ammrf
Australian Microscopy
& Microanalysis Research Facility

essential for australia

PROFILE
2016

Our vision

Through collaboration, instrumentation and expertise to be the characterisation facility of choice for researchers, contributing to Australian knowledge, innovation and growth.

Our mission

To extend the range of world-class outcomes from Australian research by providing state-of-the-art infrastructure for the characterisation of materials at the micro, nano and atomic scales.

FOUNDING NODES

THE UNIVERSITY OF SYDNEY

UNSW AUSTRALIA

Australian National University

THE UNIVERSITY OF WESTERN AUSTRALIA

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

SOUTH AUSTRALIAN REGIONAL FACILITY (SARF)

THE UNIVERSITY of ADELAIDE

University of South Australia

Flinders UNIVERSITY

FUNDED BY

NCRIS National Research Infrastructure for Australia
An Australian Government Initiative

NSW MAKING IT HAPPEN

Queensland Government

Government of South Australia

The Government of Western Australia

contents

ammrf
Australian Microscopy
& Microanalysis Research Facility

from the minister

Science and research are central to building the bridges between our best and brightest researchers and business innovators.

The Research Infrastructure Roadmap that is being developed under the leadership of our Chief Scientist will chart the course for research infrastructure over the horizon and build on the $150 million annual indexed funding certainty that the Government has provided for the National Collaborative Research Infrastructure Strategy.

The Australian Microscopy & Microanalysis Research Facility continues to contribute to Australia's rich national-scale research capacity across multiple disciplines from astronomy to art conservation in the search for solutions to tomorrow's challenges.

Facilities like the AMMRF are a part of our country's coordinated and focused approach to research priorities that are targeted at those things that make a difference to Australia and generate meaningful social and economic benefits.

Senator the Hon. Simon Birmingham

Minister for Education and Training

from the chair

The AMMRF is geographically dispersed and operates across multiple nodes in Australia. Each node has strategically invested in different microscopy instrumentation, expertise and technologies. Thus, the collaboration optimises capital utilisation and productivity in a nation-wide microscopy research infrastructure.

Early in 2016, the AMMRF's CEO, Dr Miles Apperley, left to join ANSTO as its Head of Platforms. While reluctantly accepting his resignation, I noted this was an excellent opportunity for Miles. The board is very pleased to have since recruited both a new CEO and COO. Prof. Julie Cairney of the University of Sydney accepted the CEO role, while Dr Caroline Fuery, has joined as COO.

The AMMRF is continuously improving its core services delivery, while building its international connections further, developing new capabilities and growing its Australian industry engagement. It recently updated its draft strategy for the AMMRF's continuing high quality national research infrastructure and service, supporting Australian economic growth.

In 2016, with microscopy multi-national, FEI, the AMMRF launched a version of its MyScope™ elearning tool for ages eight and upwards. At its Washington, DC launch, there was huge student involvement. Additionally, the AMMRF's acclaimed microscopy exhibition *Incredible Inner Space* will continue to tour the USA.

The AMMRF provides its world-class research infrastructure to academia, SMEs and large companies in Australia. This established model of access to microscopy research infrastructure is a proven, significant enabler for world-class Australian innovation, through leading edge instrumentation and expertise.

Dr Gregory R. Smith, Chair of Board

from the ceo

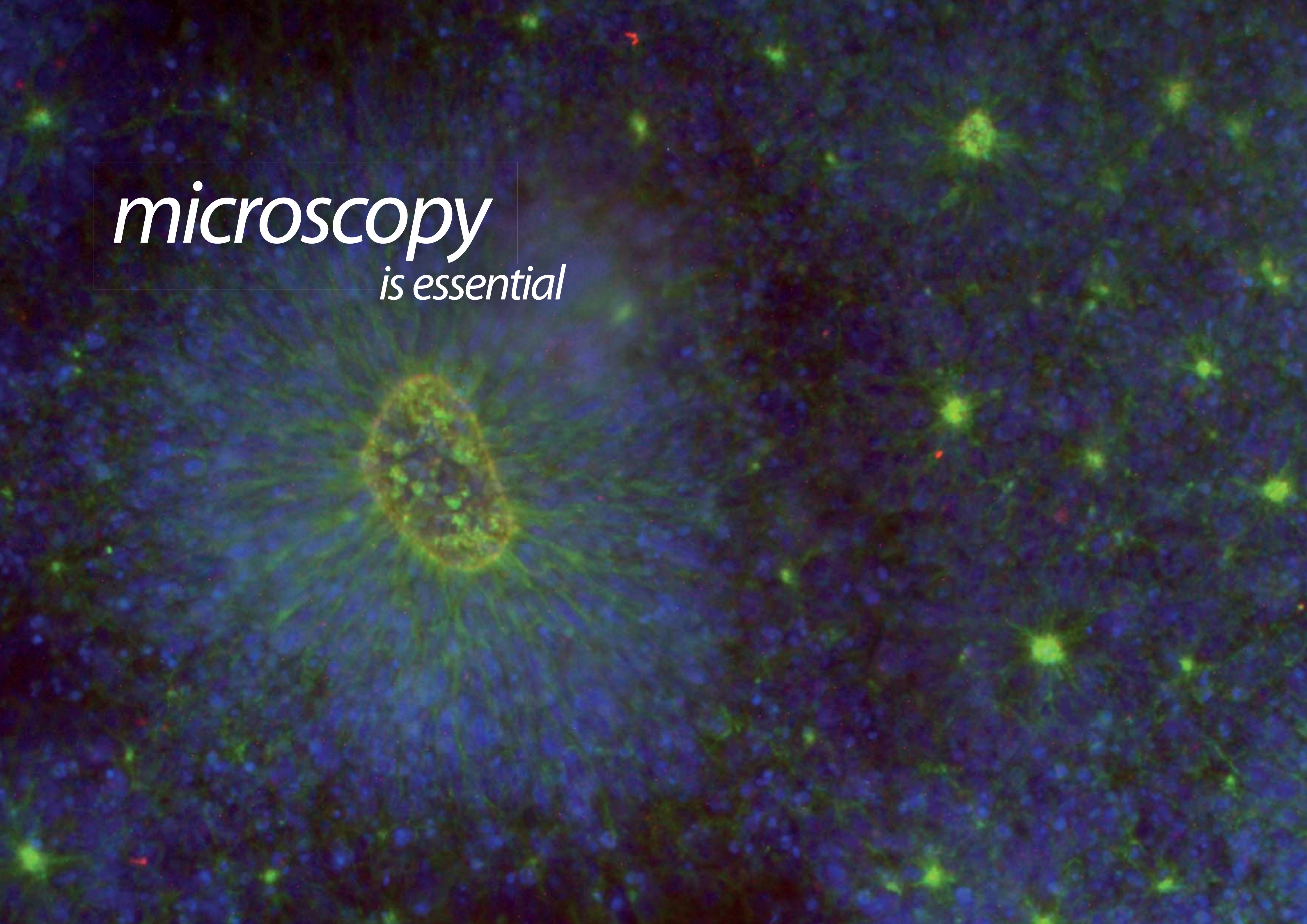
2016 has been a year of both consolidation and forward planning for the AMMRF, as the federal government continues its NCRIS roadmapping process. The AMMRF collaboration prevents duplication and maximises productivity. NCRIS investment incentivises Australian universities to make over $200M worth of microscopy instrumentation openly accessible to all Australian researchers, both within and outside of the AMMRF network. By supporting flagship instrumentation, NCRIS provides researchers access to specialised tools that are often beyond the scope of individual universities or the ARC.

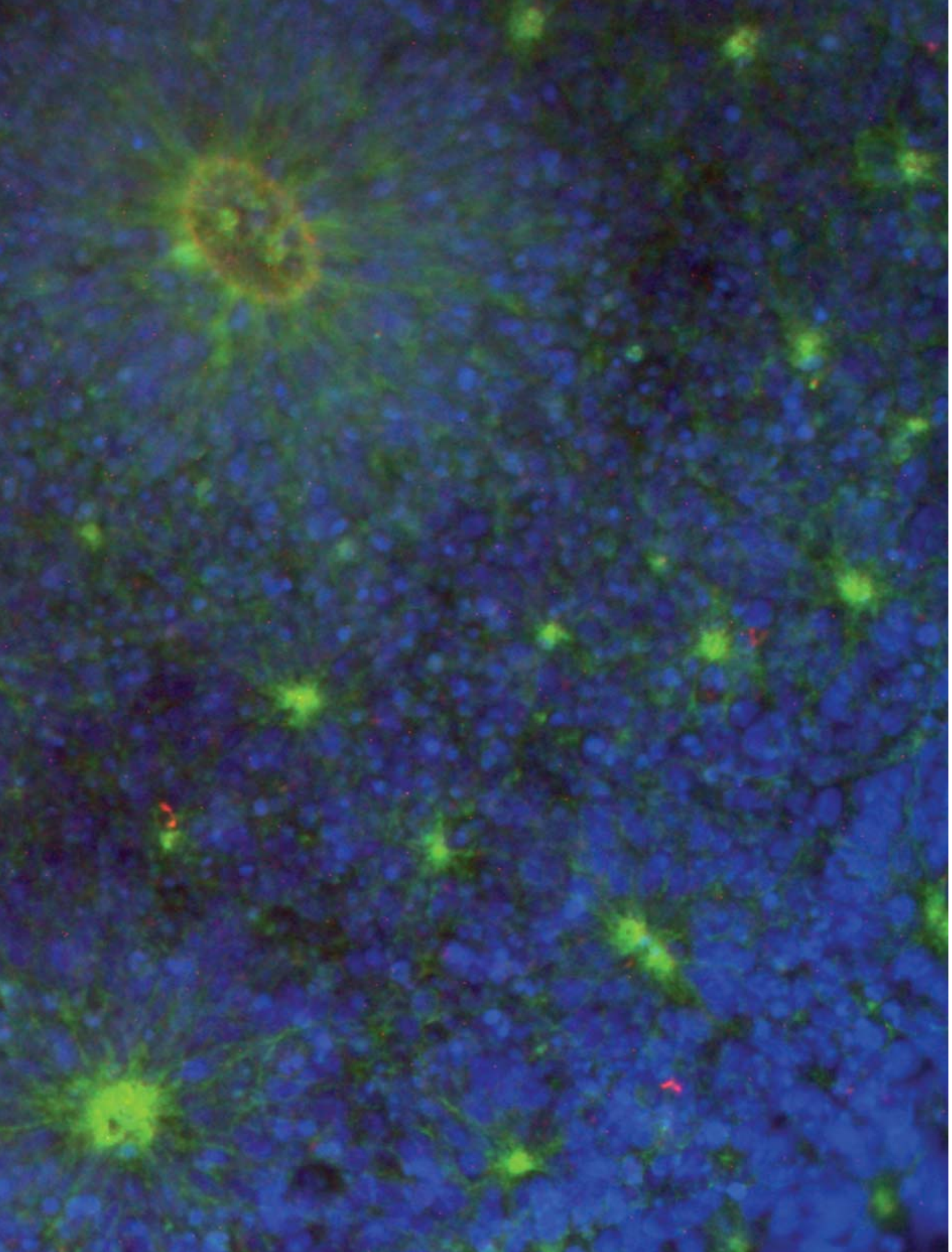
We enable high-impact research – over 1,000 publications per year. In 2016, four AMMRF-enabled papers were published in the top journal, *Nature*. Almost 20% of our users have formal industry links, through long-term research partnerships or as direct commercial clients.

We developed MyScope™, the world's leading online training for microscopy. Both this tool and MyScope™ Outreach, our new digital resource for kids, were shortlisted this year for the UK Learning Technologies awards.

From training and data collection to analysis and publication, our infrastructure supports Australian research across a wide range of disciplines. Game-changing microscopy technologies will be crucial for Australian science in the coming years: cryo microscopy, atomic-scale microscopy and high-sensitivity microanalytical tools. The AMMRF has a strategic five-year plan to invest in these next-generation technologies. We look forward to engaging with the government to deliver these 'Essential to Australia' technologies and continuing to enable world-leading research.

Dr Julie Cairney, Chief Executive Officer


microscopy
is essential



For so much of Australia's great research, and the innovation that flows from it, microscopy is essential.

Our collaborative facility provides micro-scopy expertise and support, adding value to our world-class instruments. Over 200 instruments are run by our expert staff.

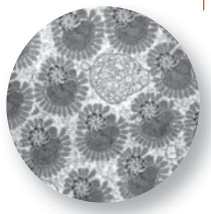
Advanced microscopy and microanalysis underpins modern science, medicine, engineering and industry. We enable researchers to achieve discoveries that address important challenges.

advanced microscopy

We enable access to microscopy and microanalysis for all Australian researchers on the basis of merit.

Our federally funded collaboration has enabled strategic investment in flag-ship instruments, many of which are unique in Australia. They are run by dedicated engineers, to help researchers to get meaningful results. The AMMRF offers industry and academia a wide range of specialised techniques, outlined on this page. Collaborative strategic investment in open access facilities maximises Australian research efficiency and productivity.

In this book, research stories featuring our flagship infrastructure are highlighted with the flag icon.

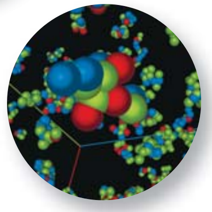


Transmission Electron Microscopy

Imaging & Analytical Spectroscopy
Cryo-Techniques & Tomography
Phase & Z-contrast Imaging
Electron Diffraction

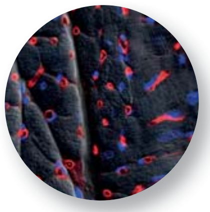
Specimen Preparation

Biological & Materials
Cell Culturing & Molecular Preparation
Thermomechanical Processing
Ion Milling & Machining
Ion Implantation



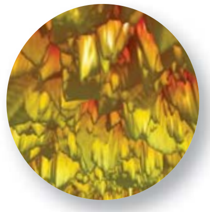
Ion & Spectroscopy Platforms

Nanoscale Mass Spectroscopy
Atom Probe Tomography
Nuclear Magnetic Resonance



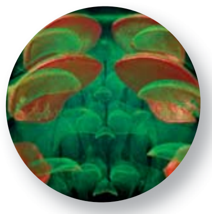
Light & Laser Optics

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



Scanned Probe Techniques

Atomic Force Microscopy
Scanning Tunneling Microscopy
Near-field Scanning Optical Microscopy

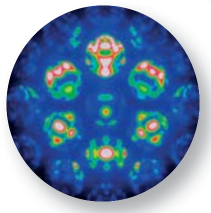


X-ray Technologies

X-ray Diffraction
X-ray Fluorescence
X-ray Micro- and Nanotomography

Scanning Electron Microscopy

Imaging & Analytical Spectroscopy
In-situ Imaging & Testing
Cathodoluminescence
Electron Backscatter Diffraction



Visualisation & Simulation

Computed Spectroscopy
Computed Diffraction
Image Simulation & Analysis
Data Mining

ammrf: in demand

3000+ researchers each year

100,000+ online tool users each year

We enable discovery and innovation across many scientific disciplines and industries. Our facility complements other national research infrastructure, bringing economic, health and technological benefits to Australia. We support high-impact research:

19% industry-linked users per year

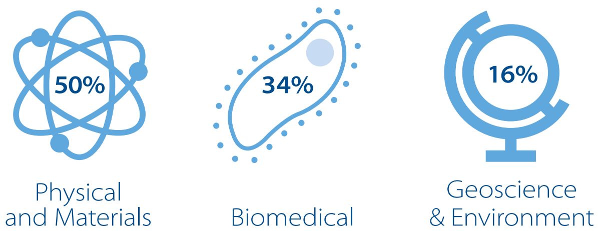
Users from industry

By sector July-Dec 2015

over 15,000 publications since 2007

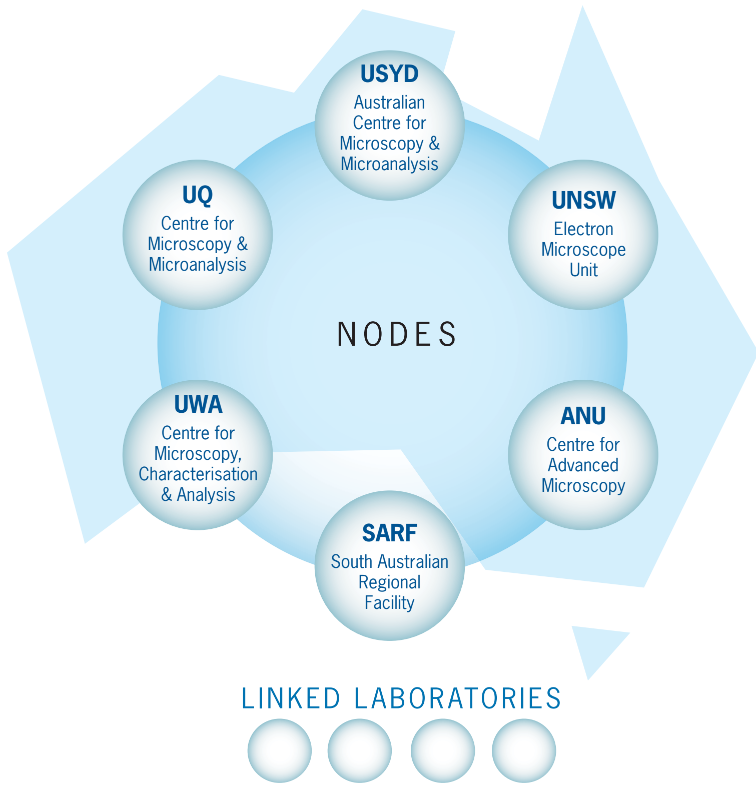
Total users

By discipline July-Dec 2015



since 2007

Established in 2007 the Australian Microscopy & Microanalysis Research Facility (AMMRF) is a national grid of instruments, expertise and online tools dedicated to nanostructural characterisation. Medical, soft matter, plant, materials and geological sciences all require cutting edge microscopy in order to address Australia's Strategic Research Priorities.

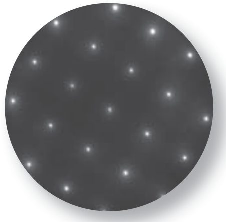


innovation paths

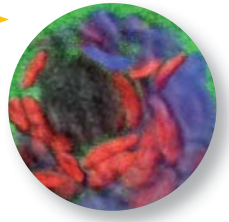
microscopy
enables innovation

from ideas…

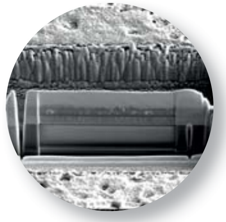
discovery



Cosmic minerals
here on Earth!
– pg26

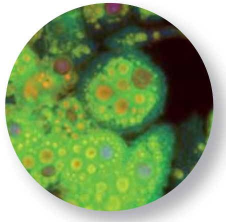


Global food security
– pg28



Cheaper, greener solar cells
– pg30

Infection protection
– pg 29



Targeting Type II diabetes
– pg22

Universities and industry rely on AMMRF microscopy

Journals select their cover images for outstanding quality and scientific impact. We are proud to present these examples of AMMRF-enabled covers.

new industries ...enabled by the AMMRF

Economic modelling has shown that every $1 invested in the AMMRF returns between $4.70 and $6.50 to the Australian economy over the 2007–2031 period.

Economic contribution of the Australian Microscopy & Microanalysis Research Facility, Allen Consulting Group, 12/2011.

ONDEK PTY LTD

Founded by Australian Nobel laureate Prof. Barry Marshal to harness the properties of a common gut bacterium to re-balance the immune system and help manage child-hood eczema.

ELASTAGEN

Awarded $4M from NSW Health's Medical Devices Fund in 2016 to develop Elastatherapy for skin regeneration and wound repair. Elastagen is a University of Sydney spin-off company.

THUNDELARRA

Australian grown minerals exploration company with active projects in Western Australia and the Northern Territory. Main commodity focus: copper, gold and uranium. Raised $4.3M from share issue in Q3, 2016.

NANO-NOUVELLE

Better batteries – higher energy in a smaller volume. This University of Queensland spin-off company was listed in H2 Ventures Top 50 TechPioneers for 2016.

R&D for big industry

a small selection of our many big industry clients

Procter & Gamble

More effective cosmetic products

Net sales, 2016: $65B

Weir Minerals

New alloys for durable mining machinery, operates in 70 countries.

Revenue, 2015: £1.9B

Paladin Energy Ltd.

Australian grown uranium production company. 2016 financial year sales:

Revenue US$185M

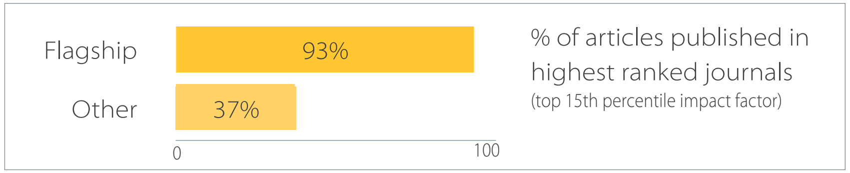
Dyesol Ltd.

Australian grown, third generation photovoltaic tech-nology, exports to 60+ countries

Market cap: $79M

growing australia

The AMMRF drives Australia's research excellence.



Through NCRIS funding, we provide Australian researchers access to flagship instruments that are often beyond the scope of individual universities or the ARC.

Our world-class technical staff develop new tools for microscopy. These are available first to Australian researchers, giving them an edge. Some have been commercialised worldwide.

A new tool from the AMMRF at the ANU and UNSW was commercialised by Lithicon AS – sold to FEI for $76 million.

For more on this story, download the AMMRF 2014 *Profile* from ammrf.org.au

ideas boom

Enabling the ideas boom: next-generation research infrastructure

FUTURE MATERIALS

The design and manufacture of innovative materials drives growth as they are used across industries from health to transport and engineering. Relatively simple alloys and oxide ceramics are giving way to to nano-engineered alloys and polymer composites, tougher and lighter than ever.

New aberration-corrected transmission electron and atom probe microscopes will enable design at the nanoscale and refinement of manufacturing processes.

HEALTHCARE REVOLUTION

Data from the 'omics revolution promises better diagnosis and more targeted drugs with fewer side effects. To translate this information into treatments, medical researchers increasingly need to understand how the structure of biological molecules affects their function.

Cryo-electron microscopes will be used to visualise these tiny molecules in their natural state revealing structure–function relationships.

PLANT SCIENCE & FOOD SECURITY

Australia has diverse climates and soils, and unique and fragile ecosystems. Microanalytical techniques help us understand the relationships between complex soils and the plant–fungi symbiosis necessary for nutrient delivery and plant growth.

Advanced microscopy and microanalysis tools will be needed to secure Australian biodiversity and agricultural productivity in the face of increasing environmental challenges.

future focus

Our plan builds on a decade of experience and continues our mission to enable world-class Australian research through leading edge instrumentation and expertise.

Australia's Strategic Science & Research Priorities, our national team and international advisors inform our infrastructure plan.

This 5-year strategic plan enables:

- future areas of Australian research excellence essential to economic growth
- acquisition of next-generation tools to underpin this research
- expert technical staff to support the use of these tools

ATOMIC SCALE MICROSCOPY

Electronics
Chemical processing
Manufacturing
Mining

CRYO-ELECTRON MICROSCOPY

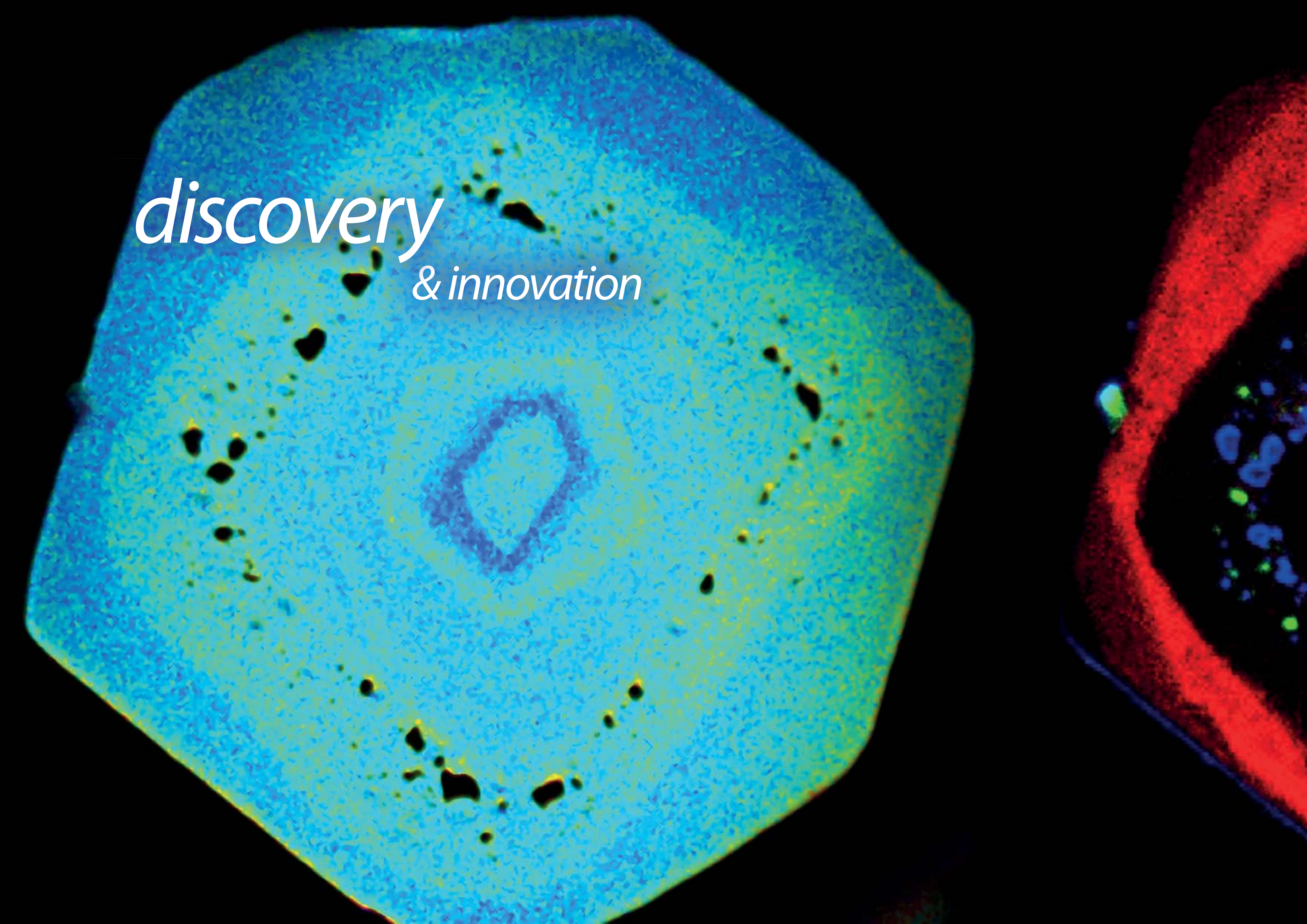
Structural and molecular biology
Medicine
Pharmaceuticals
Polymer science

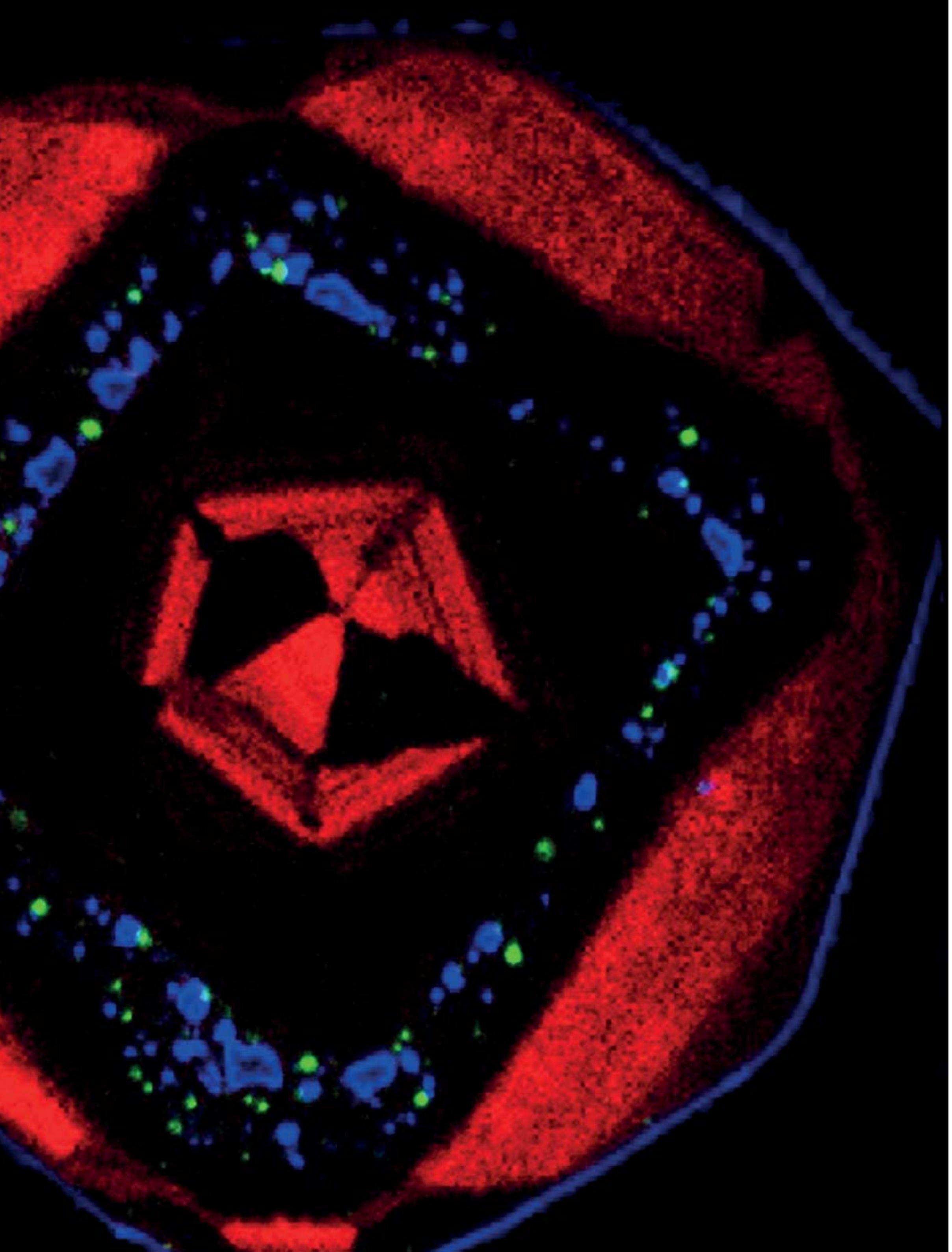
HIGH SENSITIVITY MICRO-ANALYTICAL TOOLS

Sustainable agriculture
Renewable energy
Mining
Cosmology

AMMRF future focus also includes:

- increased industry engagement with support for innovative start-ups
- international engagement to extend access for Australian researchers
- expansion of our world-leading MyScope™ eLearning tools
- addressing emerging challenges in data and informatics


discovery
& innovation



ammrf
Australian Microscopy
& Microanalysis Research Facility

A strong innovation sector brings economic growth. Microscopy infrastructure is essential for discovery and invention across many research disciplines in academia, SMEs and large companies.

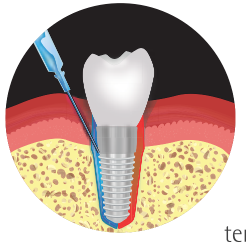
We offer a range of engagement models from fast turnaround testing services to long-term research partnerships.

Our successful model of world-class research staff and instrumentation supports innovation in Australia.

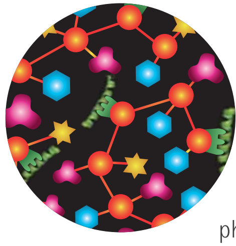
idea to market

Dr Ali Fathi has invented an injectable tissue scaffold to provide implant stability and expedite tissue repair. The invention, enabled by the AMMRF, could reduce post-surgery healing time from eight weeks to two.

Patients typically have many weeks of physical, dietary or other restrictions post surgery, while damaged tissue heals. This Australian invention could significantly reduce recovery time for a variety of procedures – great for patients and for the economy.



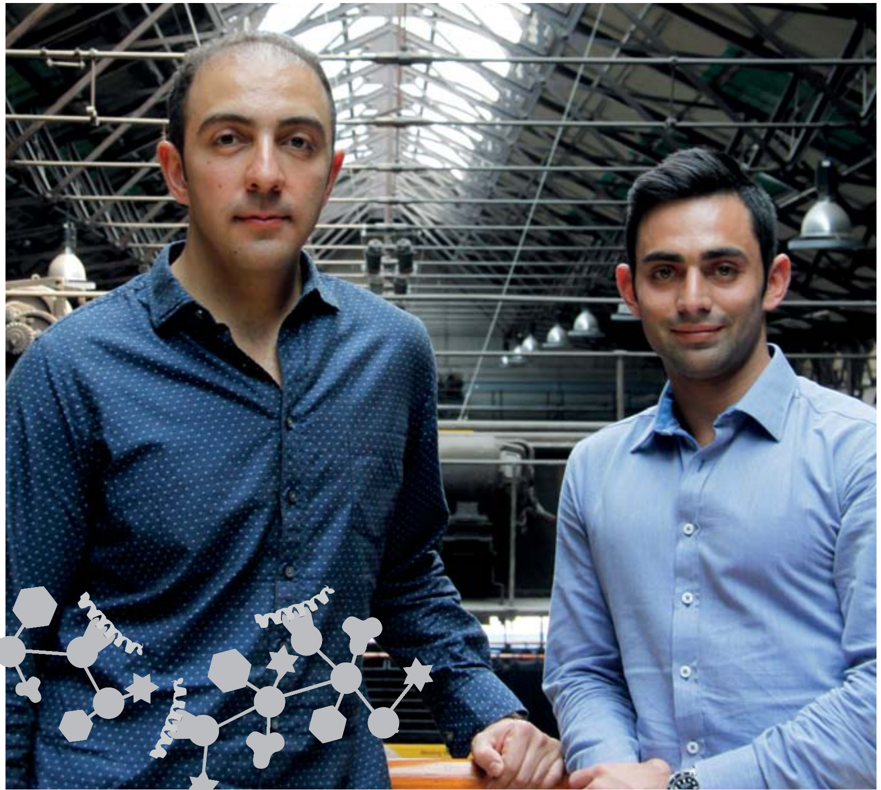
This scaffold, called Trimph, is a liquid at low temperatures, making it easy to inject precisely during surgery. At body temperature it hardens to provide mechanical support. Trimph also contains compounds that signal the body to repair tissues.



Trimph has components that can be customised for a variety of surgical applications. The mechanical and physical properties of the scaffold can be changed to provide different levels of hardness, elasticity or softness, and the compounds carried in the scaffold can be changed to encourage different kinds of tissue to grow. The tissue repair compound can also be targeted to specific tissues.

T R I M P H

TR	I	M	PH	S
temperature-responsive	injectable	modifiable	peptide hydrogel	antiseptic



The entrepreneurial Dr Fathi invented Trimph during his PhD at the University of Sydney.

Excited about its medical potential, Dr Fathi licensed the invention from the University and co-founded Trimph Pty Ltd with Terence Abrams. With capital investment secured to commercialise the product and with the benefit of NSW Health Medical Device Commercialisation training, this exciting startup is based at Cicada Innovations incubator.

Trimph Pty Ltd chose AMMRF instrumentation and expertise to support R&D from early research through to clinical trials.

Trimph products are manufactured in a cleanroom facility in Sydney and protected by patents granted in the US (# pending) and Europe EP (2794701).

ammrf
Australian Microscopy
& Microanalysis Research Facility

Enabling invention from idea to product.

PhD at the University of Sydney, Trimph concept invented

R&D developing scaffold structure
– environmental scanning electron microscopy: to study microstructure of the scaffold in a hydrated state
  – transmission electron microscopy: to test different additives to the scaffold

Pre-clinical testing in cell models
– confocal microscopy: to check that cells had the ability bond and regenerate in the presence of the scaffold

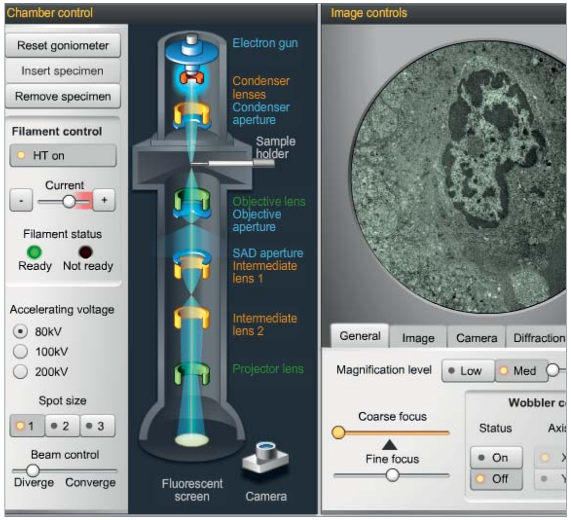
Pre-human testing in animal models
– micro-CT: implants with Trimph were monitored for tissue regeneration over time
  – light microscopy: studied interaction between cells and the scaffold

Clinical trials in humans – expected by the end of 2016.

"Start ups have to be cognisant of where their money is spent. To have organisations like the AMMRF helps with business growth".

Terence Abrams, COO & co-founder of Trimph.

learning innovation



MyScope™ has been shortlisted for the *Best blended learning project* in the international Learning Technologies Awards.

100,000+

online users each year

Our world-leading suite of online tools supports scientific research in Australia and beyond.

my SCOPE™ global research training

MyScope provides tailored, interactive, foundational training online, for researchers who need to use advanced microscopes. This improves efficiency and access to these costly and limited resources.

Testimonials from leading international researchers

"This Australian eLearning platform is unique for its comprehensiveness and integration of... video material, virtual microscopy experience and the opportunities for users to test their own learning progress. In the past years, the MyScope platform has become a (valuable tool) supporting users in basic training, and thereby increasing instrument and staff availability for other advanced training and research. For this reason, MyScope is appreciated by many imaging communities, also outside Australia such as in the UK, Germany and France, where many regular users are located."

Antje Keppler, CEO, Euro-Bioimaging

I've incorporated (MyScope virtual instruments) into various educational seminars that I give to provide outreach to the general scientific population, merging between the life science side and the engineering side of our campus... Longterm I'm going to push for MyScope to be integrated into our short course trainings... I wanted to say thank you for the Australian support for funding the creation of MyScope, because

there's nothing else like it out there and personally, I feel it's a great resource.

Paul Shao, Core Facility Manager at Princeton University

If you would like to hear Paul's full testimonial, open this video link in your browser: https://vimeo.com/191397550

techfi™ technique finder

TechFi™ enables researchers to quickly identify relevant microscopy techniques and experts to address their experimental questions. TechFi is also used in teaching applications.

Try these and more online tools at ammrf.org.au

stem outreach

MyScope Outreach is an e-learning resource for ages 8 years and upwards, freely available to all. It is an interactive multimedia virtual microscopy experience, developed in consultation with science educators in Australia and beyond. Science, Technology, Engineering & Maths (STEM) education is a priority in advanced economies.

This makes the nano-world real … allows us to explore things you wouldn't otherwise see – which adds to the excitement of scientific discovery, and really fuels the enthusiasm for these students

Ryan Sewell high school
science teacher (pictured >)

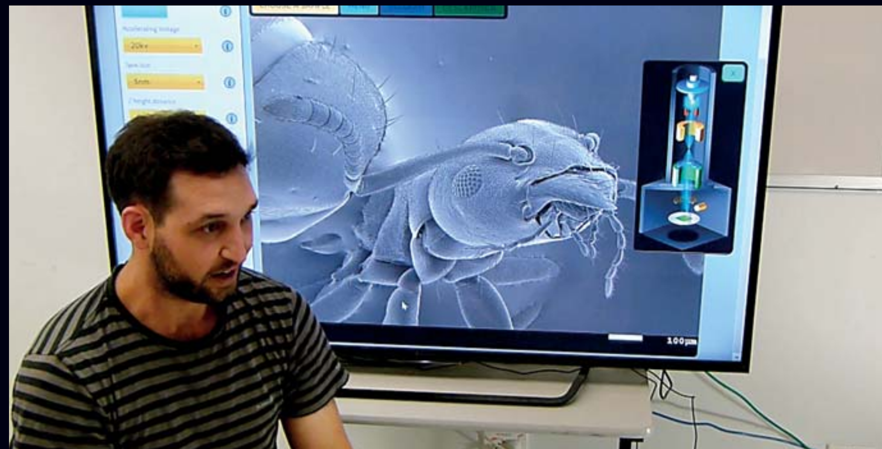
myscopeoutreach.org

myscope™ outreach

MyScope™ Outreach has been shortlisted for the *Best use of simulations* in the international Learning Technologies Awards.*

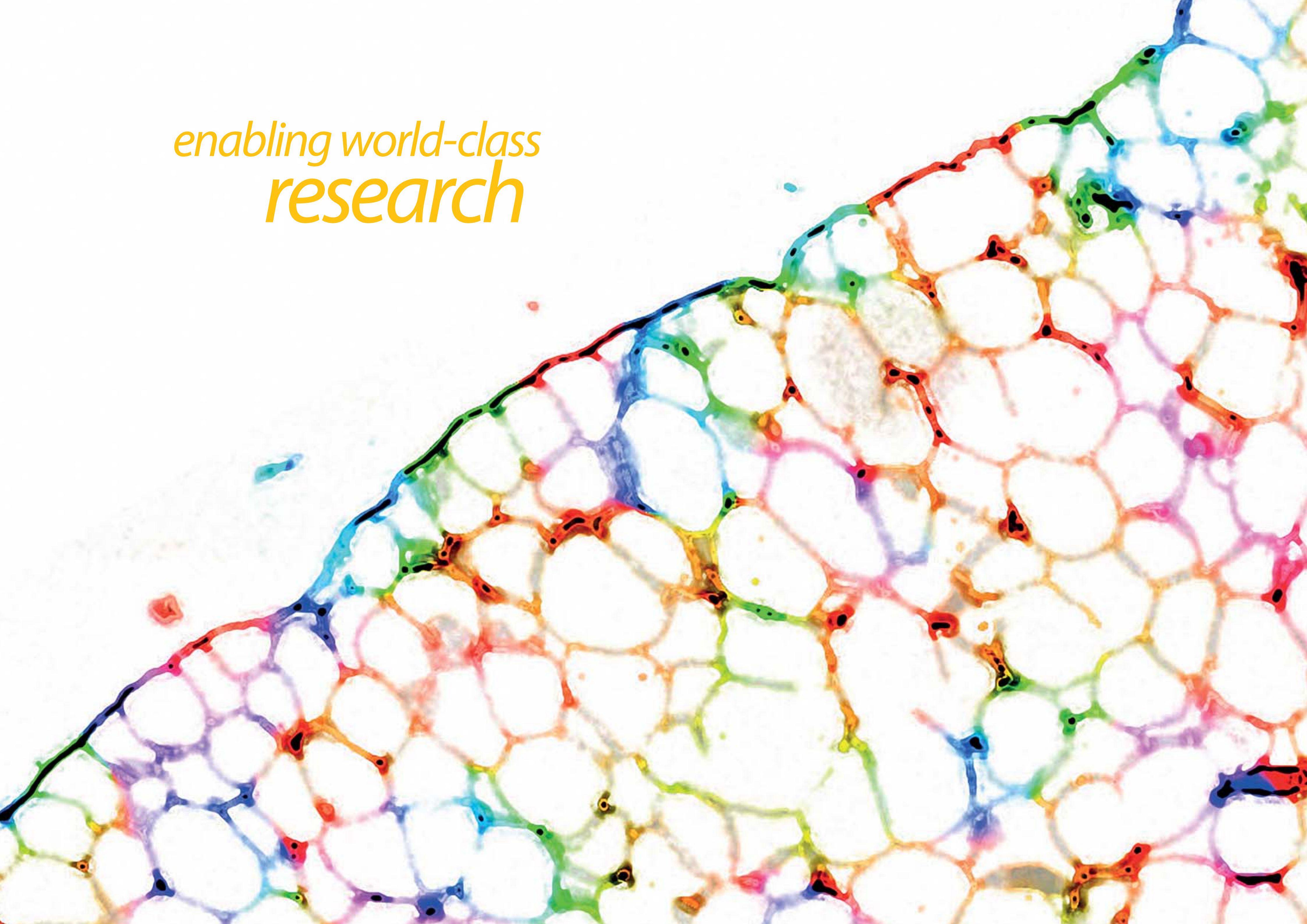
FEI™

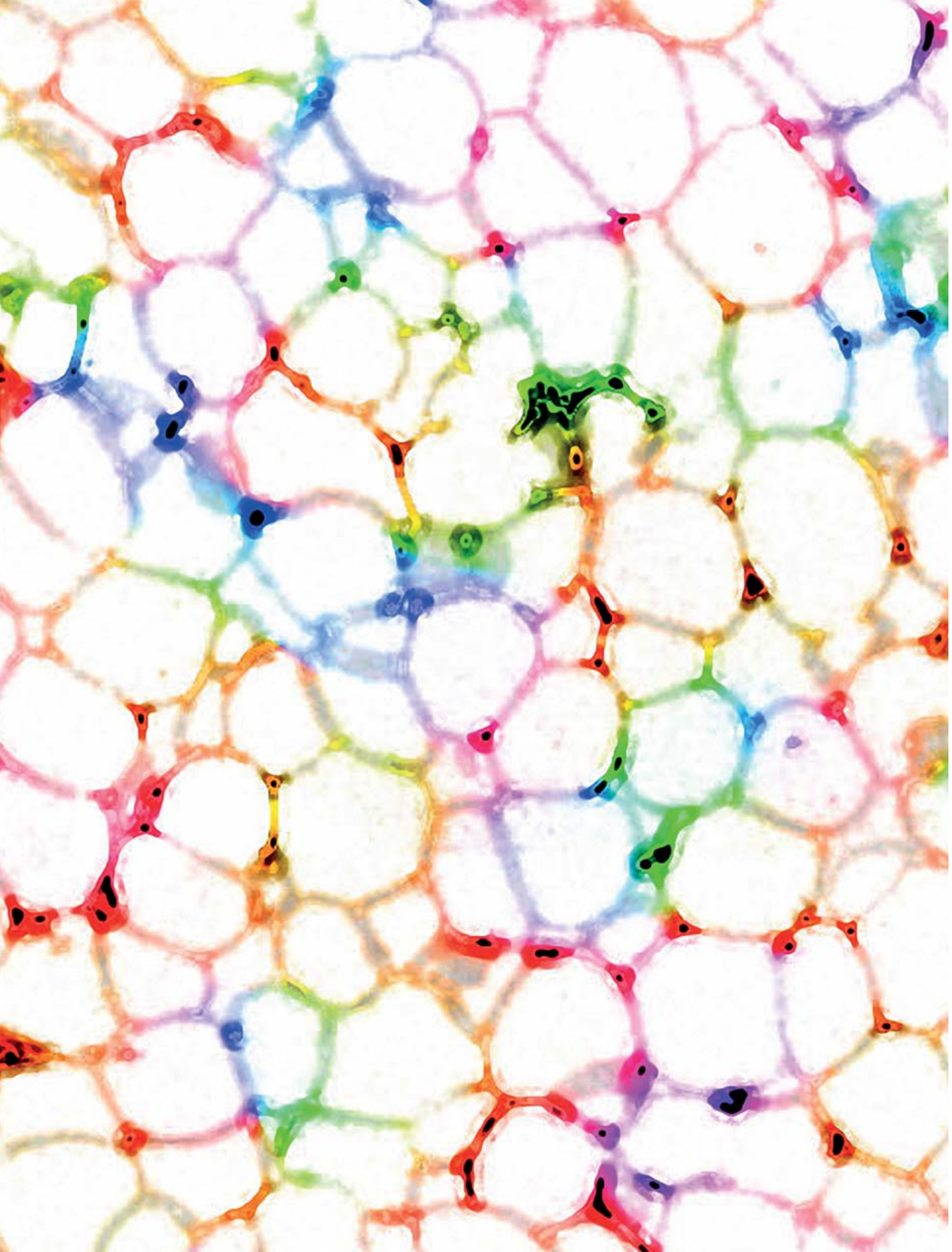
The AMMRF and FEI partnership on MyScope Outreach began with a common goal – to enable young students to experience the nanonscale and learn how science works – inspiring the next generation to find the answers to global challenges. The reaction from teachers and learners has been very positive: try it on a tablet or PC with your budding scientists or watch the video of two primary school children in their first exploration of the virtual SEM samples in this link: https://vimeo.com/190958248



*The winners in all categories will be announced on 30 November – after this book has gone to print, so fingers crossed! www.learningtechnologies.co.uk

enabling world-class research





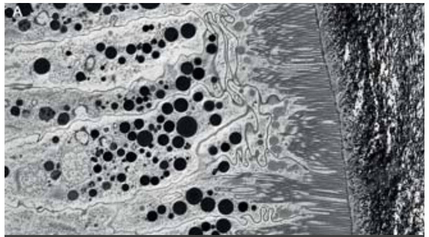
Australian Microscopy & Microanalysis Research Facility

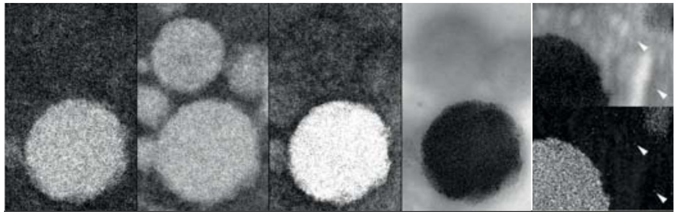
Our instrumentation and expertise extend the range of inspirational and world-class research outcomes from Australian science.

This section illustrates how the research we support is contributing to finding solutions to global challenges. Their alignment to Australia's Strategic Science and Research Priorities is indicated by these icons:

Energy & Resources
Transport
Manufacturing
Food
Health
Soil & Water
Environmental Change

multimodal microscopy

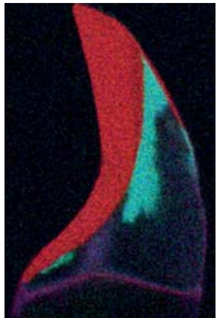

TEM imaging of cells supporting growing teeth

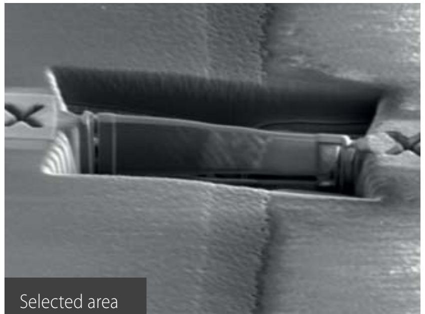

Energy-filtered element mapping in TEM to determine nature of granules

BIOMINERALISATION EXAMPLE: ONE PROJECT, MANY TECHNIQUES

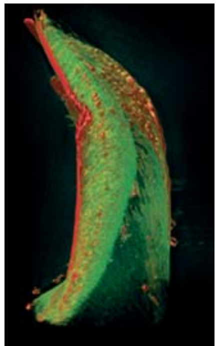
Images from a study by Dr Jeremy Shaw on chiton teeth – a very strong natural composite material.

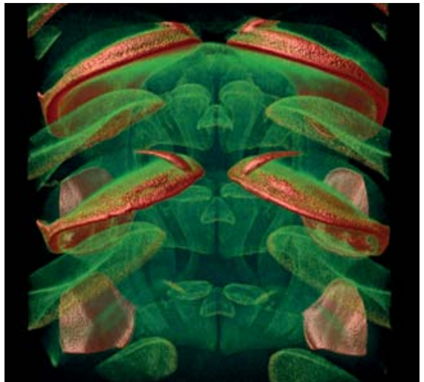
He used transmission electron microscopy (TEM) for structural studies and energy-filtered elemental mapping at high magnification, along with scanning electron microscopy (SEM) and elemental analysis (EDS) at the tissue level. Focused ion beam (FIB) milling was used to extract small slices from selected areas of the tooth for diffraction studies. X-ray nano- and micro-tomography revealed the 3D structure of the teeth. Together these techniques give insights into the process that forms this tough biomineralised, iron-reinforced material at ambient temperatures.


Elemental analysis in SEM showing formation of minerals


Selected area cut out using FIB to be used for diffraction


Diffraction in the TEM to identify mineral structure


X-ray nanotomography for 3D nanostructure


X-ray microtomography for 3D structure of anatomical arrangement

Multimodal microscopy: breakthroughs by combining advanced techniques.

The power to extract complementary information with ever-greater sensitivity, spatial and temporal resolution has made multimodal microscopy increasingly sought after by researchers. The combination of different types of data acquired over different length scales and over time generates deeper understanding and more significant outcomes. This *Profile* contains many examples where multimodal microscopy enabled discovery and innovation.

The collaborative structure of the AMMRF facilitates multimodal microscopy through instrument proximity and the critical mass of expertise available to researchers. This ecosystem is also immensely valuable in developing innovative new instruments, techniques and analysis tools.

Dual- or multi-modal instruments that automatically correlate data from the same region of the same sample are now becoming available. Around the AMMRF, staff work with microscope manufacturers to help develop these emerging technologies. Such integrated instruments are an exciting frontier in microscopy and promise increased efficiency in acquiring highly accurate correlated data.

Complimentary data → deeper understanding of complex systems, materials and processes.

Find more AMMRF-enabled multimodal microscopy research stories on pages 22, 24, 27, 29, 30, 32, 33 and opposite.

multimodal outcome

CHALLENGE

Metals and gases are discharged by volcanoes. Gases, such as SO_2 and HCl, react readily with the volcanic rock below the surface. To learn how deposits, which may be economic to mine, have accumulated in now-extinct volcanoes, we need to understand how these chemical processes work.

SOLUTION

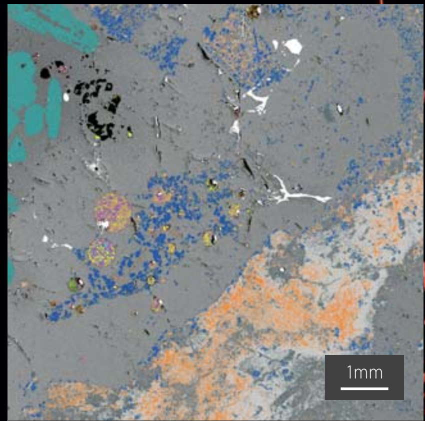
Dr Dick Henley, Dr Penny King and colleagues at the Australian National University (ANU) have combined high temperature experiments with microanalysis in the AMMRF. They identified how highly reactive volcanic gas interacts directly with minerals inside volcanoes. To analyse blocks of rock ejected from extreme fire fountain eruptions they used multi-modal microscopy:

- X-ray microtomography
- QEMSCAN mineral mapping
- elemental analysis in the scanning electron microscope
- laser ablation inductively-coupled mass spectrometry
- and X-ray diffraction

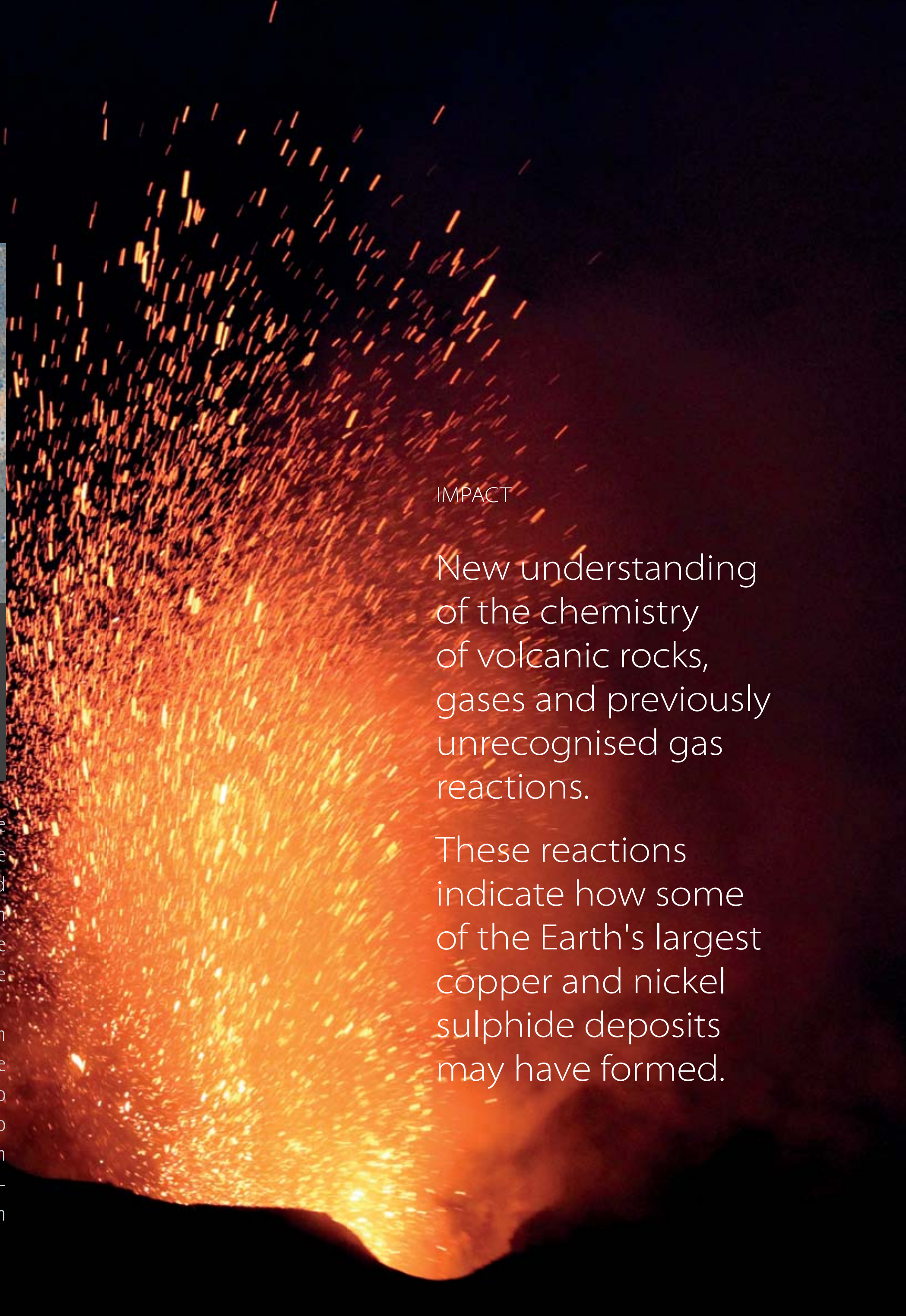
The results reveal a complex natural process of melting, remelting and reactions with gases. These materials have been mapped on a scale and at a resolution not previously achieved.

The map of an ejected volcanic rock from Stromboli, Italy, shows the progressive loss of positively charged ions to leave skeletons of original minerals and a residue of aluminium and silicon oxides trapped inside glass. Tiny spheres of copper-iron sulphide are also scattered through the glass. X-ray microtomography showed the number and distribution of these spheres.

Sulphide globules are very uncommon at Stromboli. Their abundance in these particular rocks is thought to be due to calcium and magnesium ions diffusing to the surface of the glass and reacting with the surrounding gases. The sulphide globules form at the same time as sulphur-rich gas dissolves into the melt.



QEMSCAN mineral map of Stromboli rock showing the round sulphide globules containing low copper pyrrhotite, purple; pyrrhotite, yellow; and high copper pyrrhotite, light blue. The surrounding amorphous glass is grey. The other colours show the presence of a range of original and new minerals within the rock.



IMPACT

New understanding of the chemistry of volcanic rocks, gases and previously unrecognised gas reactions.

These reactions indicate how some of the Earth's largest copper and nickel sulphide deposits may have formed.

SPINNING CARBON INTO SHAPE

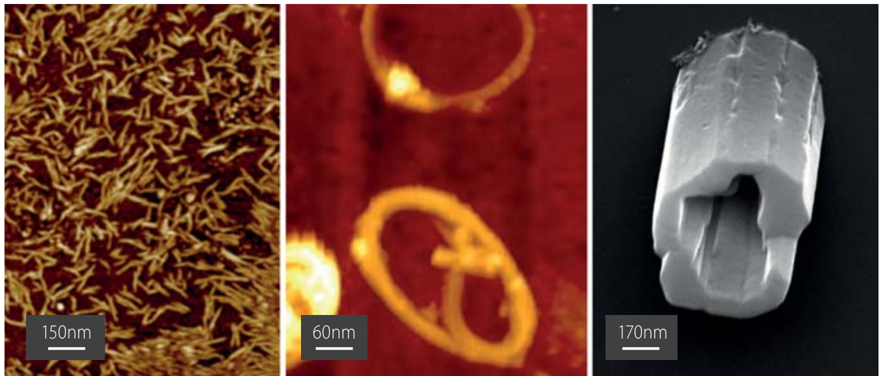
In 2015 Prof. Colin Raston from Flinders University won the Ig Nobel Prize for the development of a 'Vortex Fluidic Device' (VFD) that can unboil an egg. This feat grabbed world headlines and demonstrates a seriously useful invention.

The VFD can be used to refold misshapen proteins, produce biodiesel from waste oils, modify the characteristics of wine and facilitate a range of different chemical transformations. Prof. Raston's group is using the VFD to create carbon nanostructures that could increase the efficiency of solar cells and improve polymer composites, sensing devices, electronics and drug delivery.

PhD student Kasturi Vimalanathan is working with Prof. Raston on these carbon nanostructures, which are made of graphene; single layers of graphite. Single-walled carbon nanotubes (SWCNT) can be cut into specific lengths by using a pulsed laser with various solvents and altered shear forces in the VFD. The VFD can also bend SWCNTs into rings without reactive chemicals or stabilising surfactants. The diameter of the nanorings is controllable; either from 100 to 200 nm or 300 to 700 nm and production can be readily scaled up.

Ms Vimalanathan has also used the VFD to assemble nanoscale carbon spheres, commonly known as buckyballs (C_{60}), into crystalline nanotubules without stabilising agents and without trapping solvent molecules during crystallisation. The VFD efficiently controls the assembly and can form micrometre-length nanotubules with a hollow diameter of 100-400nm.

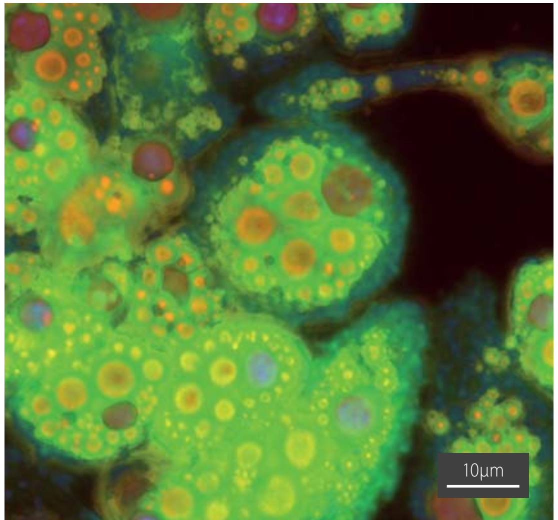
During these manipulations, atomic force microscopy and scanning electron microscopy in the AMMRF at Flinders University were used to visualise and measure the nanoscale products.



Atomic force microscopy shows SWCNT (left), SWCNT rings (centre). Right: SEM image of buckyball tubules.

TARGETING INSULIN RESISTANCE

Type II diabetes is the world's fastest growing chronic disease, and the biggest challenge to Australia's health system. This potentially debilitating metabolic disorder is estimated to cost the nation $14.6 billion per annum.



Cultured fat cells: compound image derived from light, fluorescent and TIRF microscopy and probability mapping. The GLUT4 and TUSC5 at the cell surface are seen as blue-green particles around the edge of the cells.

In a healthy body, when blood glucose is elevated, insulin is released from the pancreas into the blood where it triggers glucose movement into tissues for immediate use as energy or to store for later.

A state described as insulin resistance begins when tissues stop responding to insulin. More insulin is then required to control glucose levels. In some people this increased demand for insulin is not met and Type II diabetes ensues. Although not all insulin resistant individuals develop Type II, insulin resistance itself is a risk factor for diseases such as cancer and neurological disease.

Dr Daniel Fazakerley and Prof. David James at the University of Sydney (UoS) study why and how insulin resistance develops. Insulin triggers the movement of a glucose transporter, GLUT4, from specialised compartments called GLUT4 storage vesicles to the cell membrane where it then carries glucose into the cell.

The researchers used high-end fluorescence imaging techniques in the AMMRF at UoS. They discovered that a protein called TUSC5 resides in the GLUT4 storage vesicles and helps insulin-stimulated GLUT4 translocation to the membrane. Further, they found that TUSC5 was lost in insulin resistance suggesting that it has a role in this condition and could be investigated as a drug target.

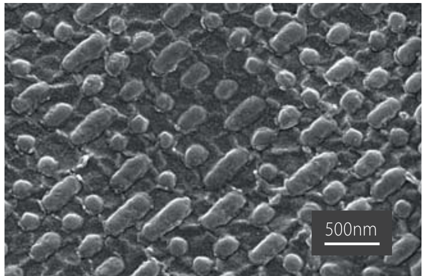
D. Fazakerley et al., 2015, *JBC*, 290 (3)

essential: safer surgery

CHALLENGE

Sutures and staples are standard tools for surgeons but their use can have adverse effects on the patient. The intermittent nature of the connection points allows air and fluid to leak through the wounds, particularly undesirable in procedures involving lungs, blood vessels, brain, intestines and urinary tract. Sutures and staples that remain in the body can cause scarring, adhesions and infection. Continuous strips of biocompatible material that can be securely bonded to tissue would help to avoid these problems.

SOLUTION



Scanning electron microscope image of the chitosan adhesive surface.

A team led by Dr Antonio Lauto at Western Sydney University has developed a biocompatible and suture-less adhesive polymer for wound repair. It is made of chitosan, a linear polysaccharide, derived from the chitin shells of crustaceans. Photochemical bonding to tissue is mediated by a dye called rose bengal. When exposed to a cool laser the rose bengal crosslinks the adhesive to collagen in the tissue, forming a secure bond. There is no thermal or mechanical damage, unlike other laser crosslinking techniques which raise the temperature to around 70°C, burning the tissue.

To make the adhesive even stronger the research team took inspiration from geckos' feet and incorporated nanoscopic bumps on the surface of polymer. This increases the surface area of the adhesive in contact with the tissue, increasing the Van der Waal's forces that hold the two surfaces together.

Dr Rhiannon Kuchel worked with the team using high resolution scanning electron microscopy in the AMMRF at the University of NSW to confirm the repeating pattern of rounded bumps on the polymer surface. Microscopy has also shown less tissue disruption during healing and functional experiments demonstrate better recovery with the chitosan adhesives as compared to sutures and staples. The polymer can also incorporate bioactive compounds that help the adhesive to gradually dissolve over time.

SJ Frost et al., 2016, *NPG Asia Materials* 8, e280; doi:10.1038/am.2016.73. US Patent 9,029,349, 2015

IMPACT

One-step nanofabrication technique produces a gecko-inspired monolayer adhesive that is biocompatible and bonds effectively to tissue.

- secure wound closure, preventing air and fluid leaks after surgery
- easy manufacturing method – mix, pour into mould and dry
- adhesive is patented and licensed to AROA for integration into their wound repair products

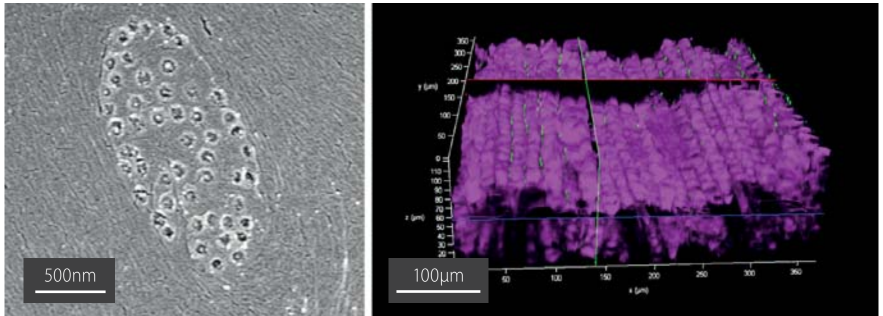
INCREASING FOOD PRODUCTION

Feeding the growing world population is a significant challenge. Maximising how efficiently crops convert carbon dioxide into food would increase production. Food crops use one of two photosynthetic pathways – C3 or C4 – to convert carbon dioxide into carbohydrate in the leaves. Maize and sorghum use C4, while rice and wheat, like most plants, use the less efficient C3 pathway. Integrating C4 components into C3 plants should produce food more quickly while requiring less nitrogen and water.

Florence Danila is investigating differences between these pathways, with Prof. Susanne von Caemmerer at the Australian National University (ANU) and the ARC Centre of Excellence for Translational Photosynthesis in collaboration with CSIRO and the International Rice Research Institute (IRRI) in the Philippines.

Plasmodesmata are very small structures in leaf cell membranes: more than 25,000 would fit across the diameter of a human hair. They enable metabolite transport between leaf cells and appear to affect photosynthetic efficiency. Counting plasmodesmata has been difficult because traditional 2D transmission electron microscopy (TEM) cannot capture the randomly distributed plasmodesmata in a single image.

Ms Danila combined scanning electron microscopy (SEM), carried out in the AMMRF at ANU, with 3D immunolocalisation by confocal microscopy. Her subsequent visualisation of the 3D distribution of plasmodesmata revealed that C4 leaves have up to nine-fold more plasmodesmata than C3 leaves. This could be helping C4 plants to achieve their high photosynthetic efficiency. This data is essential for developing strategies to introduce aspects of C4 photosynthesis to C3 food crops.



Zea mays leaf. Left: SEM image of a cluster of plasmodesmata, called a pitfield.
Right: 3D confocal image of intact tissue showing pitfields (green) within cell walls (magenta)

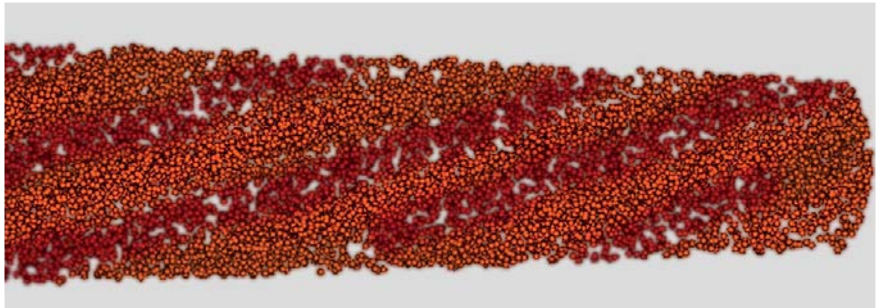
F. Danila et al., 2016 *The Plant Cell* June 10.

NANOSCALE TOOTH ENAMEL

We are all very familiar with our tooth enamel and how damaging tooth decay can be. Tooth enamel is a very tough material – the hardest in the body, and its nanoscale structure is extremely intricate. It is a biocomposite with 96 percent mineral phase, one percent enamel proteins and three percent water. This leads to a unique combination of strength and fatigue resistance. The mineral is hydroxyapatite (HAP) organized into orderly bundles of nanowires. It is known that magnesium ions regulate HAP crystallisation by stabilising its precursor, amorphous calcium phosphate (ACP). Knowledge of the atomic-scale distribution of Mg ions within the precursor ACP in mature human dental enamel would provide much needed information for a better understanding of enamel formation.

Dr Alex La Fontaine and Prof. Julie Cairney from the University of Sydney have used atom probe tomography to produce the first-ever three-dimensional positional maps of the atoms. These are the first direct observations of a Mg-rich ACP phase between the HAP nanowires in mature human dental enamel. The research team also observed Mg-rich elongated precipitates and pockets of organic material among the HAP nanowires.

Because the Mg-ACP phase at the enamel boundaries is susceptible to dissolving in acidic environments, the researchers propose that decay occurs via dissolution along the enamel rod boundaries. This knowledge will inform further research to develop strategies to enhance remineralisation, slow the progression of or prevent caries, or even restore lost dental enamel.



Atom probe data showing the regular arrangement of increased Mg concentration throughout the enamel.
Length of sample approx: 350 nm

A. La Fontaine et al., 2016, *Science Advances*, 2 : e1601145

essential: electronics

CHALLENGE

The race is on to discover the secret properties of materials at the nanoscale and harness them for the development of new technologies. a (Ga) is used in electronics and circuits involving microwaves, infrared and high-speed switching. In its ordinary 'bulk' form it is a soft, silvery bluish metal that melts at 30°C and becomes hard and brittle at sub-zero temperatures. But how does it behave at the nanoscale?

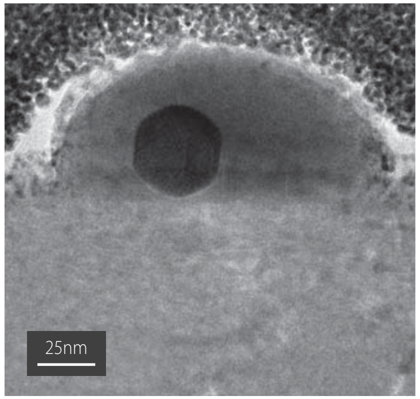
A/Prof.Nicola Gaston from the University of Auckland says "...the TEM images alone are reason enough for excitement. Interfaces buried in the interiors of metal nanoparticles are both notoriously difficult and important to study. This is the first (confirmation of) theoretical predictions that Ga's solid–liquid interfaces are not atomically abrupt but roughly four atoms thick. The quality of the experimental images is fantastic."

SOLUTION

By experimenting with gallium nanoparticles, an international team of researchers, including Dr Alexandra Suvorova at the University of Western Australia (UWA) observed for the first time the coexistence a solid and a liquid phase of the same material at the nanoscale. When gallium nanoparticles sit on a sapphire surface, they form a solid core surrounded by a liquid outer layer (image, top right). This arrangement stays stable even over a temperature range of more than 600°C. Dr Suvorova visualised this highly unusual phenomenon with transmission electron microscopy in the AMMRF at UWA. The expertise involved in this visualisation has been recognised in *Physics Today*.

The coexistence of a liquid and solid state has been predicted theoretically, and observed indirectly only in narrow temperature ranges. With this new finding, phase diagrams can be developed to plot how these materials behave at the nanoscale.

Maria Losurdo, et al., 2016 *Nature Materials*, DOI: 10.1038/nmat4705



<< The black sphere in the centre is solid gallium within within a liquid drop, atop a sapphire base. The sapphire base is rigid with a relatively high surface energy. As the nanoparticle and sapphire try to minimise their total energy, this combination of properties drives the formation and coexistence of the two phases.

Dr Alexandra Suvorova,
AMMRF at UWA

IMPACT

Useful in ultraviolet sensors, molecular sensing devices and enhanced photodetectors.

"(We) need to reconsider all our presumptions about solid–liquid equilibrium. At a more applied level, the results hold much promise for future nanotechnology applications."

News and Views, Nature Materials

BIRTH OF BLOOD CELLS

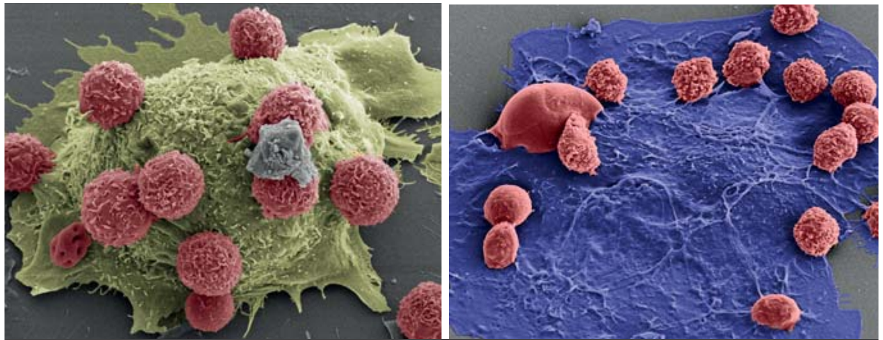
Red blood cells (RBCs) transport oxygen and carbon dioxide around the body. Understanding how they normally develop can help find effective treatments for the many diseases of RBC development and functioning. RBCs develop in the bone marrow in cell clusters called erythropoietic islands. Prof. Stuart Fraser from the University of Sydney (UoS) has been studying the relationship of island structure to the development of RBCs.

Different proteins are present on the surfaces of RBCs at different stages of their development. These proteins can be labeled to identify the developmental stage of any particular cell. By attaching tiny gold nanospheres in turn to each of the unique molecules it is possible to determine the developmental stage of the RBCs.

Prof. Fraser has used the imaging capability of the scanning electron microscope (SEM) in the AMMRF at UoS that shows a much lighter shade of grey for heavy elements, like gold, enabling clear visualisation of the gold-labelled proteins. His labeling experiments revealed that two distinct types of islands were present in the bone marrow. Each island has a central cell called a macrophage surrounded by the developing RBCs. Islands with a domed macrophage appear to be a niche for the earlier stages of differentiation whereas the flat islands appear to support later stages of RBC development and their eventual release into the blood.

This new understanding of RBC developmental processes will help interpret the errors that occur in RBC diseases.

J. Yeo et al., 2016, *Microsc. Microanal.* 22.



SEM images of the domed (left) and flat (right) EBIs. The developing red blood cells are about 5µm in diameter.

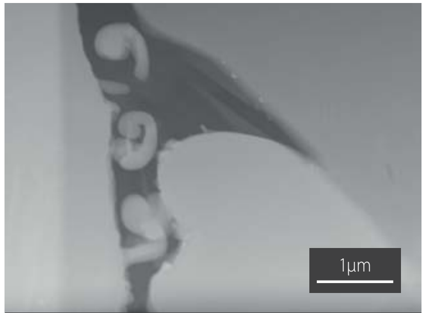
HEAVEN ON EARTH

Dozens of rare minerals, some entirely new, others only previously reported in meteorites, have now been discovered on Earth. The AMMRF at the University of Western Australia (UWA) and the University of NSW (UNSW) has helped researchers from the ARC Centre of Excellence for Core to Crust Fluid Systems at Macquarie University (MU) confirm the identity of these exotic minerals. This is a collaborative research project with Israeli gemstone mining and exploration company, Shefa Yamim, lead by Prof. Bill Griffin at MU.

Prof. Griffin's team found the rare minerals trapped inside melt pockets in aggregates of corundum (aluminium oxide) crystals ejected from Cretaceous volcanoes on Mt Carmel, North Israel. The flagship focused ion beam in the AMMRF at UNSW was used to extract ultra-thin samples of mineral from precise locations within this complex material. Then the AMMRF at UWA used transmission electron microscopy to identify the minerals by analysing their crystal structure and chemistry.

One of the minerals is tistarite (Ti_2O_3), previously known only as a single grain in the Allende carbonaceous chondrite meteorite. This is believed to have formed as high-temperature molten material condensed during the nebula stage of solar system evolution when oxygen availability was low. Other 'nebular' minerals from Mt Carmel include silicon carbide, grossite, hibonite, osbornite, gupeiite and wassonite, all typically found in carbonaceous chondrite meteorites. The research shows that similar conditions existed in the Cretaceous upper mantle beneath Mt Carmel. They also reveal mantle environments and parts of the global carbon cycle that were previously unrecognised.

WL Griffin et al., 2016, *Geology* 44(10).



A high angle annular dark field scanning transmission electron micrograph of the sample.

An electron diffraction pattern used to identify the crystal structure of tistarite.

muscle health

CHALLENGE

Finding effective treatments for genetic disease is a long but essential process. A range of muscle diseases, including some muscular dystrophies, are caused by mutations in genes controlling the formation of caveolae. Caveolae are nanoscale pits on the surface of muscle cells.

Evidence accumulating from Prof. Rob Parton's research at the University of Queensland (UQ), suggests that these caveolae could act as a reservoir of extra membrane to ease tension when the cell surface is stretched. This hypothesis was put to the test.

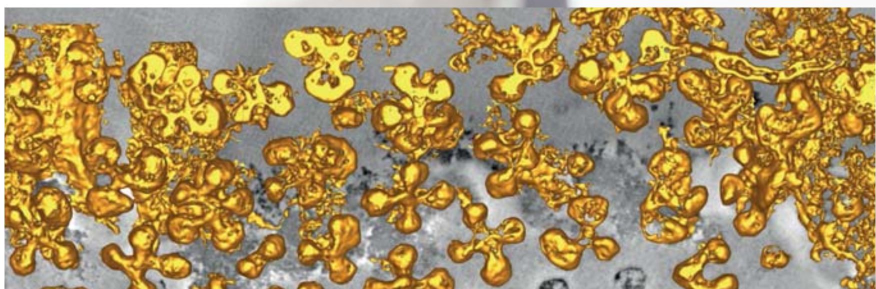
SOLUTION

Dr Harriet Lo, working with Prof. Parton, compared muscle cells from normal mice to those from mice genetically modified to prevent caveloae formation through the deletion of the *cavin-1* gene. By using 3D electron microscopy in the AMMRF at UQ she found that caveolae occupied around 50% of the normal muscle cell surface and were predominantly assembled into multi-lobed rosettes. Increased membrane tension caused these rosettes to disassemble. Muscle fibres lacking caveolae showed a loss of cell membrane organisation, abnormal internal tubules, and increased sensitivity to membrane tension. This was all overcome when the *cavin-1* gene was added back into the muscle cells of the mutant mice.

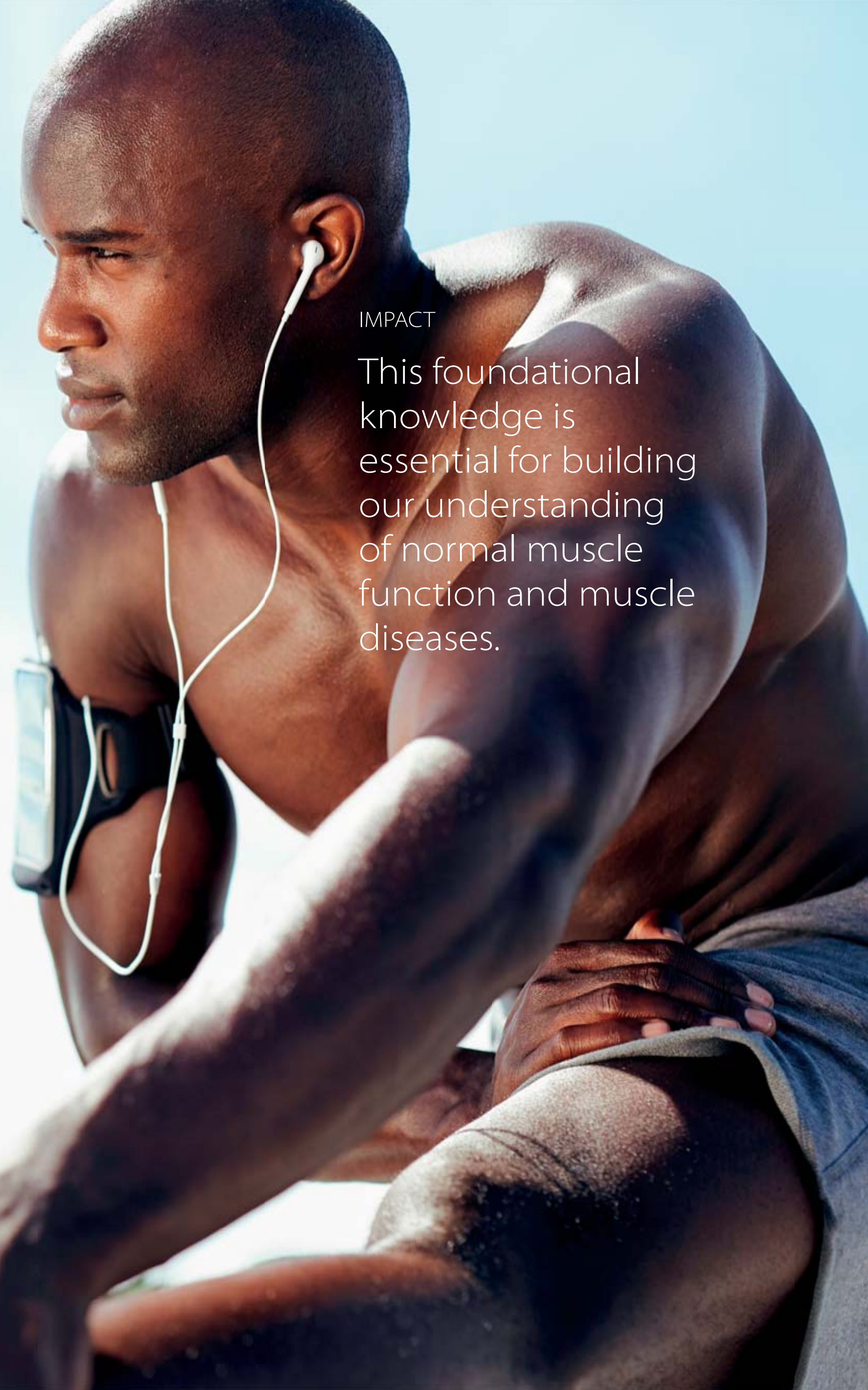
Following this, the team imaged living zebrafish embryos. In these embryos, disruption of caveolae led to cell membrane damage but only after vigorous muscle activity. It also seems likely that caveolae play a part in muscle repair.

Taken together their results demonstrate that caveolae, and the genes that produce them, are key to an inbuilt muscle protection system.

H. Lo et al., 2015, *Journal of Cell Biology* 210 (5).



Surface-rendered reconstructions of caveolar rosettes in normal muscle fibres. Each caveola is approximately 50 nanometres in diameter.



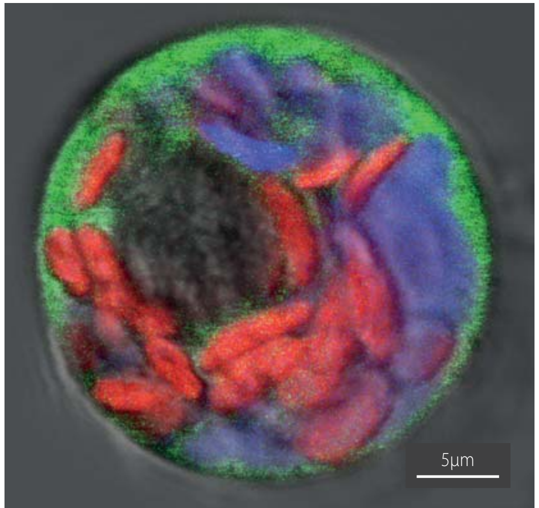
IMPACT

This foundational knowledge is essential for building our understanding of normal muscle function and muscle diseases.

A BUST FOR WHEAT RUST

Wheat stem rust is a very important disease of wheat with severe epidemics causing heavy crop losses. It is caused by the fungus *Puccinia graminis* fsp *tritici* and is combated mainly through the breeding of disease-resistant wheat. Recently, major epidemics of resistant rust strains have devastated Africa. Global wheat production is also under threat due to potential long-range dispersal of fungal spores. Consequently breeders and researchers are seeking new sources of genetic resistance to stem rust to protect worldwide wheat crops.

Currently little is known about how resistance genes work. Drs Stella Cesari and Peter Dodds at CSIRO Agriculture and Food have been investigating two stem rust resistance genes that provide protection against the current devastating rust strains. These genes encode receptor proteins that recognise fungi, including *P. graminis*, and induce plant immune responses. Working with staff in the AMMRF at the Australian National University, the researchers determined that these receptors function in the cytoplasm of the wheat leaf cells. They initiate a signaling pathway of other molecules that ultimately leads to a change in the protein profile of the cells and to cell death.



Fluorescently tagged receptor protein (green) occurs in the cytoplasm of wheat leaf cells but not the nucleus (N), chloroplast (red) or vacuole (blue).

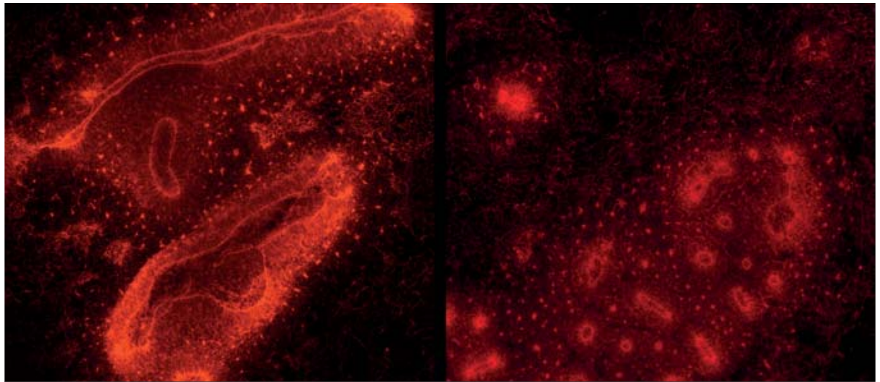
Rust fungi need living plant cells for their survival and propagation so if the plant can sacrifice its infected cells quickly it has a chance of stopping the rust infection before it can spread.

Understanding the complexity of wheat resistance signaling pathways will improve strategies to utilise natural plant immunity systems in protecting wheat and other crops from disease.

S. Cesari et al., 2016 *PNAS* Sep 6;113(36).

THE X-FACTOR IN EPILEPSY

Patients with a female-specific epilepsy called PCDH19-Girls Clustering Epilepsy have a spectrum of neurodevelopmental and behavioural problems. The disorder is caused by mutations in a gene on the X-chromosome called *Protocadherin 19 (PCDH19)*. The random inactivation of one of the two X chromosomes in each of the patient's brain cells leads to a mosaic of healthy and unhealthy cells.



Fluorescence microscopy image showing altered structures formed by iPSCs from human cells containing a normal copy of the *Pcdh19* gene, left, and cells with a disease-causing version of *Pcdh19*, right.

PhD student Claire Homan at the University of Adelaide (UoA) used two different models to learn how the mutant gene affects brain development. She first extracted neural stem cells from the cortex of a mouse lacking the *Pcdh19* gene. These experiments found that *Pcdh19* helps developing nerve cells move to the right place in the brain and then to turn into the appropriate types of brain cells.

Ms Homan then established a human model of PCDH19-GCE. She extracted skin cells from patients with the disorder and reprogrammed them into induced pluripotent stem cells (iPSCs). She then compared normal iPSCs with those from the PCDH19-GCE patients in a cell culture model of human cortical brain development. Immunofluorescence microscopy in the AMMRF at the UoA was used to identify and measure morphological and gene activity changes in the two cell types as they developed into brain-like structures.

Data showed that when the PCDH19 protein is absent, cells cannot form correctly oriented structures during early brain development. This could cause long-term changes to brain architecture and contribute to the disorder's pathogenesis.

essential: safer hospitals

CHALLENGE

Secondary infections are a serious and potentially fatal complication for hospital patients. The emergence of multi-resistant bacteria or 'superbugs' makes this problem even more dangerous. Silver and copper are currently used to convey antibacterial properties to fabrics and other surfaces. However, these leach out relatively quickly, reducing the protective effect and potentially polluting the environment. While metal nanoparticles can overcome some of these limitations, they sit on the surface of the fibres and gradually wear away with repeated laundering. In current wound dressings, antibacterial silver ions can leach into the wound and damage the patient's own tissue. A better solution is needed.

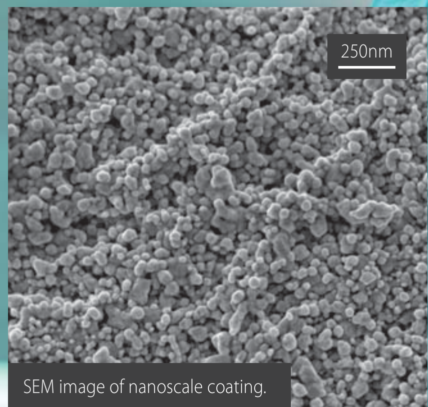
SOLUTION

Dr Rajesh Ramanathan and Prof. Vipul Bansal at RMIT, have been working with copper- and silver-based nanostructured fabrics, for their ability to degrade many organic molecules.

The researchers have developed a straightforward and efficient method to grow nanostructured silver and copper directly onto cotton fabric to create antibacterial textiles. They use tiniest amounts of palladium and tin catalysts that create a much stronger bond between the metal and the fabric, which reduces leaching of metals into the environment during washing. This coated fabric is ideal for hospital textiles like sheets and gowns. Improved wound dressings would protect against bacteria while reducing metal toxicity to the patient.

The team used scanning electron microscopy (SEM) and elemental analysis in the AMMRF linked lab at RMIT to characterise and monitor the production and action of their materials. The metal coating absorbs visible light, which enhances the chemical reactions that break down organic molecules into carbon dioxide and water. Although the process works in the dark, a good blast of sunshine speeds it up. The copper-coated fabric showed faster catalytic activity: three minutes in the light to completely degrade the test molecules whereas the silver-coated fabric was slower at 30 minutes but was more robust over time. The researchers have started testing their fabrics on bacteria with some very encouraging results.

Another application of these metal-coated fabrics is self-cleaning clothes. Imagine hanging out your clothes and have the dirt and grime break down and blow away.



SEM image of nanoscale coating.

S. Anderson et al., 2016, *Advanced Materials Interfaces*, 3 DOI: 10.1002/admi.201500632.

IMPACT

The researchers are in discussion with potential commercial partners to take their innovation to market. New catalytic fabrics that kill bacteria and remove grime from clothes could:

- reduce hospital acquired infections
- enhance wound healing
- save energy and water consumption by reducing laundry loads
- generate new businesses for Australia

GREENER SOLAR

Solar light absorbed and converted to electricity through a photovoltaic device is an attractive source of renewable energy. Solar cells made from earth-abundant, non-toxic raw materials would make solar even cleaner, more cost-effective, scalable and sustainable.

Copper-Zinc-Tin-Sulphide (Cu_2ZnSnS_4), also known as CZTS, is a very promising eco-friendly photovoltaic due to its abundant and nontoxic constituents, and because its band gap is well matched to the solar spectrum. However, its energy conversion efficiency is still significantly lower than its theoretical limit. One of the key problems is sub-optimal nanoscale structure and chemistry of the interface between the energy-absorbing CZTS layer and the adjacent cadmium sulphide layer. Electron flow across this interface generates the electrical current. The structure and chemistry of this interface varies depending on the "cooking atmosphere" during production. Dr Xiaojing Hao at the University of NSW (UNSW) is working to optimise production of CZTS photovoltaics.

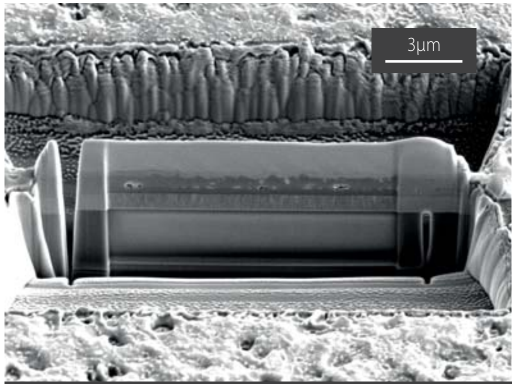


Image from the focussed ion beam instrument showing a thin section being cut from the layered CZTS material.

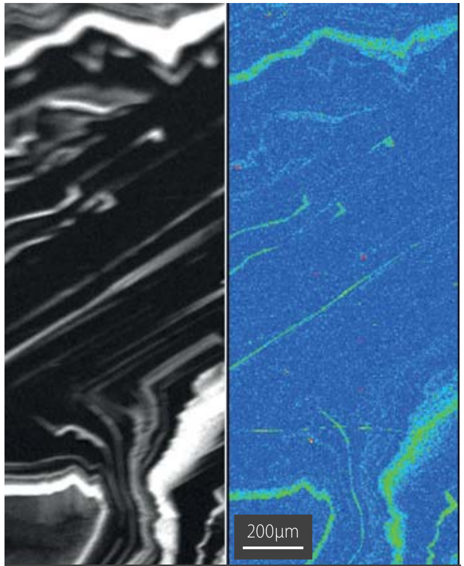
She used the flagship focused ion beam in the AMMRF at UNSW to prepare ultrathin samples of the interface region for aberration-corrected high-resolution transmission electron microscopy and elemental analysis. Results showed that mono-tin sulphide (SnS) and sulphur gas used together during production led to more structurally consistent and favorable CZTS surface. When sulphur gas alone was used unwanted small grains were present on the surface, which disappeared when SnS was included.

By correlating the microstructure with device performance, they found that controlling the "cooking gas" determined the behaviour and interaction of the precursor components; crucial for realising high efficiency CZTS solar cells.

Liu F., et al., *Advanced Energy Materials*, 2016, DOI: 10.1002/aenm.201600706.

EXPLORATION CLUES IN QUARTZ

The Cobar Basin in central NSW is one of Australia's most diverse and prolific mining regions including pre-mining reserves of >2.2 million tonnes copper, >7.0 million ounces of gold, >4.7 million tonnes of zinc, >2.8 million tonnes of lead, and 145 million ounces of silver.



Quartz grain showing correlation between the cathodoluminescence map (left), which locates defects in the crystal lattice and the electron probe microanalyser image (right) showing bands of aluminium (green = higher concentration, blue = low concentration).

Quartz can co-crystallise with silver-, lead- and zinc-bearing minerals in the Cobar basin suggesting that similar source fluids form the quartz and the economic minerals. Deciphering the source and compositions of mineralising fluids and the conditions for crystal growth could aid the discovery of similar economic deposits within the Cobar Basin. Geologists Angela Lay and Stephen Harris, working with Dr Elena Belousova at Macquarie University (MU) are investigating.

AMMRF staff and collaborators at the University of NSW (UNSW) and the University of Western Australia joined the MU researchers for a range of characterisation techniques, and ANSTO staff for neutron-based characterisation.

By combining techniques that identify the localised composition, trace element localisation and dates of mineral formation, the researchers have begun to unravel the complex geological history of these quartz crystals and, by extension, the genesis of the deposit itself. Preliminary trace element mapping revealed remarkable aluminium-impurity banding within the crystals, different from the usual aluminium-banding patterns within quartz reported for other deposits around the world.

This work will have a direct bearing on future exploration and exploitation of economically important mineral deposits in NSW.

inner space VR

CHALLENGE

3D visualisations make it far easier to conceive the relative positions of components in the nanolandscapes of cells and molecules. To take real 3D microscope data and combine it with virtual reality (VR) technology could help researchers make new discoveries by seeing cellular structures and processes in a new and more tangible way. This in turn could lead to new insights and 'eureka moments'.

SOLUTION

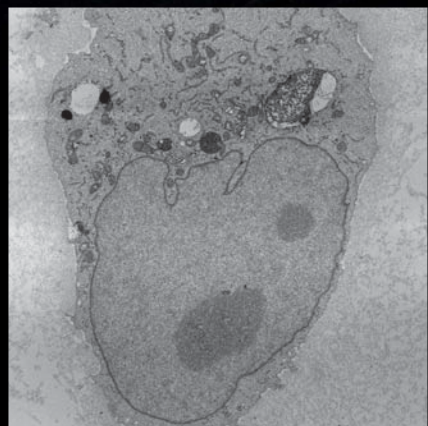
Collaboration:

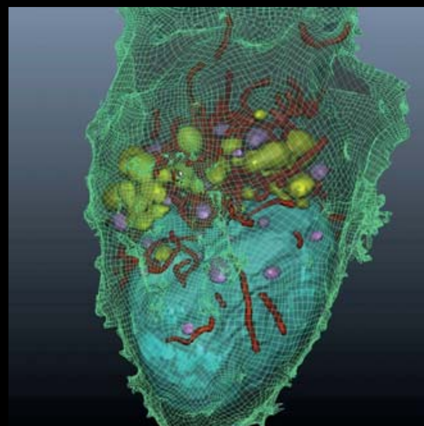
- Prof. Rob Parton and Dr Rick Webb/ AMMRF, University of Queensland (UQ),
- John Bailey/ARC Centre for Excellence in Convergent Bio-Nano Science & Technology
- Dr John McGhee/3D Visualisation Aesthetics Lab, University of NSW
- Dr Angus Johnson/Monash University.

This Australian team developed *Journey to the Centre of the Cell* using high-resolution electron-microscope data from the AMMRF at UQ to reconstruct a human breast cancer cell in digital 3D. The result is an immersive, interactive VR experience.

By wearing VR headsets scientists can navigate the 'landscape' of the cell – including the nucleus, mitochondria and endosomes. The visualisation aims to speed up the science discovery process by showing how nanoparticle drugs are absorbed by cancer cells. Researchers find it extremely useful to be able to walk around the cell, put their head inside a mitochondrion and have a look around. It also opens up the possibility of taking molecules that are mutated in different forms of cancer and putting them in the context of a virtual reality cell, so researchers can watch how they work.

Dr Johnson is focusing on how to deliver drugs inside tiny nanoparticles. He is using the VR cell to help improve delivery by finding ways to direct these nanoparticles to precise locations within the cell.





IMPACT

Improved understanding for scientists, students and patients.

More effective use of 3D data

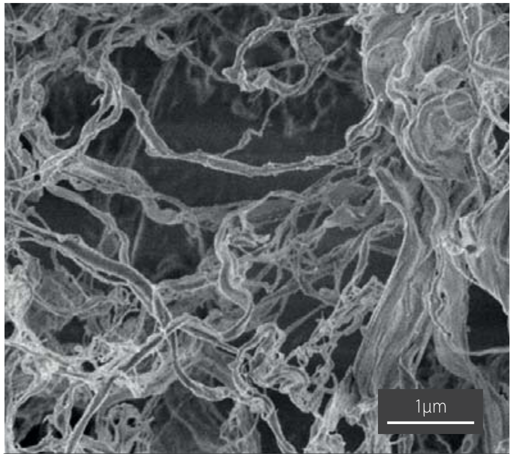
Great for science education: featured on *Catalyst*, in *New Scientist* and in the Fairfax press.

Nominated for a prestigious award: *Unity3D Best VizSim*

GREEN CARBON NANOFIBRES

Carbon nanofibres are a new class of engineering materials with excellent mechanical and electrical properties. They are suitable for wide-ranging applications including electronics, batteries, polymer-composites and medical science.

In order to realise the commercial success of these applications, it is important that carbon nanofibre production is scalable to several thousand tonnes



Scanning electron micrographs of carbon nanofibres derived from plant-based cellulose nanofibres.

per annum, inexpensive and has minimal impact on the environment.

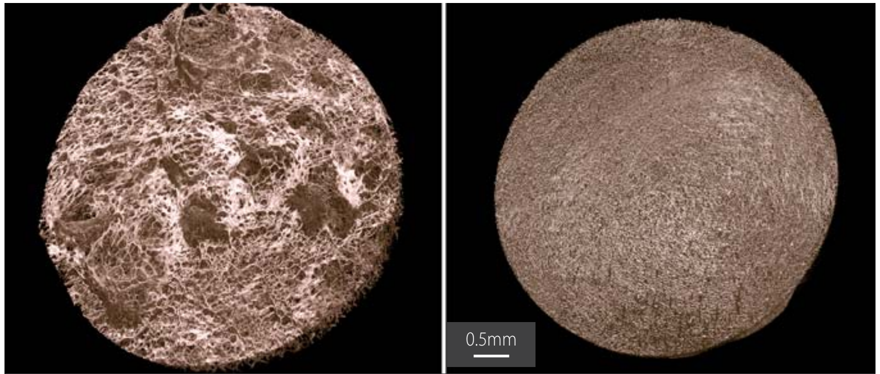
At present, most of carbon nanofibres are produced by chemical vapour deposition using petrol-derived precursors. This production process suffers from high costs, high levels of catalyst residue contaminating the end product, use of hazardous chemicals, difficulty in scale-up, and significant levels of carbon-dioxide emissions.

A/Prof. Takuya Tsuzuki's group at the Australian National University (ANU) has been working towards more sustainable manufacturing process for carbon nanofibres. His group demonstrated that renewable raw materials, such as plant-derived cellulose, can be converted into polymer nanofibres. They use a scalable green mechanochemical process and the pyrolysis of cellulose nanofibres to form the carbon nanofibres.

This study was enabled by the AMMRF at ANU, where scanning electron microscopy, transmission electron microscopy and elemental analysis were used to investigate the structure, crystallinity and purity of these 'green' carbon nanofibres. The optimisation of eco-friendly, scalable carbon nanofibre production will underpin improvements in lightweight structural composites, solar cell and battery technologies.

THE FUTURE IS ELASTIC

Elastin is a crucial building block in our bodies – it is a flexible and durable protein network that allows skin to stretch and twist, blood vessels to expand and relax with every heartbeat, and lungs to swell and contract with each breath. It is known to consist of tropoelastin molecules strung together in a chain, but how does such a flexible protein keep its defined structure and yet still deform and reform so consistently?



Colour-enhanced X-ray microtomography images of normal (left) and modified (right) elastin networks.

An international team of researchers lead by Prof. Tony Weiss at the University of Sydney (UoS) has now discovered the hierarchical structure of elastin. They used a wide range of characterisation techniques in the AMMRF at UoS including scanning electron microscopy, X-ray microtomography, and confocal microscopy. They examined normal and modified tropoelastin proteins and combined this data with modelling information by collaborators. They found that two-pronged appendages of one tropoelastin molecule naturally lock onto the narrow end of another molecule. This process continues, building up long, chain-like structures. These long chains weave together to produce the flexible elastin.

By determining the structures across different scales the team could predict the dynamics of the molecule. The typical movements of the molecule are controlled by the structure of key local regions working within the overall shape of the molecule.

This discovery of the structure and assembly processes of the tropoelastin molecules will inform the design of advanced materials. Possible applications include bio-compatible materials to replace damaged body parts or durable materials for engineering.

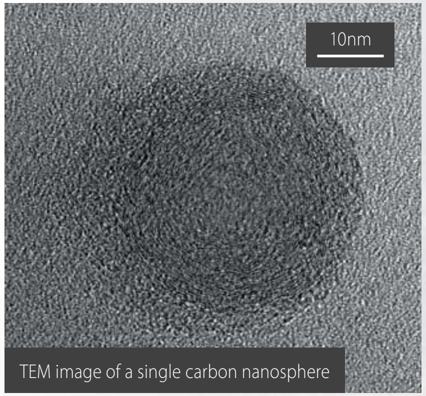
Yeo et al., 2016 *Sci. Adv.*, 2 : e1501145 essential: environment

CHALLENGE

Black carbon particles come from incomplete combustion of any kind - bush fires, coal plants, and diesel engines are all big emitters. These particles are very dynamic in the atmosphere and can have a substantial effect on climate by absorbing heat and potentially forming cloud droplets. Black carbon nanoparticles are transported in the atmosphere and deposited at the poles, becoming incorporated into the polar ice. They affect atmospheric chemistry, and large-scale changes in atmospheric circulation. Understanding the physical and chemical characteristics of these particles and how they impact climate, is important for accurate climate modelling.

SOLUTION

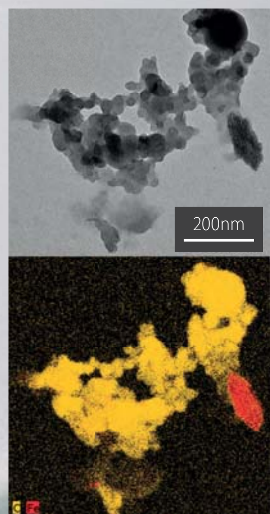
The particles exist at only parts per billion within the ice. To separate the carbon nanomaterials from the ice and concentrate them sufficiently to allow analysis using the transmission electron microscope (TEM), Curtin University PhD student Aja Ellis developed a sophisticated filtration method, applied in a clean room, to avoid



TEM image of a single carbon nanosphere

any risk of contemporary contamination. She then worked with A/Prof. Martin Saunders in the AMMRF at the University of Western Australia to analyse the carbon nanoparticles from time points before and after industrialisation between 1759 and 1930. The shape, size, and structure of the separated carbon nanoparticles were investigated, revealing for the first time the presence of individual carbon spheres 30nm wide inside ice cores. The spheres also formed groups of two particles up to dozens. The carbon spheres from all the dates tested had a similar, partially ordered crystal structure with a series of concentric shells of carbon atoms. Many of the carbon particles were associated with metal and mineral particles, thought to have come from dust associated with bushfires or possibly from early industrial activity in the Southern Hemisphere.

Most climatic models treat black carbon as simplified spheres with static characteristics, which Ms Ellis showed is not the case. The associated minerals, metal impurities, and insoluble coatings, all affect black carbon's optical properties as it ages in the atmosphere before falling to Earth in rain or snow.



Top: TEM image of a group of carbon nanospheres attached to a mineral particle; bottom: element map from the TEM showing the carbon spheres (yellow) and confirming iron (red) in the mineral particle.

IMPACT

Current atmospheric chemistry and climate models do not account for the complexity of black carbon nanostructures in the environment. More accurate climate change models will be enabled by this research.

Ellis, A., et al., 2015, *Atmospheric Measurement* Techniques 8.
Ellis, A., et al., 2016, *Geophysical Research Letters* (accepted November 2016).

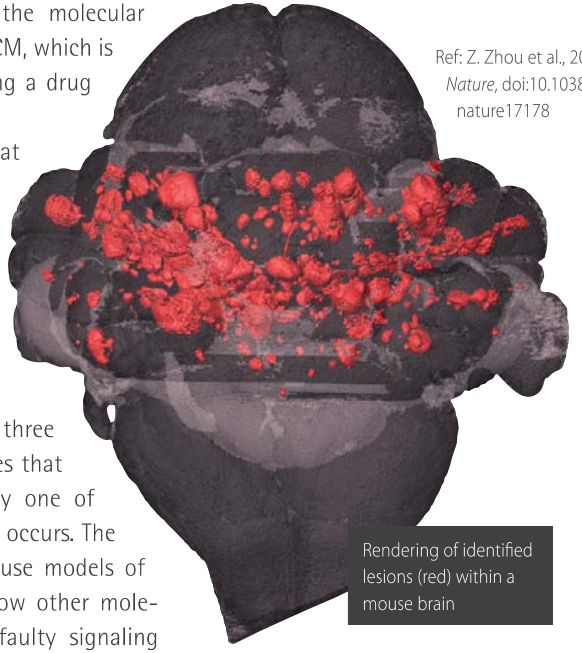
TOWARDS STROKE PREVENTION

Cerebral Cavernous Malformation (CCM) is a disease where blood vessels in the brain are deformed and result in lesions. If these lesions rupture they can cause a stroke. Other symptoms include headaches, hearing, vision or cognitive problems, weakness and paralysis. Up to 0.5% of population is affected by CCM and current method of treatment is surgical removal, if their location in the brain permits. No drug treatments are available but researchers have recently identified the molecular mechanisms that cause CCM, which is the first step in developing a drug treatment.

Dr. Xiangjian Zheng at the University of Sydney (UoS) and Prof. Mark Kahn, University of Pennsylvania, have led a team of researchers to investigate causal molecular pathways for CCM. They identified three critical signaling molecules that work together. When any one of them is faulty the disease occurs. The team then generated mouse models of the disease to identify how other molecules interact with the faulty signaling pathway. This could identify potential drug targets.

Human patients with clinical symptoms of CCM can be relatively easily diagnosed by magnetic resonance imaging (MRI). Mice are too small for MRI, so the researchers chose X-ray microtomography in the AMMRF at UoS to efficiently and quantitatively measure CCM lesions in their mouse models.

Drugs that target the causative signaling pathway for CCM are now being tested. If successful they will greatly benefit people at risk of stroke, particularly where surgical removal of the lesions is not possible.



Ref: Z. Zhou et al., 2016, *Nature*, doi:10.1038/nature17178

Rendering of identified lesions (red) within a mouse brain

IMPROVED MEDICAL DEVICE BIOCOMPATIBILITY

Implantable biomedical devices play an important role in modern medicine. However, these devices often don't integrate well with host tissue and may need replacing through revision surgery. This causes significant pain and suffering, as well as being an economic burden. Biomaterial coatings can mitigate these problems by masking the implanted devices, mimicking the surrounding tissue, and allowing successful integration with the body.

Ideal surfaces interact seamlessly with host tissue through a surface covered with appropriate proteins. Although whole proteins can improve device biocompability, they don't always survive the required sterilisation and can bring the risk of infection. Prof. Marcela Bilek, Dr Behnam Akhavan, and Mr Lewis Martin at the University of Sydney are designing synthetic short protein segments, called peptides, to recapitulate the function of specific proteins. Their small size can make them more resilient to sterilisation. The main challenge is ensuring they attach to device surfaces at appropriate densities and orientations. The team have discovered how to control peptide attachment by using applied electric fields. The charged peptides interact with the surface in a preferred orientation and density when an electric field is applied.

The team uses the AMMRF flagship time-of-flight secondary ion mass spectrometer at the University of South Australia. This can measure the atoms on the top-most surface of the device, enabling a detailed understanding of the distribution and orientation of the attached peptides. This new knowledge is being used to develop strategies to create a new generation of biologically functional surfaces for implantable devices.

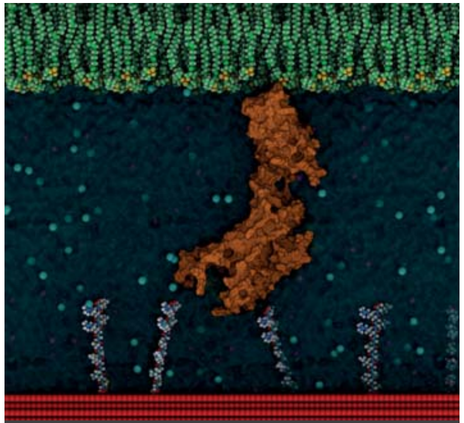


Illustration of a cell surface receptor protein (orange) on the outside of a cell (green) coming into contact with a peptide-functionalised surface (red). The peptides on the surface can bind to the protein and influence the cell's behaviour.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FEATURED IMAGE CREDITS

Front cover

Microscopy & microanalysis in the AMMRF. Photos, left and bottom: by Tom Francis, courtesy of the University of Queensland. Right: by Deirdre Molloy.

Back cover

Top left: Atom probe reconstruction of human tooth enamel. Image: Tom Hartley. See story p24

Top right: Microprobe map of minerals. Image: AMMRF at University of Western Australia.

Bottom: Colour-enhanced transmission electron micrograph through the midpiece of octopus sperm. Image: G. Rouse

Inside back cover

Colour-enhanced transmission electron micrograph of a huntsman spider's eye. Image: Anne Simpson-Gomes.

Section opener images

Pages 4–5: Confocal image of neural rosettes derived from human induced pluripotent stem cells. See story p. 28. Image Claire Homan, University of Adelaide.

Pages 12–13: Colour-coded image of fat cells. An algorithm assigned colours to different cells to enable cell volumes to be measured. Image: Dr James Burchfield, University of Sydney.

Pages 18–19: Nano-SIMS images of a grain of the mineral pyrite. The different coloured bands in the left image represent different ratios of two isotopes of sulphur. The right image shows the distribution of arsenic (red), nitrogen (green), and oxygen (blue). Images: Erica Barlow, University of NSW.

Page 35: Using a focused ion beam instrument. Photo: Scott Walker

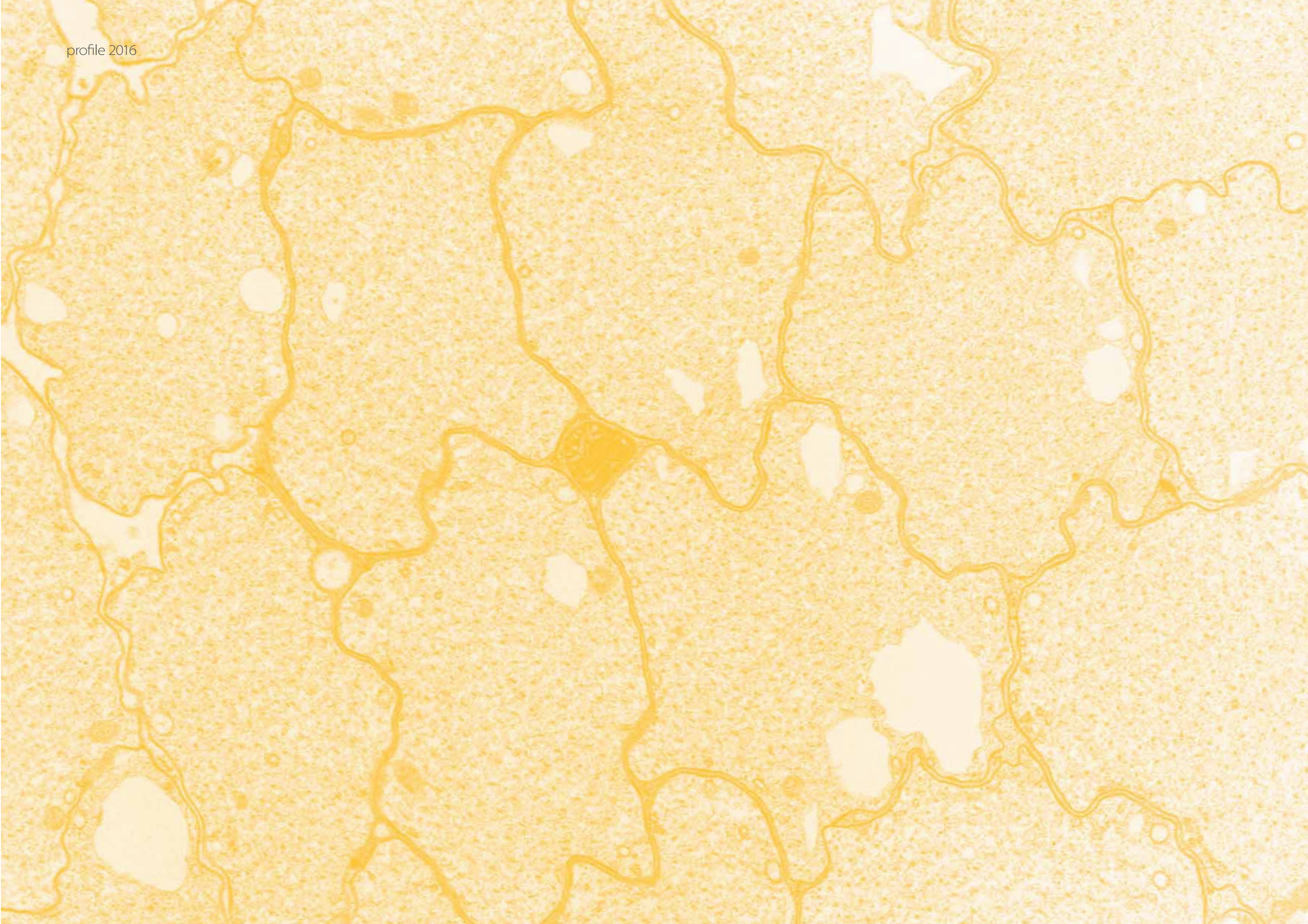
Icons

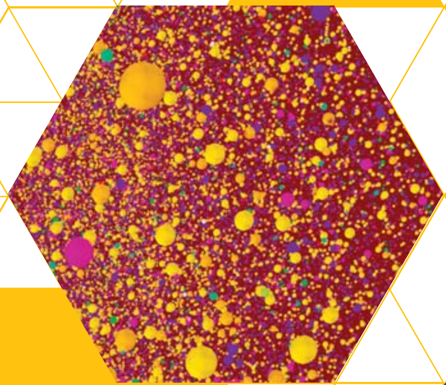
Icons from Noun Project: on p7, 11.

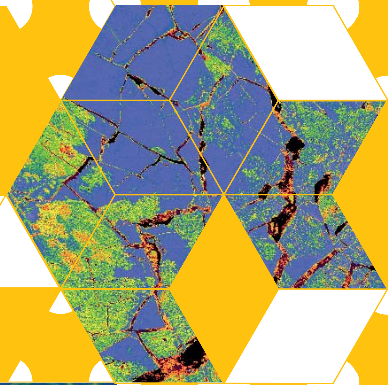
Industry Implementation by WARSLAB, Graphene by Creative Stall, Heartbeat by iconsmind.com, Atom by Vectors Market, Bacteria by Barbara Marsillac, Globe by Role Play.

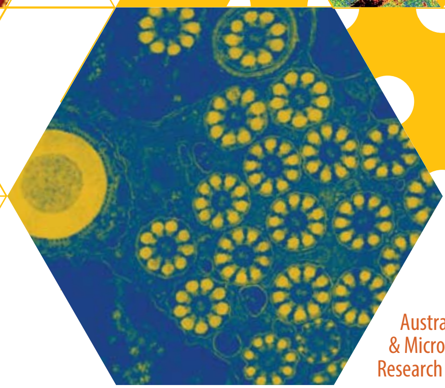
Icons from Noun Project: on p15.

Light Bulb by Félix Péault, Cube by icon 54, Cell by Maurizio Fusillo, Mouse by Andrew Richardson, Human by Beau Wingfield.









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