nanostructures have proved to be very good electrodes. To monitor the construction process of these nanoscale structures, specialised microscopy such as atomic force microscopy (AFM) is required and an example is shown in the figure. The nanotube bundles themselves are only tens of nanometres in size.

The covalent attachment of the carbon nanotubes provides a robust basis for further functionalisation with light-absorbing elements, such as porphyrins, to construct a nanoscale solar cell as shown in the schematic. The very rough surface created by the nanotubes means that a high number of porphyrin molecules can be immobilised. This should lead to very efficient solar cells being produced. Other chemical species could also be used to attach to the nanotubes, potentially opening up this platform to a wide variety of other applications.



Schematic of the attachment of porphyrin molecules to nanotubes vertically aligned on a silicon surface. Below: a 5 µm x 5 µm AFM image of the substrate depicted in the schematic.

METALLIC JAWS – BUILT FOR DESTRUCTION



Backscattered SEM image of the mandible of a drywood termite: zinc-rich regions at the edges appear lighter.

Drywood termites have huge demands placed on their jaws. Unsurprisingly, it has been found that their mandibles are considerably harder than the jaws of other termites whose food is wetter and softer wood. Evolutionary pressures are likely to have led to this strengthening of their jaws to enable them to exploit such a hard and dry diet, but how is it achieved?

Dr Bronwen Cribb at the University of Queensland has used backscattered scanning electron microscopy and energy dispersive X-ray spectroscopy to investigate the elements present in the mandible and their location. She found the presence of much higher levels of zinc and significant levels of chlorine in the edges and tips of the drywood termite mandibles – those regions required for the serious cutting and grinding of the wood – when compared to other types of termites with less demanding diets. The presence of the zinc correlated with a 20% increase in hardness. These results are consistent with other previous studies that have shown that the incorporation of metals and halogens into biological polymers leads to increases in hardness. How the zinc affects the strength of the cuticle is a question for further investigations, and could be of considerable interest to many wider fields of biology and materials science.

This work was featured as a 'Research Highlight' in *Nature* in February 2008.

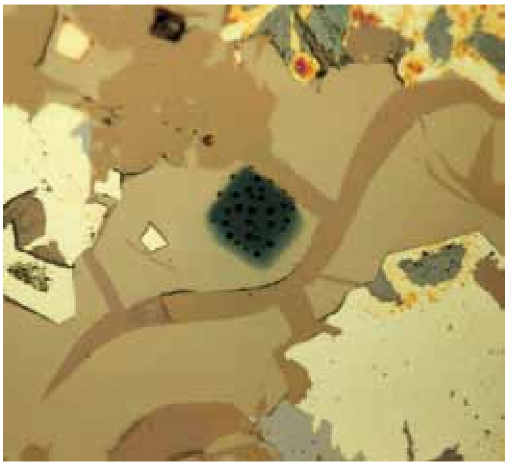
REWRITING HISTORY

FLAGSHIP The AMMRF flagship NanoSIMS facility at the University of Western Australia has helped to rewrite the history of major groups of life on the planet. The accumulation of oxygen around 2.4 billion years ago irreversibly transformed the Earth's surface, leading to the oxygenation of the atmosphere and oceans. It profoundly changed biogeochemical cycles and ultimately paved the way for the appearance of large aerobic organisms, including animals. The appearance of the oxygen in the atmosphere has been connected with the evolution of oxygen-producing bacteria in the ancient environment. Previous evidence, based on the extraction of organic compounds (biomarkers) from 2.7 billion year old rocks from Western Australia, had suggested that such oxygen-producing bacteria – the cyanobacteria – were already present at that time. However, this created a gap in timing of 300 million years before the accumulation of atmospheric oxygen, which was proving difficult for researchers to explain. Apart from the biomarker evidence, however, the earliest fossil evidence for cyanobacteria is around 2.15 billion years old.

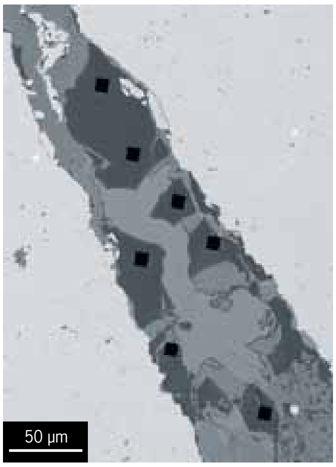
NanoSIMS has the unique ability to measure isotopic fractionation *in situ* at the micrometre scale and through the application of this technique at the University of Western Australia (UWA), Prof. Birger Rasmussen and Dr Ian Fletcher from the Curtin University of Technology, Dr Jochen Brocks from the Australian National University and Dr Matt Kilburn from UWA found that the biomarkers previously extracted from 2.7 billion year old rocks were likely to be contaminants and not the evidence of the earliest cyanobacteria previously thought. Carbon isotopes, measured in micrometre-sized droplets of solidified oil contained within the rock itself, were measured by NanoSIMS and compared to the extracted biomarkers. The researchers found that the isotopic composition of the solidified oil was distinctly different to that of the biomarkers, which suggests that the biomarkers were contaminants, possibly introduced from other rocks or during drilling or sample handling.

As a result of this investigation, the team has revised estimates of the earliest oxygen-producing bacteria on earth by 500 million years. The findings, challenge the previous research using the biomarkers that claimed the earliest existence of the microbes that produce oxygen by photosynthesis was 2.7 billion years ago, bringing it back to the 2.2 billion year mark.

The implications for the evolution of more complex cells (known as eukaryotes), which are the basis of higher organisms such as fungi, plants and animals, are also profound. The revised timeline, based on existing fossil evidence, places the first appearance of eukaryotes at about 1.7 billion years ago, well after the rise in atmospheric oxygen, and 1 billion years later than previously thought.



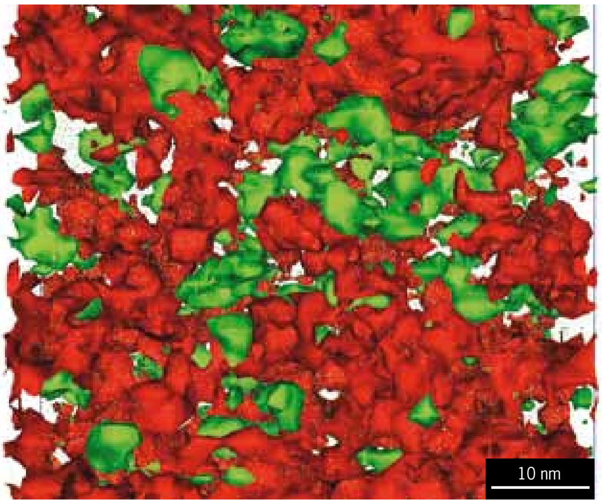
Reflected light image showing pyrobitumen with sinuous shrinkage crack and a NanoSIMS raster area spotted with µm-sized caesium balls (from implantation). Raster area is about 10 x 10 µm in size.



Backscattered electron image of pore-filling pyrobitumen (dark grey) with seven NanoSIMS raster areas. The pyrobitumen is fractured and itself fills a fracture in an early diagenetic pyrite nodule.

This work was published in *Nature* in October 2008 and was featured as a 'News & Views' item.

PREPARING FOR A GLASSY FUTURE



Zirconium-rich (red) and titanium-rich (green) nanocrystalline phases in heat-treated metallic glass.

FLAGSHIP

Intriguing materials known as bulk metallic glasses (BMGs) are being intensively studied to understand more about their structures and the associated properties of increased strength, hardness and plasticity, in addition to novel magnetic behaviours. Metals, which normally have a crystalline structure, can be induced to form amorphous 'glass' when cooled extremely quickly. This requirement for very rapid cooling imposes considerable limitations on the production of larger objects made of BMGs. In a process combining semi-random experimentation and modern metallurgy, different metal alloys are being produced in order to find combinations of elements that allow for the formation of the glassy structure at slower rates of cooling to make development of large products more practical.

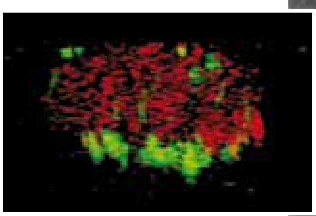
Zirconium-titanium metallic glasses are one of the more promising classes of BMGs available, being less expensive than palladium-based glasses whilst still having a high glass forming ability, allowing for the formation of bulk materials. Heat treatment of these materials typically generates nanocrystalline phases, with grain size and chemistry controlled by the heat treatment parameters. The nature of the decomposition from amorphous to nanocrystalline is not clearly understood and has been the focus of a study by Dr Mike Miller from the Oak Ridge National Laboratory in Tennessee in collaboration with Prof. Simon Ringer's group at the University of Sydney. By using the unique capabilities of the laser-pulsed atom probe, they have quantitatively evaluated the phase separation of the components as a result of a novel, multi-stage heat treatment. The atom probe data clearly reveals the distinct and fine-scale phase separation. By controlling the heat treatment time and temperature, the final size and composition of the phases can be manipulated as desired.

These studies help to form the basis of our understanding of the behaviour of this new class of materials and to find ways to exploit their properties in the future.

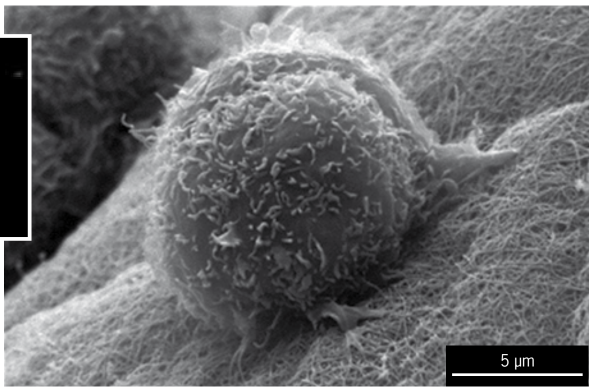
CANCER CELLS ON THE MOVE

A particularly dangerous property of cancer cells is their tendency to migrate around the body causing secondary tumours in a process known as metastasis. Understanding how this occurs is fundamental to our knowledge of this hugely disparate disease. During their walkabout, the cells must negotiate their local environment, moving through the intercellular matrix. Dr Lilian Soon from the University of Sydney's Australian Key Centre for Microscopy and Microanalysis, is investigating this process in breast cancer cells by using a combination of live-cell confocal, total internal reflectance and electron microscopy. She is looking to see how cultured cancer cells move through different types of matrix of defined pore sizes. She finds two very different processes at work. When the pores are large, the cells manage to squeeze through the gaps, following the path of least resistance. However, when the pores are considerably smaller, squeezing through doesn't seem to be a feasible option. Instead, in order to progress, the cells need to start enzymatically digesting the matrix that is impeding them. Lilian and her team have found that the proteolytic enzymes responsible for this process sit in the leading edge of the invading cell. They have also described a new structural feature of the cells migrating through the dense matrices, curved, claw-like extensions that occur at the front of the cell as it moves forward.

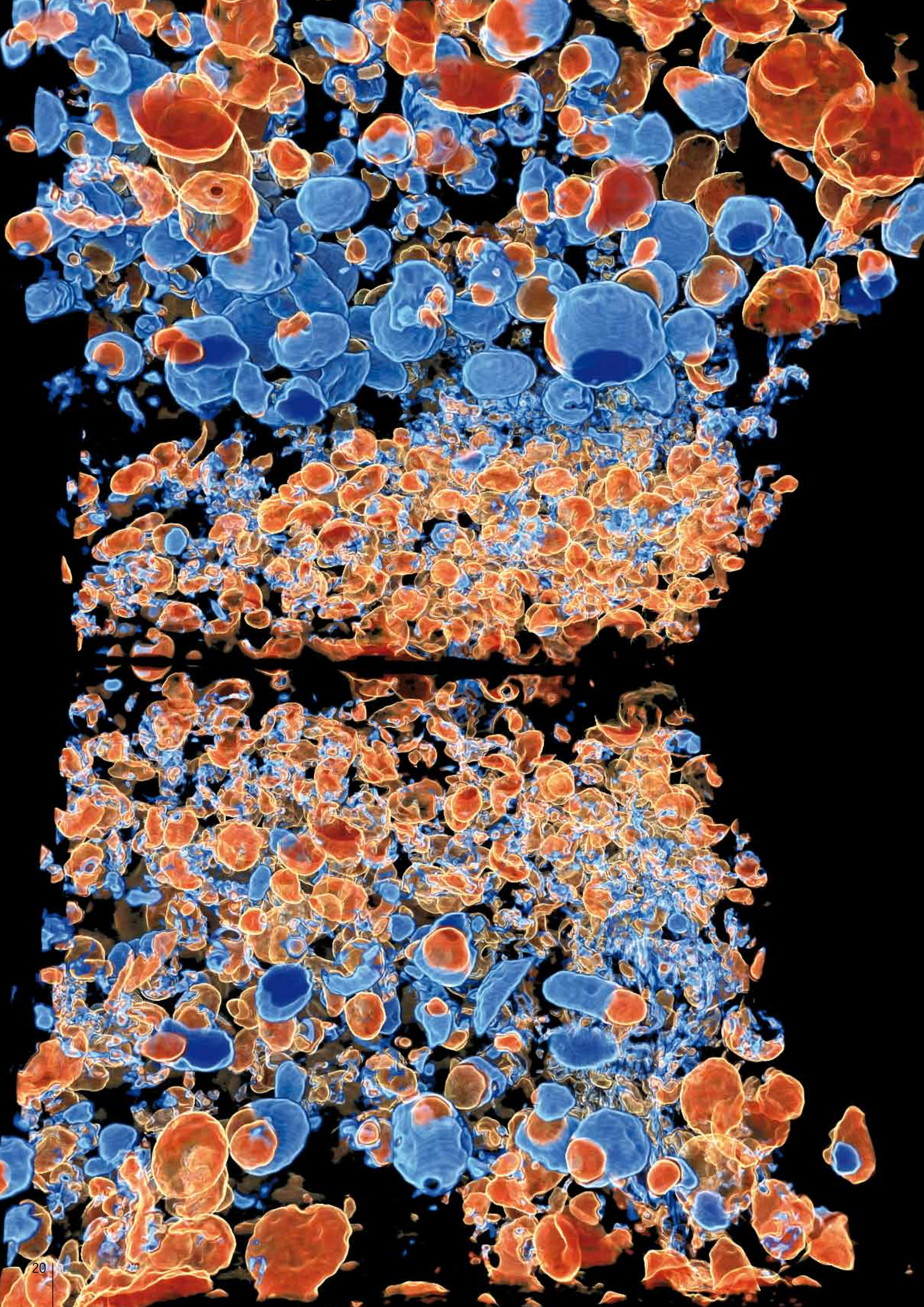
These experimental findings can be dramatically related to the clinical situation when we consider that a variety of tissue densities are evident in mammograms and that these appear to relate to different propensities of tumour cells to migrate. Lilian's work could therefore contribute to our understanding of the risks associated with metastasis in breast cancer.

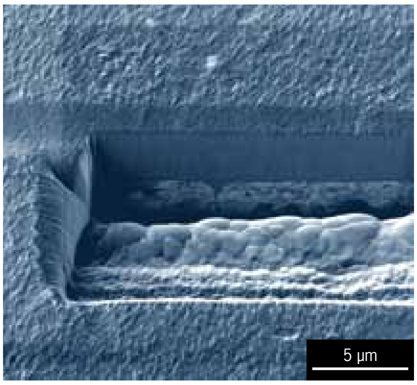


A cancer cell migrating down through a dense matrix (not visible) showing the proteolytic enzymes in green.



A cancer cell starting to migrate into a dense matrix showing its distinctive 'claws'.





Ion-beam-induced secondary electron image of a cross-sectional view parallel to the scratch direction of a thick TiSiN coating (150 nm) alternated with thin TiN interlayers (50 nm) on a stainless steel substrate. The sample was tilted to 44.2˚ in order to reveal the subsurface deformation.

MAKING STRONG STRONGER

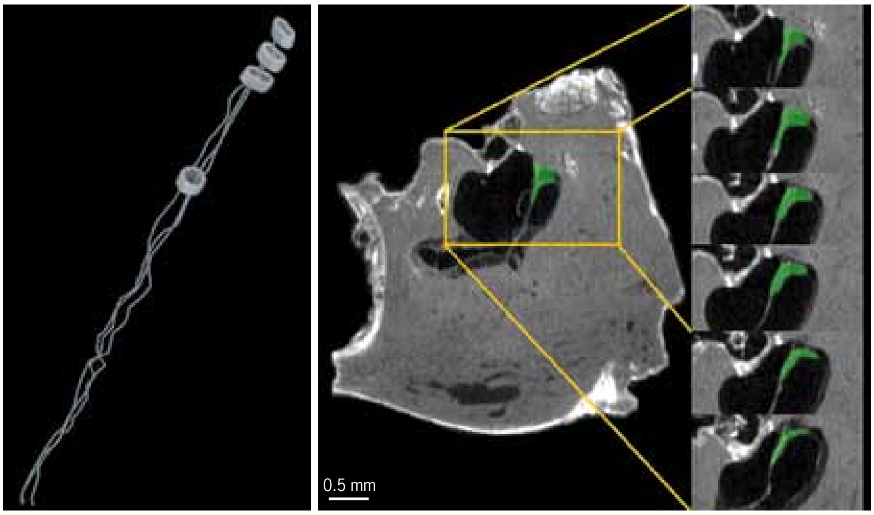
FLAGSHIP

Titanium nitride (TiN) based coatings for steel are widely used as protective surfaces on drill bits and other cutting tools due to their high hardness, wear resistance and high chemical stability. However, improvements are continually sought, and it has been found that the mechanical properties can be improved further by either the addition of a Ti-based interlayer or by the addition of silicon (Si). These alterations modify the microstructures, effectively improving resistance to deformation. The TiSiN coatings are much harder than columnar-structured TiN alone, but more brittle and less damage tolerant. To optimise performance, Dr Amy Pui Ching Wo from the University of New South Wales is working on the idea that further improvement in the strength of such coatings might potentially be achieved by the addition of interlayers, as in the case for TiN/Ti multilayer systems. In her project, samples with alternating layers of TiSiN and TiN of differing thicknesses were examined in order to study their effects on deformation. Sub-micrometre deformation was achieved by performing well-controlled nanoindentation and nano-scratch tests on the samples. The resultant sub-surface deformation structures were revealed by focussed ion beam (FIB) fabrication of cross sections. Better understanding of the deformation mechanism can be obtained from the results of this study, which will ultimately help in generating more wear-resistant coatings.

NEW VISIONS OF THE INNER EAR

The inner ear is a complex sensory organ that not only lets us hear the world but also stops us falling over while we do it. While the cochlear of the inner ear lets us hear, another part of the inner ear, the labyrinth, provides our sense of balance and orientation, without which, life can be very difficult. Unfortunately, this fact is known only too well to many Australians, particularly older people, who suffer from balance problems due to disorders of the inner ear.

It is very satisfying to see a new technology, in this case X-ray microtomography, provide primary insights into this important area of research. Since the first scan of a human ear using this technique, a small group of active researchers has formed and reached out across national and international boundaries to give a view of the inner ear that has significance much greater than initial expectations. Hilal Uzun-Coruhlu, a student working with Dr Allan Jones at the University of Sydney, has been asking a simple question – what if the soft tissue sensory membranes of the inner ear could be made visible under X-rays by staining them with heavy metals such as osmium. Hilal has shown this can be done very successfully, and her work has opened the doors on a whole new raft of ideas. She has explored the 3-D orientation of critical balance sensors (the utricular and saccular maculae) clearly showing their shape, orientation and attachment as never before seen. As Hilal now nears the completion of her PhD, the group has forged new links with the CRC for Hearing in Melbourne to expand this research. The aim is to image cochlear implants to improve our understanding how they can be optimally designed and implanted without damage to the surrounding delicate structures, and some exciting results are already emerging.



Left: an experimental cochlear implant.
Right: microtomography image of the membrane attachments (green) in the inner ear.

X-ray microtomogram of carbonate rock core revealing the water (blue) and oil (red) distributions in the pores. The rock itself is not visible. Image by Munish Kumar from the Australian National University.

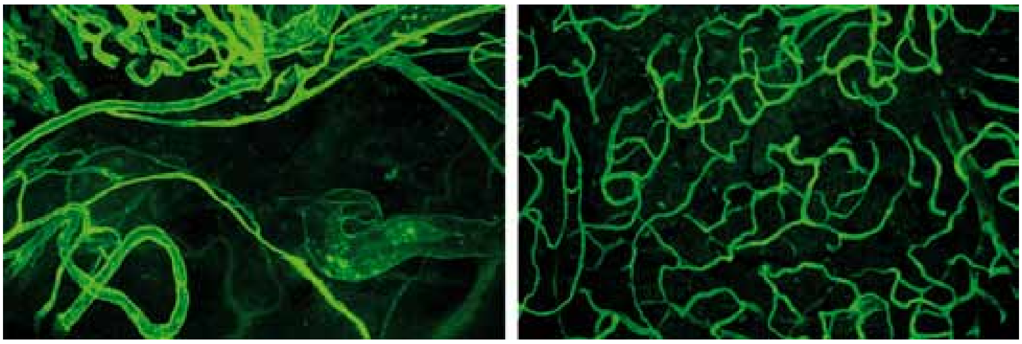
BETTER BLOOD VESSELS – BETTER CANCER TREATMENT

The blood vessels that grow through tumours are not like other blood vessels. Their cells are disorganised and their walls are fragile and leaky. These abnormal structures make it more difficult for the patient's immune system to attack the tumour and for immune-based therapies to target the tumour cells. An enormous amount of work is being done around the world to understand these processes and how they are controlled so that new treatments can be developed.

During their investigations into this area, A/Prof. Ruth Ganss and her colleagues at the Western Australian Institute for Medical Research and Centre for Medical Research at the University of Western Australia, have made a fascinating and unexpected discovery. RGS5 is an intracellular signalling protein that is normally present in some specialised cell types in the body and is seen in increased amounts in tumour blood vessels. By using confocal microscopy at the Western Australia node, Ruth's group has looked at the structure of tumour blood vessels in mouse mutants lacking the *Rgs5* gene (and therefore having no RGS5 protein). Their exciting finding is that the removal of the gene leads to tumour blood vessels that look normal rather than disorganised. The normal blood vessels actually lead to a small increase in oxygen getting to the tumour, which is initially to the tumour's benefit; however, immune cells that normally have problems getting through the abnormal blood vessel walls can now pass through easily, which opens the way for treatments with activated immune cells.

Before that can happen, RGS5 needs to be studied in much more detail to gain an understanding of the signalling pathways it controls. It would then be necessary to develop a drug to block RGS5 functioning in the tumour blood vessels. Such a drug could be used in combination with activated immune cell therapies and would hold out real hope for a highly effective treatment.

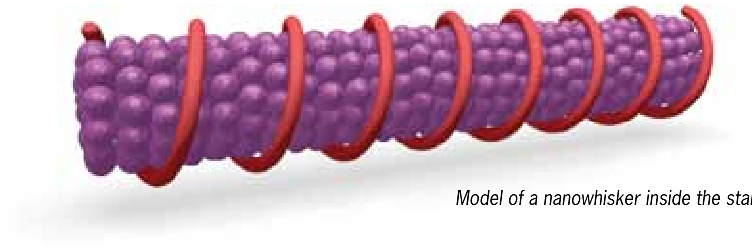
This work was published in *Nature* in May 2008.



Abnormal blood vessels in tumours where the RGS5 gene is active (left) and normalised vessels where the RGS5 gene is removed (right).

ORGANISING THE BUCKYBALLS

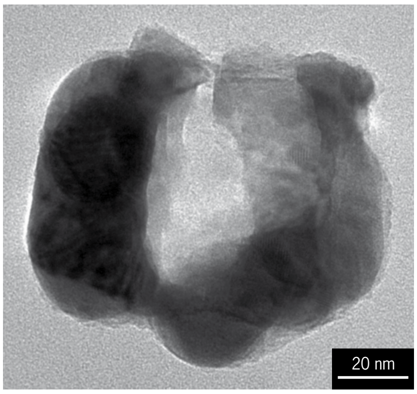
A major challenge in nanotechnology is to control the construction of the nanomaterials and to do so in an energy- and cost-efficient way without the need for noxious reagents. This is now becoming known as 'green chemistry'. Carbon-based nanomaterials have great potential in many fields, including drug delivery, sensor technology, nanoelectronics, catalysis and fuel cells, but their application has been hampered by the difficulty in dispersing them in water, making them very awkward to manipulate. They are also hard to coat with other materials such as metals and are expensive to synthesise.



Model of a nanowhisker inside the starch helix.

A humble mixture of iodine and starch, just like those used in so many school science labs, has now come to the rescue, providing a 'green chemistry' route to the controllable synthesis of carbon nanostructures. Dr Swaminathan Iyer, Dr Martin Saunders and Prof. Colin Raston at the University of Western Australia have found that the starch provides an ideal template, forming a spiral shroud around an inner helical chain of polyiodide, resulting in hollow tubes with a water-repelling space in the centre. C_{60} molecules, otherwise known as buckyballs, have an affinity for this environment and assemble into an ordered helical arrangement inside the tube. Without the guidance of a structured template, C_{60} molecules will just form clumps in water. After removing the iodine-starch template with ascorbic acid, the nanowhiskers are stable in water and can be functionalised for a multitude of uses – in this case, by coating them with silver. The spinning-disc processing method has been used to do this and has successfully achieved good coverage, something normally very difficult to do with carbon nanotubes and fullerenes.

By using the advanced microscopy facilities at the University of Western Austra-



TEM image of a nanowhisker in cross section.

lia, the team was able to confirm all levels of the nanowhiskers' construction, demonstrating the effectiveness of the method. High-resolution transmission electron microscopy (TEM) and electron diffraction clearly revealed the ordered arrangement of the C_{60} core and the polycrystalline nature of the silver coating.

This innovative work demonstrates a new level of control over the handling of these difficult C_{60} structures. The biopolymers and spinning-disc technology make this a controllable and sustainable method for producing carbon nanostructures that will allow further studies of their potential applications to be done far more easily and will move this field forward much more rapidly than could have been possible previously.

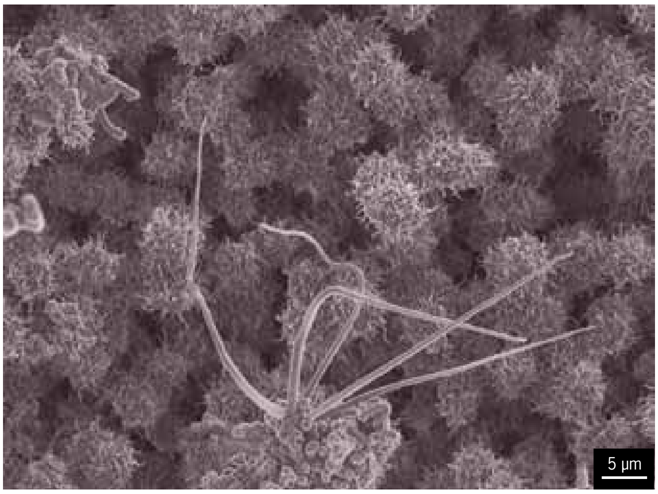
This work was selected as a 'Hot Article' by the Royal Society of Chemistry in September 2007.

NANOWIRES GET GROWING

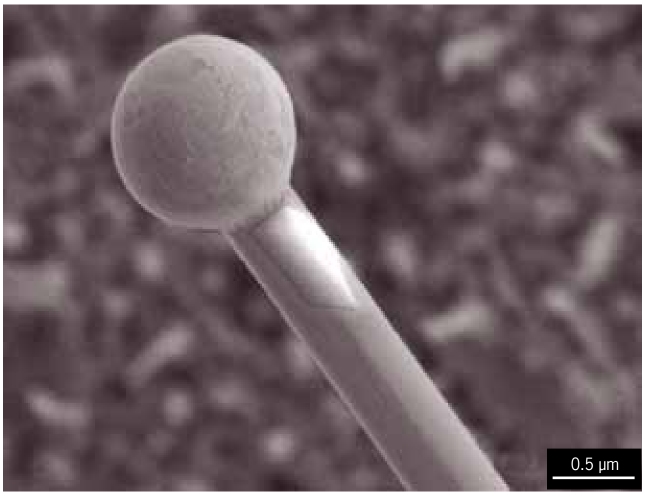
Nanotechnology is a large and burgeoning area of research, and the efficient fabrication of nanostructures of great importance. Dr Avi Shalav and his colleagues from the Australian National University (ANU) are looking into methods of growing silicon oxide nanowires (or nanowool) with different metal-catalyst deposition techniques such as sputtering and implantation. The catalysts act as 'seeds' for nanowire growth via the vapour-liquid-solid growth mechanism. They have found that, at very low oxygen concentrations, silicon oxide nanowires will form on the surface of a silicon wafer. In some cases, the metallic catalyst nanoparticles can be found at the tip of each growing wire as seen below.

By depositing catalysts on already grown nanowires, the growth of secondary nanowires is made possible. These secondary nanowires further increase the very large surface area of the primary nanowires. Analysis by scanning electron microscopy in the Electron Microscopy Unit at ANU shows the primary nanowires are around a few hundred nanometres in diameter whereas the secondary nanowires are typically an order of magnitude smaller. The synthesis routes developed by the ANU group could be used to produce cheap, novel nanowires and wafers with extremely large surface areas for wide-ranging applications. For instance, if a mat of suitably prepared nanowires is excited by a laser pulse, the photoluminescence signal emitted from the fibres will have a characteristic intensity and lifetime when the air between the fibres contains certain chemicals. These nanowire mats are, therefore, excellent candidates for sensitive solid-state gas sensors, capable of being applied to the detection of any number of important gases such as alcohol, explosives, toxic gases and biological molecules.

This secondary nanowire growth mechanism can be extended to other nanowire materials and developed to enhance hybrid and organic solar-cell efficiencies. Excited charge carriers from within an organic material have a very short diffusion length and the very large surface area of these nanowire structures would allow rapid and efficient charge separation at the organic-nanowire interface.



Secondary nanowires growing on the larger primary nanowires.



Metallic catalyst ball on the end of a nanowire.

A confocal microscopic image of an isolated myofibre from a mouse model of human actin disease. The mutant actin is tagged with an enhanced green fluorescent protein and the nuclei are stained blue with Hoechst.

CULTURED MUSCLES

Human muscle and neurological disorders are being intensively studied to better understand the causes and progress of these diseases, and to develop prevention and treatment options. Prof. Nigel Laing's laboratory at the Western Australian Institute for Medical Research (WAIMR) is working to develop better model systems that maintain the characteristics of mature muscle in culture long enough to test potential therapies.

They dissociated muscles into individual fibres and treated them in such a way that the isolated cells could maintain a mature form in culture for up to ten days, without displaying more immature properties as are common in other culture systems. Confocal analysis of the cells not only demonstrated that adult forms of specific proteins were still being expressed after different time frames in culture, but also that these proteins were correctly localised, and that the mature muscle cells maintained their morphological characteristics. They are now applying this system to study mouse models of human diseases.

Complementing this work they also used flow cytometry to develop a novel technique for analysing cells from freshly dissociated whole mouse skeletal muscles and hearts, something that had not been reported before. Conventional methods for measuring proteins within muscle samples are often time consuming, labour intensive and subject to sampling errors. Their new method allows rapid detection and quantification of a variety of important and very specific proteins in heart and skeletal muscle samples, and can be applied to determining the efficacy of potential therapies for muscle diseases.

Dr Kristen Nowak, the Premier's Western Australian Young Scientist of the Year 2007, was part of this team.

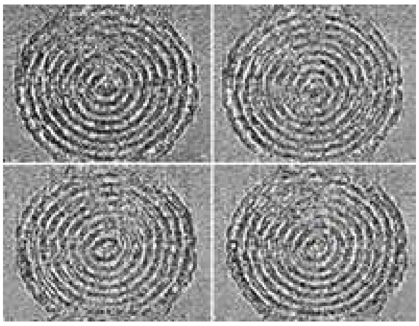
SEEING PATTERNS IN PORES

FLAGSHIP

Extraordinary attention is being lavished on nanoscience and nanotechnology, and the development of ordered mesoporous materials generates considerable excitement. These materials contain arrays of pores on the nanometre scale. The versatility of their applications in catalysis, sensing, bio-separation and controlled-release technologies has driven research in new directions – towards a greater understanding of their internal structure and the external morphology. Subtle differences in the nature of the ordered pores can be of vital importance for their performance in different applications.

A/Prof. Jin Zou from the University of Queensland, together with his collaborators at Fudan University in China, has synthesised ordered silica mesostructures and has been working to determine whether they assume a closed helical structure or a concentric circular one, the two theoretical possibilities for the structure. To resolve these two possibilities, he and his team have used the power of electron tomography. This technique was originally applied mainly to solving biological structures but is now finding application in the area of materials science. It has allowed his team to produce tomographic slices with a thickness of less than one nanometre and to reconstruct the true internal structure of their material for the first time, showing it to be a concentric circular mesostructure rather than the similar closed helical mesostructure.

Studies of this sort can help scientists to understand the formation mechanisms of these novel ordered porous structures and so guide the future design and synthesis of new materials.

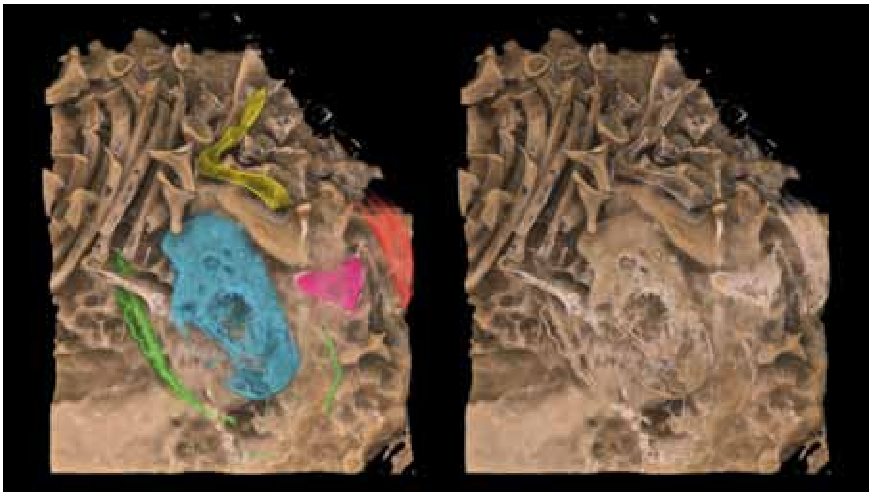


Top: Models of the two alternative structures. Left: Tomographic slices through the ordered mesostructure, each one 150 nm in diameter.

LIVE BIRTH IN FOSSIL FISH

The oldest example of live birth known amongst the vertebrates has been found in a 380-million-year-old fossilised fish from Gogo, in the Kimberley district of Western Australia. A well-preserved embryo has been discovered amongst the fossilised bones by Dr John Long, Head of Science at Museum Victoria. He extracted the specimen from a limestone nodule by using acetic acid, and discovered a partly developed small skeleton inside the body cavity.

Researchers from Museum Victoria, the University of Western Australia (UWA) and the Australian National University (ANU) have collaborated in documenting this remarkable fossil – a new genus and species named *Materpiscis attenboroughi*, after Sir David Attenborough. It has revealed details of the umbilical cord and recrystallised yolk sac, soft-tissue structures very rarely preserved as fossils. The anatomy of the preserved embryonic structures was studied with the AMMRF X-ray microCT facility at ANU by A/Prof. Tim Senden and revealed additional small bones, confirming that the structure was indeed an embryo. Dr Kate Trinajstic from UWA complemented this work by using the AMMRF scanning electron microscopy facilities at UWA to examine the microstructure of the umbilical cord.



MicroCT image of the embryo with and without shading to highlight the juvenile components. Scale is approximately 15 x 15 mm.

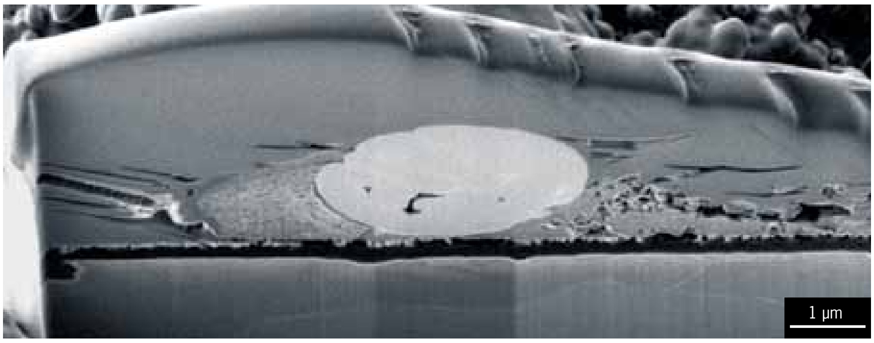
Materpiscis belongs to the extinct armoured-fish group called the *Placodermi*. These are common fossils at Gogo, the world's best-preserved site of Devonian fossilised fish. Dr Trinajstic also re-examined some key specimens in the museum collection in Perth and found an additional three small embryos inside an adult female of a closely related form, *Austroptyctodus*. Dr Gavin Young from ANU had previously described male *Austroptyctodus* and had discerned an advanced reproductive biology, involving copulation and internal fertilisation, as in modern sharks. The preserved embryos demonstrated that these placoderms did not lay eggs, but produced live young, a remarkably advanced reproductive strategy for its time.

This work was published in *Nature* in May 2008.

ANATOMY OF A SPLAT

FLAGSHIP

Thermal-spray processing is used to deposit coatings onto functional surfaces such as aluminium. Little is known about the microstructural interactions that occur when particles (or splats) interact with a surface during deposition. Sophie Brossard from the University of New South Wales has examined these interactions by using focussed ion beam (FIB) milling and scanning electron microscopy. Nickel-chromium (NiCr) particles were sprayed onto heat-treated aluminium substrates with different surface chemistries then cross-sectioned with the FIB. An example of this is seen in the picture. The light-coloured, oval NiCr particle is surrounded by a porous layer, which is a complex foam-like mixture of nickel and chromium oxides, formed on solidification of the splat. The particle/oxide composite is seen to be well bonded to a layer of aluminium oxide (black band) on the substrate surface that was grown by the heat treatment prior to plasma-spray processing. The splat has been covered with a layer of platinum during specimen preparation as a protective layer.



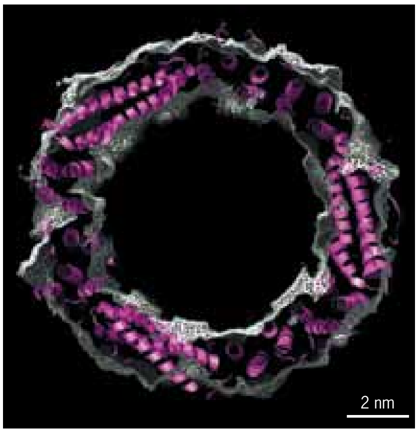
Cross-section of a nickel-chromium splat on an aluminium surface.

The work has shown that conditions that create a layer of aluminium oxide lead to the best adhesion of the splats and should generate improvements in spray processing technology.

FROZEN INTO SHAPE

FLAGSHIP

In biological systems, protein function is intimately tied up with structure, hence the push to unravel the structural intricacies of biological macromolecules in ever greater detail. Technical advances in cryo-transmission electron microscopy (cryo-TEM) and image processing are resulting in the capture and recovery of structural information at rapidly increasing resolution. Improving the analysis of the resulting data must move forward hand-in-hand with developments of the microscopes in order to fully realise the benefits. A/Prof. Ben Hankamer's group at the University of Queensland has focussed on this aspect of cryo-TEM, developing and linking a range of algorithms and programs into a semi-automated pipeline designed to rapidly align ten-thousand to a million molecular projections generated by the microscope into 3-D structures in a coordinated and efficient way.



Structure of the ferritin protein determined by using cryo-TEM.

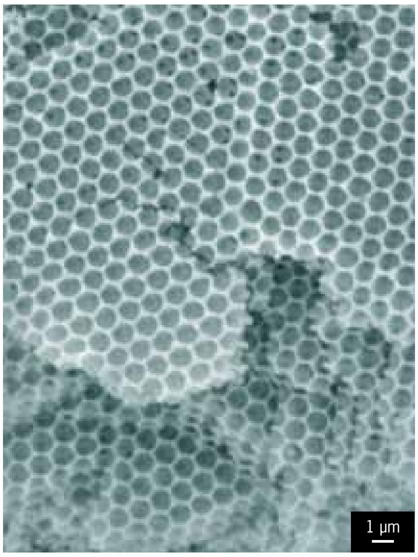
An advantage of cryo-TEM coupled to single particle analysis, over the more traditional method of structural determination by X-ray crystallography, is that protein crystals are not required and the structures can be retained in a more natural conformation. Cryo-TEM particularly lends itself to solving structures such as soluble macromolecular assemblies, membrane proteins and icosahedral viruses. Through the application of his analysis techniques to these kinds of molecules, their structures are now being resolved to sub-nanometre resolution, visualising details of subunit organisation and the arrangement of α-helices within the proteins.

The group has established a rapid, high-resolution, high-throughput, single-particle-analysis pipeline at the University of Queensland. This is already resolving a wide range of diverse and complex biological structures. The next phase of development is to improve the technology to facilitate the recovery of high-resolution detail approaching atomic resolution.

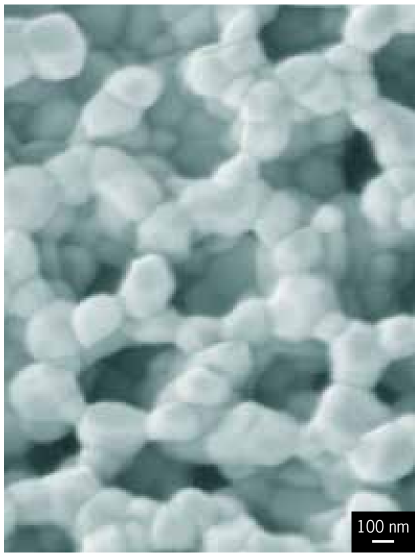
BUILDING BETTER FUEL CELLS

Fuel cells generate electricity from hydrogen-rich fuels, and improving fuel cell performance is the focus of a great deal of research, as it will allow the effective development of alternative ways to supply our future energy needs.

Dr Anna Lashtabeg from the University of Queensland has been working in this area, aiming to develop more-efficient solid-oxide fuel cells with longer operational life. Producing electrodes with a larger catalytic surface area and well-ordered microstructure is one way to achieve this end. She has used one-micrometre-wide polystyrene spheres as a templating material to produce well-ordered macroporous structures from yttrium-stabilised zirconium (YSZ).



YSZ microstructure sintered at 650°C.



YSZ microstructure sintered at 1400°C, showing grain growth and with ordered porosity at a higher magnification.

The 3-D structures synthesised in this way had significantly larger surface area to give enhanced catalytic activity. The effects of sintering temperatures of 650°–1400°C on pore size, particle size and pore wall thickness were then examined with a scanning electron microscope. She found that ordered porosity was maintained at all temperatures, though some structural degradation was observed at 1400°C. This study demonstrated that templated porosity is maintained well above the conventional sintering temperature of the YSZ fuel-cell electrodes, and higher than previous studies had reported. The stability of these structures at high temperatures makes this fabrication technique a promising alternative to conventional methods of synthesising porous materials, and helped to establish a collaboration with Ceramic Fuel Cells Limited.

WHEN THE GOLD FLOWED

An accurate knowledge of the timing of geological events is a necessary precursor to understanding the causes of these events. This is particularly important when investigating the origins of economic mineral deposits, as the timing of mineralisation can be used to constrain models of ore formation and therefore guide exploration for new deposits.

To clarify the thermal history of the world's largest goldfield, the Witwatersrand basin of South Africa, Prof. Birger Rasmussen and Dr Ian Fletcher from the University of Western Australia used the presence of the 'mineral clocks' monazite and xenotime within the gold-bearing reefs. These minerals are rare-earth-element phosphates and are minor components in a wide variety of mineral deposits and other rock types. The team determined the relationships and chemistry of these minerals in a number of deposits from across the Witwatersrand goldfield by using scanning electron microscopy (SEM) imaging and electron probe microanalysis (EPMA). Isotopic dating was done on the basis of the uranium, thorium and lead concentrations measured within selected grains with the sensitive high-resolution ion microprobe (SHRIMP) at the AMMRF Linked Laboratory in the John De Laeter Centre at Curtin University. Their results show that the goldfields in the northern and central parts of the Witwatersrand basin experienced metamorphism and fluid circulation due to emplacement of the gigantic Bushveld mafic intrusion into the crust 2.06 billion years ago, and that gold was mobilised into its current formations during that event.

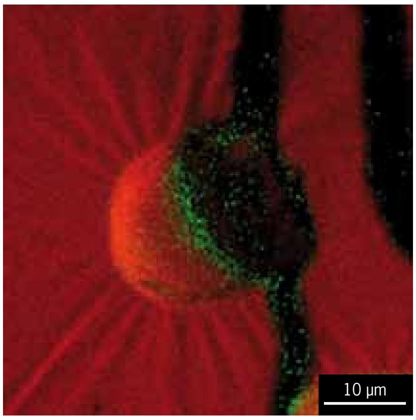
Backscattered electron image of monazite (light grey) formed at 2.04 billion years intergrown with gold (white) from the Elsburg reef.

Backscattered electron image of monazite (light grey) intergrown with chloritoid formed at the peak of metamorphism in carbonaceous shale.

DESIGNING ANTIBIOTIC MICROPARTICLES

Bacterial infections of the respiratory tract are a very significant group of diseases and are usually treated with systemic antibiotics. It would, however, be ideal to deliver the drugs directly to the site of the infection. By removing the requirement for the drug to enter the patient's circulation, higher doses can be targeted directly to the infected site. Although the respiratory tract has inbuilt processes for removing foreign bodies, making very small and light drug-delivery particles could help get the antibiotic right down into the alveoli, tiny air sacs deep in the lung, where it is needed.

Susan Hoe, from the University of Sydney, is working on this problem and has been preparing hollow, spray-dried microparticles of tobramycin mixed with varying but small amounts of sodium stearate. The particles range in size between 5 and 20 µm. The sodium stearate is included with the aim of preventing the particles from sticking together in the spray device used for delivering the drug. To analyse the particles she had produced, and to localise the sodium stearate within them, Susan travelled to the Ian Wark Research Institute, part of the South Australian node of the AMMRF, to apply time-of-flight secondary ion mass spectrometry (ToF-SIMS).



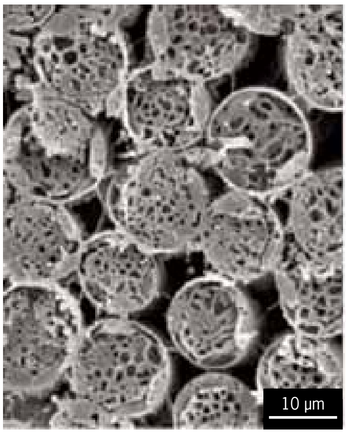
ToF-SIMS image of an antibiotic microparticle.

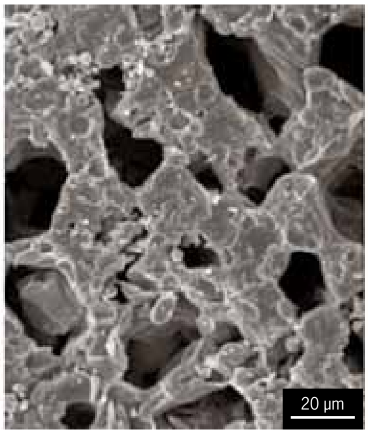
The picture shows a ToF-SIMS image recorded with a focussed-ion-beam-milled particle where the right-hand side of the microparticle (the round area in the centre of the image) has been sliced off, revealing its hollow structure. At this particular concentration of sodium stearate, the signal from sodium (green) is well dispersed throughout the particle, but is not found on its outer surface. The total ion signal (red) was used as a mapping reference. This forms the basis for further work to develop the design of these particles.

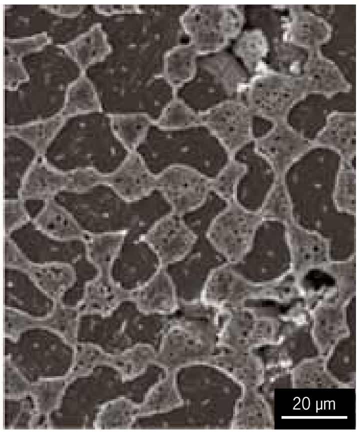
This work was enabled by a TAP grant.

STRESSED SNOW GUMS

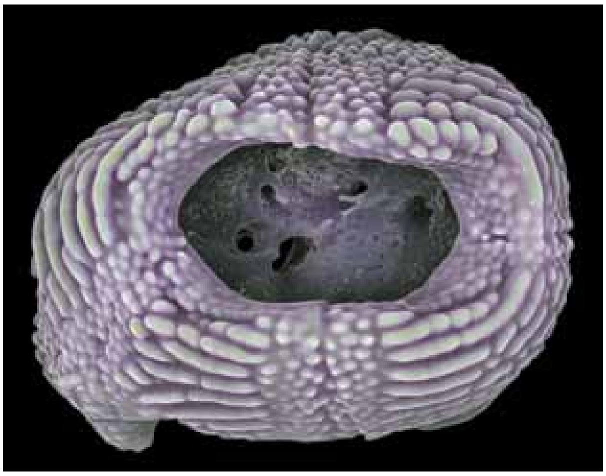
Both drought and frost dry out plant tissues; drought by evaporation into dry air, frost by attracting liquid water to grow ice crystals. Prof. Martin Canny from the Australian National University has a project to compare the drying effects of low humidities with those of sub-zero temperatures on cells of snow gum leaves. Snow gums are an ideal system to study as they are subject to both types of stress. As the leaf cells lose water they shrink, and the stress is measured as the ratio of the shrunken cell volume to that in fully hydrated leaves. Volumes were measured in planed paradermal faces of leaves with the cryo-scanning electron microscope, which holds the snap-frozen fixed tissue at the original state of hydration. The images compare the cell size of a fully hydrated leaf (left) with those after equilibration with air at a relative humidity of 86% (centre), and those in a leaf frosted to –3ºC (right). The cells are surrounded by air in the left two images, and by ice in the right. The relative volumes of the cells in these three states are 100:58:54, demonstrating that the stress of 86% relative humidity is similar to that of –3ºC of frost.







Sections through snow gum leaves: fully hydrated (left), dehydrated in air (centre), and in ice (right).



3-D computer reconstruction (in ANU Drishti software) from the CT scanning data of the fossil eye capsule.

SEEING THROUGH ANCIENT EYES

Studying fossils is how we know about the long and complex history of life on earth, and how the great diversity we see today arose. Although there are copious examples of many types of fossils, others are unique, existing as precious, fragile and isolated samples. These limitations severely hamper the studies that can be done on them. Just such a fossil from the Devonian period was collected near Lake Burrinjuck, 50 km north-west of Canberra. It is the oldest detailed evidence of the complexities of the vertebrate eye known from the fossil record. It is 400-million-years old and about 28 mm in diameter. It is held at the Australian National University and is considered to be one of the 'crown jewels' of the fossil record. The perfectly preserved placoderm (armoured fish) eye capsule was made of bone and cartilage and would have sat within the eye socket of the skull, enclosing the eyeball.

Dr Gavin Young has been studying this fossil and has made use of the microCT scanning facilities at the ANU node of the AMMRF to collect a high-resolution 3-D CT scan of the eye capsule that captures all the exquisite details. Preserved and recorded in the scan are the openings for all the nerves and blood vessels supplying the eye, the muscle scars for the muscles controlling eye movements and the reticular network containing the blood vessels supporting the retina.

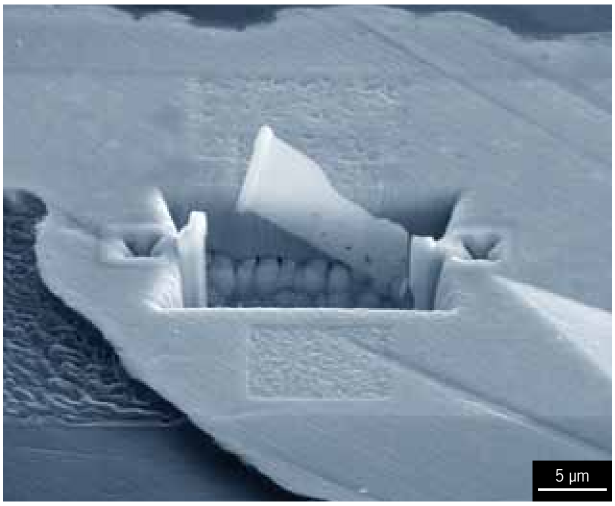
The CT scanning technique means that internal structures of this fossil can be examined so much more thoroughly than was ever possible before, without the need for potentially damaging handling. It is now possible to do a virtual dissection of this delicate object and describe in detail all the intricacies of its functional complexity.

GETTING THE INSIDE STORY

FLAGSHIP

There are lots of different ways to make nanomaterials these days, from wet chemical reactions to chemical vapour deposition, but one of the less obvious routes is ball milling. As the name implies, ball milling involves tumbling hard balls together inside a vessel to 'mill' or grind material, and it has traditionally been used for fine grinding of mineral ores and ceramic powders. More recently, researchers have begun to explore the potential of high-energy ball milling to create nanomaterials by inducing chemical reactions or by causing mechanical alloying of separate metals.

Lately, researchers at the University of Waikato in New Zealand, led by Prof. Deliang Zhang, have been using high-energy ball milling to create nanocomposite metallic particles; that is, particles made up of nano-sized bits of two or more metals. Together with Dr Charlie Kong and Prof. Paul Munroe at the University of New South Wales, they are using the AMMRF's advanced microscopes to study the effects of heating on the microstructure of copper-lead nanocomposite powders, comprising 5 nm lead particles uniformly distributed in copper matrices. Focussed ion beam (FIB) milling has allowed Charlie and colleagues to prepare thin sections of the particles for transmission electron microscopy (TEM). This has revealed that particle microstructure was relatively unaffected by heating at 300°C. In contrast, heating at 550°C caused the average grain size of the copper matrix to increase from 50 nm to 200 nm and caused large lead particles to form at the triple junctions of the grain boundaries. Of course, this coarsening of the microstructure also reduced the measured hardness of the particles. This work is providing new understanding of how ball milling and heating affect the powders' microstructures and properties. Such insights are essential if we are to use high-energy ball milling to make nanomaterials for specific applications in the future.



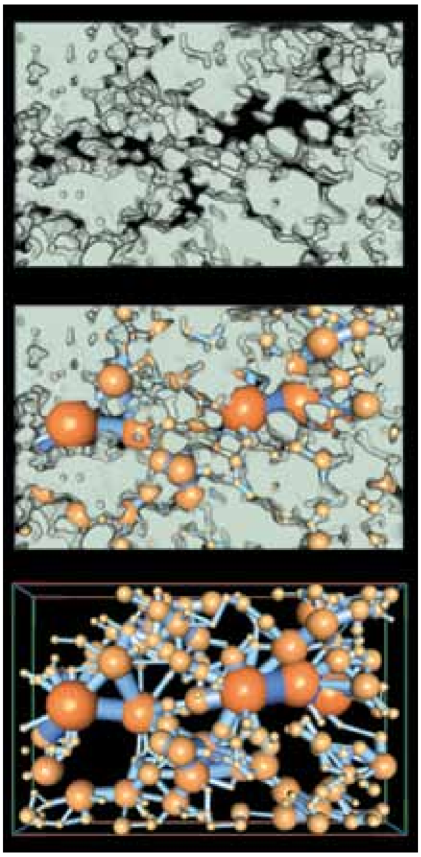
Section of a nanopowder particle cut by focussed ion beam milling.

LOOKING INTO OIL-BEARING ROCKS

The nature of fluid movements in oil-bearing rocks is clearly going to have a great influence on the ease with which the oil can be recovered. If the oil is only found in isolated, unconnected pores, it will not flow out of the rock. Abid Ghous, a PhD student jointly with the University of New South Wales and the Australian National University (ANU), has used the focussed ion beam and X-ray microtomography facilities at ANU to analyse and reconstruct the pores of an oil-bearing carbonate rock from the Middle East.

The sample was first imaged with X-ray tomography at 2 µm resolution to look at the overall pore structure. Areas containing the finest pores were then thin-sectioned with a focussed ion beam (FIB). Data from FIB serial sections were then constructed into a 3-D tomogram to show the structure of the rock (top panel), and complex software was employed to model the spaces, showing how the micropores connect with each other. This model can be seen separately in the bottom panel and incorporated with the FIB tomogram in the centre.

This analysis has shown that even the finest pores in this particular rock form a connecting network and that the oil contained in them will be recoverable.



3-D tomogram of a microporous oil-bearing rock (top) and a model of the pores (bottom). The two are shown together in the centre.

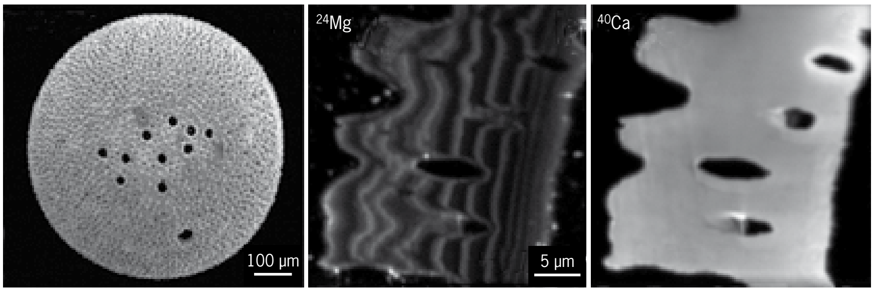
FINE-TUNING THERMOMETERS FOR ANCIENT SEAWATER

FLAGSHIP

Foraminifera are unicellular marine organisms that precipitate an exoskeleton of biomineralised ($CaCO_3$) calcite. They also incorporate trace elements and stable isotopes into the calcite, in amounts dependent on the oceans in which they live. Temperature, nutrient abundance, pH and carbon dioxide (CO_2) levels in the ocean all affect the composition of the skeletons and are determined by the climatic conditions. Fossilised foraminifera retain their distinctive compositional fingerprint and therefore have been thought to provide a record of conditions in ancient oceans. Researchers have used the compositions to reconstruct palaeoclimates over timescales ranging from hundreds to millions of years.

The magnesium (Mg) to calcium (Ca) ratio in the foraminifera is known to increase by 10% per degree Celsius making it a highly sensitive seawater thermometer. However, mounting evidence suggests that other biological effects can also modify the composition of precipitated calcite and bias the accuracy of reconstructed seawater profiles.

Dr Steve Eggins and Aleksey Sadekov, from the Australian National University, have been using NanoSIMS at the University of Western Australia to look more closely at the Mg/Ca ratio in foraminifera grown under controlled conditions in the laboratory. They have found cyclic banding of the Mg/Ca ratio that correlates with the number of days over which adult specimens calcified their exoskeletons. The Mg bands were very narrow and formed during the night when host respiration and the absence of photosynthetic activity by symbiotic algae drives the CO_2 concentration up and carbonate-ion concentration down. This finding is contrary to the assumption that Mg variability in foraminifer shells is controlled solely by temperature, and challenges the basis of the widespread use of foraminifera Mg/Ca ratios to reconstruct past seawater temperatures. Further work will help to fine tune how these tools can be used most effectively in the future to reconstruct past changes in climate.



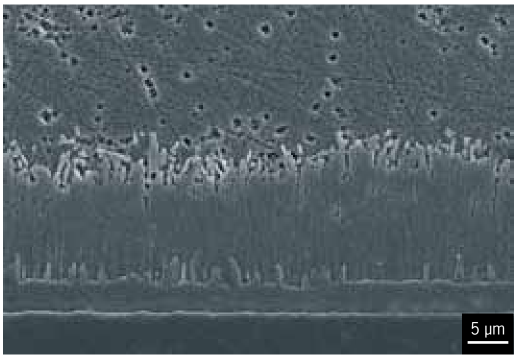
(a) The calcite shell of a foraminifer, (b,c) NanoSIMS ion maps showing the distribution of magnesium (Mg) and calcium (Ca), respectively, through wall of the thin calcite shell.

A GALVANISING STORY

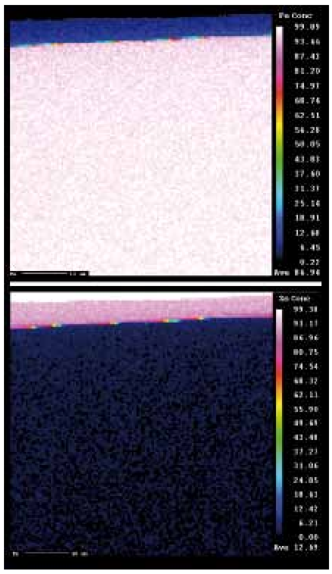
FLAGSHIP

The assembled galvanised-steel body of an automobile before painting is called the 'body in white' (BIW). A good quality galvanised coating not only protects the steel surface from corrosive degradation but also influences weldability, drawability, strength and various wear properties. As a result, significant interest has developed in zinc-coating metallurgy of automobile steels in recent decades. In particular, research on interstitial free (IF) steels has been further stimulated by their advanced properties; they are easily forged into shape, but are much softer than other steels.

Dr Syahbuddin and colleagues from the University of New South Wales coating research group is attempting to understand the reaction mechanisms that occur between the iron and the zinc during the hot-dip galvanizing process on IF steel. By using a combination of scanning electron microscopy and electron-probe microanalysis (EPMA), along with transmission electron microscopy and energy dispersive X-ray spectroscopy, they have demonstrated that three phases are generated in a coating produced from a pure zinc bath. These can be seen in the image with the sequential phases visible between the steel at the bottom and the zinc at the top. The relative thicknesses of these phases vary with process conditions, chemistry and subsequent heat treatments. Quantitative EPMA mapping shows the dramatic change in iron and zinc concentrations across the substrate-coating interface. Such spatially resolved elemental data help us to understand the relationship between phase morphology, composition and properties.

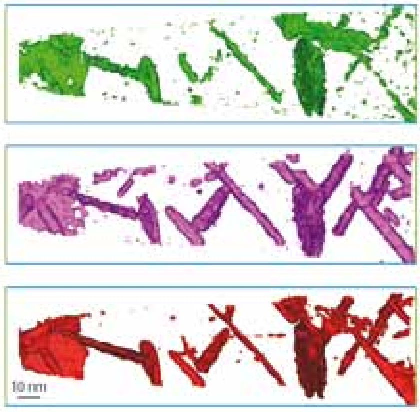


Secondary electron image of the cross-section of a zinc coating (top) on an iron-rich substrate (bottom), showing the layered structure of the three phases.



Quantitative EPMA across the substrate-coating interface. Top: iron map. Bottom: zinc map.

Left: when applied to the atom probe dataset, isoconcentration surfaces of lithium, magnesium and copper clearly reveal the complex structure of precipitates in the aluminium alloy. Below: the separate isoconcentration surfaces for lithium (green), magnesium (purple) and copper (red).



THE LIGHT (METAL) FANTASTIC

FLAGSHIP

When it comes to transportation, we all know that reducing vehicle weight is important for reducing fuel consumption (and pollution) and saving money. Perhaps nowhere is this more obvious than in aerospace applications where, for example, launching the space shuttle costs hundreds of millions of dollars. So it is hardly surprising that many researchers have been exploring new aluminium alloys that are lighter and stronger for use in the shuttle's massive external fuel tanks.

One of the most promising groups of aluminium alloys contains lithium, copper, magnesium and silver; it offers outstanding properties, displaying the highest hardness of all the aluminium alloys. This is largely due to the growth of plate-like second-phase precipitates in the alloy microstructure, which resist deformation and thus strengthen the alloy. Tailoring the properties of these kinds of alloys requires control over the formation ('nucleation') and growth of the precipitates. Although it is known that alloying elements like magnesium or silver encourage formation of these important precipitates, the mechanisms remain unclear. So a collaborative project between Monash University and the University of Sydney, under the ARC Centre of Excellence for Design in Light Metals, is on a quest to redress this lack of understanding.

The team, led by Prof. Barry Muddle from Monash, has been making use of laser-assisted atom probe tomography (APT) to complement transmission electron microscopy (TEM) examination of the alloys. Though the work is in its early stages, the three-dimensional chemical detail provided by APT has already confirmed that the intricate precipitates observed by TEM not only touch each other, in many cases, but often actually intersect. Moreover, it has shown that, while magnesium and silver occur in the plates, their proposed segregation to the interface of the precipitates does not occur.

These kinds of insights are crucial for the design of even stronger aluminium alloys in the future.

LEARNING OF BEE BRAINS

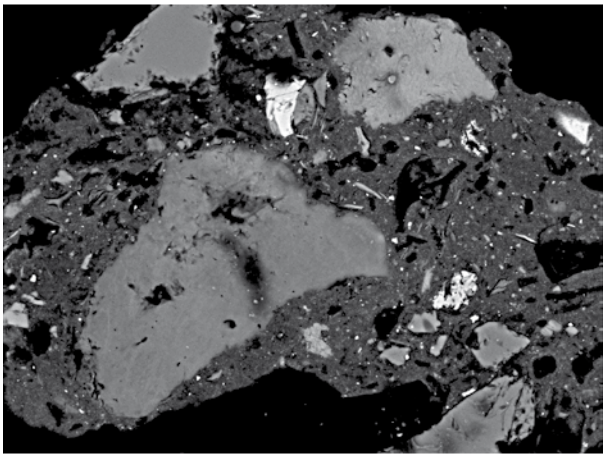
3-D reconstruction of the mushroom bodies of a bee brain.

The development of the honey bee brain has been studied intensively from the perspective of learning, ontology and sociology. The 3-D morphological changes that occur during development can be followed by using traditional microscopic sectioning methods, but these are laborious.

Liang Li, an honours student at the Australian National University working with A/Prof. Tim Senden, has helped to developed a process that combines the speed of X-ray microtomography with optical or SEM thin-section analysis to provide statistically useful datasets with considerably less labour. A computer algorithm called *Drishti*, written at ANU, matches the 3-D tomogram with the 2-D thin section. Having validated the tomographic data, measures such as surface area, curvature and volume are made more reliable. The thin sections calibrate the tomograms both in terms of staining efficacy and histology. The images show highly accurate 3-D tomograms of different aspects of the so-called 'mushroom bodies' or central brain of a bee, a structure about 160 μm wide.

Liang's studies have shown that the bee brain increases in size as the bee learns, maintaining the ratio of surface area to volume. This finding has helped to resolve an age-old dispute about the way brains grow as they learn. If learning leads to a brain growing by increasing interconnectivity between the cells, it would be expected to change its shape. However, a brain increasing in mass alone would retain its shape, as was found here.

WHY ARE ANCIENT MANMADE SOILS SO FERTILE?



Terra preta particle, 8.5 µm across.

Terra preta is a highly fertile soil commonly found in the Amazon basin. It is particularly interesting as it appears to have been deliberately created, originally by pre-Columbian peoples. It incorporates a rich and complex microstructure containing high concentrations of charcoal, together with significant amounts pottery shards and organic matter such animal bones. Containing abundent nutrients such as nitrogen, phosphorous and calcium, it is known to be highly fertile and less prone to leaching than many of the surrounding soils. These fascinating and unique properties make it a valuable resource and something to be emulated in modern soil management. To date, however, there have been few detailed studies of the microstructure of these soils, that can be used to explain their fertility. This is being addressed by Chee Chia and colleagues at UNSW, focussing particularly on unravelling the distribution and interactions of the various organic and inorganic phases in these soils.

The picture shows a backscattered electron image of a terra preta particle, acquired with a scanning electron microscope. Ceramic phases appear lighter grey, whereas the carbon phases exhibit darker grey contrast. The lightest particles are likely to be titanium, silicon and iron oxides. It is clear that the structure of these soils is complex, an intimate mixture of components at a very fine scale – the soil fragment in the picture is only 8 µm in diameter. Additional microchemical studies show that significant diffusion of ions occurs at the periphery of the carbon particles. It is these species that are believed to contribute to the high fertility of these materials.

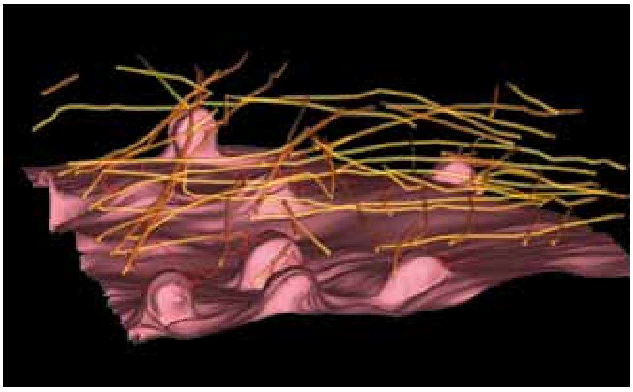
Understanding the complex strucure of these valuable soils is allowing researchers to develop twenty-first-century synthetic cousins to these ancient manmade terra pretas.

THE IMPORTANCE OF PITS

FLAGSHIP

Tiny, flask-shaped pits only 50 nm wide called caveolae exist in abundance all over the surface of many types of mammalian cells. They appear to be important in various functions such as lipid regulation and communication between cells. Caveolins are the major proteins found lining the caveolae and play a crucial role in their formation – if there are no caveolins, there are no caveolae.

Caveolar dysfunction is associated with a range of diseases such as breast cancer, prostate cancer and muscular dystrophy, but nobody knows why. In an attempt to learn more, Prof. Robert Parton and his team at the University of Queensland have studied caveolin-induced caveola formation with electron microscopy. These studies have been combined with high-resolution analysis by electron tomography of isolated plasma-membrane sheets (peeled off the cell surface to allow imaging from the inside), fast-frozen cells, and zebrafish embryos. These studies have defined the fine structure of caveolae in 3-D and shown that caveolae are linked by cytoskeletal elements into an interconnected structural and communication network within the cell. Their recent studies have identified a new family of coat proteins, which work together with caveolins to regulate caveola formation in mammals and lower vertebrates providing new insights into caveola dysfunction in human disease.



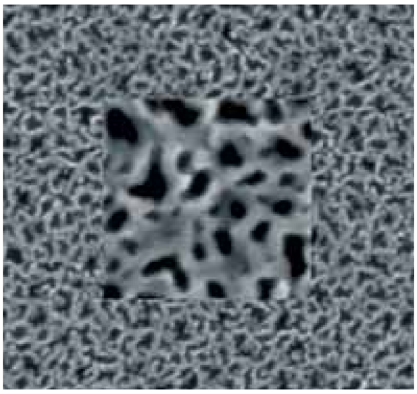
View of the inside of a cell membrane showing the caveolae's connections to the cytoskeleton.

Part of this work was published in *Cell* in 2008.

GOING OUT WITH A BANG

FLAGSHIP

Self-destructing credit cards are just one of a multitude of possible applications from work currently being done at Flinders University. Such applications could result from a better understanding of the explosive properties of microporous silicon, a new, easily portable solid-state explosive.

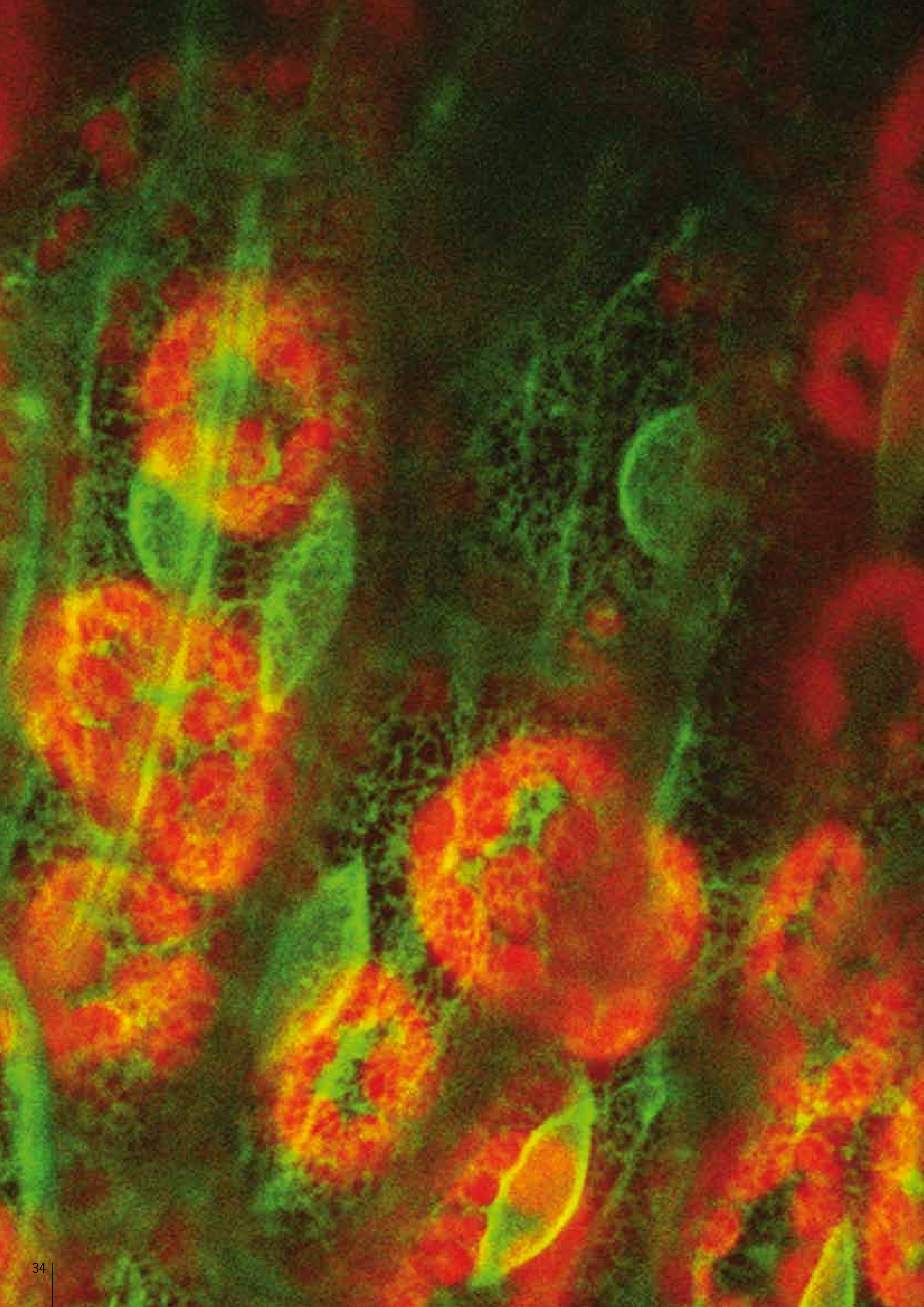


A region of microporous silicon about 130 nm across (outer image).

Porous silicon is a nanostructured material with remarkable optical, electronic and structural properties. However, its explosive properties when oxidised were discovered accidentally and it has subsequently been found to be more powerful than TNT.

Helen Cao, Prof. Nico Voelcker and Prof. Joe Shapter from Flinders University are investigating how to optimise the explosive properties of microporous silicon when impregnated with oxidising agents. Initially the surfaces are hydride-terminated, but when exposed to the oxidising agent, silicon dioxide is formed on the surface and water is released, causing a huge and rapid release of energy – in other words, an explosion. The main challenge here is to gain control over the process – ensuring that it only goes bang when you want it to. Keeping the components stable until the reaction is required will be an essential part of this. The Flinders team is preparing materials under different conditions and determining the size and interconnectivity of pores that give the best reactions. They keep track of it all by using the focussed ion beam (FIB) instrument at the University of Adelaide to look at fractured sections – prepared in the absence of oxidant!

The potential of these solid-state materials is enormous, they can be easily transported and can be arranged on surfaces in specific patterns so that explosions can be set off in a specific and complex sequence. Porous silicon wafers might serve in miniature ignition systems for explosives or to propel microscopic devices, for atomic emission spectroscopy, or even for self-destructing electronic devices. Imagine remotely detonating your stolen credit card – it gives a whole new meaning to 'money burning a hole in your pocket'.



The way forward

The National Research Priorities – An Environmentally Sustainable Australia, Promoting and Maintaining Good Health, Frontier Technologies for Building and Transforming Australian Industries, and Safeguarding Australia – along with the humanities, arts and social sciences, are important for focussing public investment in research programs and infrastructure.

These priorities highlight some of the major scientific, technological and political challenges facing Australia today, which are diverse and will have a significant impact on the future development and prosperity of the nation. Research into such areas as energy sustainability, climate change, water, mining and mineral resources, smart manufacturing, development and application of nanoscale technologies, health and an ageing population, just to name a few, require diverse research infrastructure.

There is widespread acceptance that collaborative approaches play a key role in delivering successful outcomes in modern research. Collaborating across disciplines and across institutional and geographical boundaries generates new opportunities for science and social discoveries as a result of access to greater intellectual capital.[1]

This collaborative paradigm extends to high-end research infrastructure; as the level of investment increases, so also does the drive for open access to infrastructure. The AMMRF has progressed a long way in provision of research infrastructure under this model, but there is more to do.

In 2009, the AMMRF will continue to strategically invest in next-generation microscopy and microanalysis technologies for the benefit of Australian research. The plans include the installation and commissioning of a Cameca 1280 ion microprobe at the University of Western Australia, a PHI TRIFT V nanoToF secondary-ion mass spectrometer at the University of South Australia, a high-throughput cryo-TEM capability at the University of Queensland, and a high-resolution SEM at the University of New South Wales.

The much anticipated new flagship for the University of Western Australia AMMRF node, the IMS 1280 ion microprobe under construction at the Cameca factory in Paris.

With the installation of new equipment, additional scientific and technical support engineers will also be recruited to open-up the full capabilities of the flagship instruments.

The Linked Laboratories will progressively become operational, fulfilling an important role for the AMMRF in providing a diverse range of characterisation capabilities throughout the country.

Partnerships with strategic research centres are being identified and these will be formalised with creation of Linked Centre partnerships that will further assist researchers from the centres to access the AMMRF. These partnerships will also see additional microscopy and microanalysis expertise brought to bear on major scientific questions.

The outlook for the AMMRF is good. As stated by Dr Heinrich Rohrer in the preface of this Profile "… I believe [the AMMRF] is on its way to a bright future, so I think Australian science is also on a good way."

[1] Strategic Roadmap for Australian Research Infrastructure, Department of Innovation, Industry, Science and Research, August 2008.

Confocal microscope image of the epidermis of a living tobacco leaf. Image by Dr Louise Cole from the University of Sydney.

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