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The University of Adelaide

Institute for Mineral and Energy Resources

Annual Report 2013

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seek LIGHT

IMER Answering the challenge of sustainable and efficient use of global resources

The Institute for Mineral and Energy Resources (IMER) is part of the University of Adelaide, Australia. IMER undertakes interdisciplinary research that addresses scientific, technological, environmental and social challenges in the provision of mineral and energy commodities globally.

Institute for Mineral and Energy Resources

Established in 2008, IMER aims to become a leading research and postgraduate training facility for the mining and energy sectors in the Asia-Pacific region.

The University of Adelaide is unique within Australia for its strong research and teaching groups in geology and geophysics, petroleum engineering, mining engineering and energy technology. These groups form the Institute's core.

Vision

IMER's vision is that interdisciplinary research is key to the sustainable use and development of the world's mineral and energy resources for the benefit of society, industry and the environment.

Mission

IMER's mission is to be recognised globally as a centre of excellence for interdisciplinary research, innovation and technology transfer in mineral and energy resources.

Objectives

- Advance the science and technology required to enhance the prospectivity, discovery and extraction of mineral and energy resources, including petroleum and geothermal resources.
- Advance the science and technology needed to lower the cost of and enhance cleaner energy generation, storage, transmission and use.
- Increase energy efficiency and reduce the impact of industrial processes, especially those related to mining and mineral processing.
- Maximise the social and economic benefits of mineral and energy resource developments across regional, state, national and international communities.

Key fields of research

Earth sciences: geology, geochemistry, geosequestration, geophysics and physical geography.

Energy technology: fluid mechanics and turbulence, thermal process modelling, alternative fuels, materials and nanotechnology, power systems and devices.

Resource engineering: petroleum and mining engineering.

Interdisciplinary research is also conducted in geothermal energy, decision analysis, industry and socio-economic studies and environmental impacts specifically related to energy and mineral resource developments.

Some of the University of Adelaide schools and faculties involved with IMER include the Australian Workplace Innovation and Social Research Centre (WISeR); the Australian School of Petroleum; the Business School; the School of Chemical Engineering; the School of Chemistry and Physics; the School of Civil, Environmental and Mining Engineering; the School of Earth and Environmental Sciences; the School of Electrical and Electronic Engineering; the School of Mathematical Sciences; and the School of Mechanical Engineering.

IMER is the principal point of contact for the strategic interests of the University of Adelaide in mineral and energy resources research, including industry and government partnerships.

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Dr Andrew Kwong Lee, Postdoctoral Research Fellow within the School of Chemical Engineering, working in the BioFuels laboratory.

Chairman's Report

Mr Robert Kennedy

At the Institute for Mineral and Energy Resources (IMER), we believe that interdisciplinary research is essential to enable the sustainable use and development of the world's mineral and energy resources. IMER focuses on delivering innovative interdisciplinary research outcomes for the benefit of local and global industry, our communities and the environment.

Our interdisciplinary approach has been rewarded with increased research funding every year since our inception – IMER's Category One funding is now triple that of 2009. In 2013 our researchers attracted more than $6.2 million of funding through nationally competitive research grants, including more than $5 million of Australian Research Council (ARC) funding.

Highlighting IMER's interdisciplinary and collaborative approach this year is the Centre for Energy Technology's (CET) involvement in the Australian Solar Thermal Research Initiative (ASTRI). An $87 million collaboration, led by the CSIRO and funded by the Australian Renewable Energy Agency (ARENA), ASTRI brings together solar thermal expertise from the United States and six Australian universities to advance solar fuel and solar hybrid research with the ultimate aim of lowering the cost of electricity from solar thermal energy to 12 cents a kilowatt hour by 2020.

Developing reliable, low-cost and low-emission energy is just one of IMER's priority research areas. Our scientists are using fracture mapping and modelling to aid development of unconventional energy resources and engineered reservoirs and increasing our understanding of global origins of petroleum deposits. We are using world-first microbial techniques to address complex mineral processing issues and using novel seismic and geochemical methods to maximise mineral exploration success. We are also investigating tectonic processes to help us better understand the resource potential of our State and global environment. These are just a few of the innovative and wide-ranging research projects featured within this report.

IMER continues to equip the future generation of mining and energy professionals with outstanding skills. Our members supervised more than 200 postgraduate students in 2013, including 15 PhD completions. We also continued our great record of engagement with other academics and industry through more than 600 publications. TRaX and CET also hosted research days to showcase the breadth of their research and help to identify funding opportunities as well as develop and maintain partnerships with industry, government and other research institutions.

We have actively recruited a number of researchers to strengthen IMER's capabilities in tectonics, structural geology, solar technologies and laser diagnostics in 2013. We welcome Dr Stijn Glorie and Dr Khalid Amrouch to the Centre for Tectonics, Resources and Exploration (TRaX) and Dr Woei Saw, Dr Yungpeng Xue and Dr Zhiwei Sun to CET.

I would like to take this opportunity to congratulate all of the IMER researchers who have received honours in 2013 (Key Awards page 21). It is great to see IMER researchers being publicly recognised for their expertise by their national and international peers.

Many thanks to the IMER Advisory Board, and particularly to IMER Executive Director Professor Stephen Grano and his staff, for another year of dedication and hard work.

Mr Robert Kennedy
Chair

30 September, 2014

Executive Director's Report

Professor Stephen Grano

Interdisciplinary, innovative and collaborative research for the minerals and energy sectors continued to be IMER's core business in 2013. Our research priorities directly align with the challenges of our State's industries to deliver research outcomes with local as well as global impact. These challenges centre around deep exploration; deep mining; complex processing; unconventional energy resources; and developing reliable, low-cost, low-emission energy.

IMER's interdisciplinary initiatives are addressing these challenges through a wide variety of research. We are developing geochemical tools to enhance mineral exploration of hydrothermal ore deposits; exploring magmatic plumbing systems to enhance oil exploration; developing efficient and sustainable graphene-based catalysts for use with renewable energy technologies; and developing technology to take advantage of advanced manufacturing opportunities arising from the minerals and energy sector. These are just a few examples of IMER's expertise highlighted throughout this report.

Our focus on delivering practical solutions for industry is clear, with many IMER projects heading towards successful commercial outcomes. Of particular note are the two patents pending from CET's research into novel solar hybrids and another which aims to decrease noise and increase the performance of airfoils, such as those used in wind turbines.

IMER's facilities also expanded in 2013. A major highlight was the awarding of an ARC grant to Prof Martin Hand and collaborators for a micro-sampling thermal ionisation mass spectrometry facility. This facility will enable researchers to trace our continent's ancient evolution and characterise mineral deposit formation with a new level of accuracy and precision.

We continue to be well supported by the South Australian Government's Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE [Department of State Development as at 1/7/2014]) and enjoy our close relationship. IMER supported the Roundtable for Unconventional Gas Projects in SA through a joint meeting with DMITRE on Unconventional Energy Resources – Research and Technology Needs. This forum brought together industry, government and researchers to help foster collaboration and innovation and identify research goals as well as coordinate research activity and technology transfer. I see this facilitation as a key role for IMER, not only within the unconventional gas industry but in the minerals and energy sectors as a whole.

Another exciting development in 2013 was the South Australian Government's commitment of $10 million over five years to establish the Mining and Petroleum Services Centre of Excellence. We are privileged to be involved one of the Centre's initiatives – the Information and Communications Technology (ICT) Roadmap for Minerals and Energy Resources Project: a partnership between DMITRE and the Australian Information Industries Association. We look forward to continuing our work with this new Centre in the coming years to ensure our mineral and energy sector remains globally competitive.

IMER facilitates connections between researchers and the minerals and energy industry, both locally and internationally. IMER co-supported Prof Alan Collins' visit to China to investigate the establishment of a West China Geoscience Research Centre. A/Prof Ben Cazzolato and Dr Maziar Arjomandi visited Carnegie Wave Energy Ltd to build new industry links and with our support A/Prof Anthony Zander also travelled to Europe, Canada and the United States to meet with potential wind turbine research collaborators. I look forward to seeing these relationships develop over the coming years.

Challenges continue to evolve in the mineral and energy resources sector and we need to continue to increase the competitiveness of these industries. We must also leverage off our investment and develop niche manufacturing and service offerings that harness the full benefits of our State's natural resources and equip us for applications around the world. IMER's interdisciplinary, strategic and innovative approaches are more relevant now than ever and I would like to acknowledge the significant contribution of IMER researchers towards achieving these objectives to date. I heartily thank them for their efforts and look forward to sharing their achievements with you.

Professor Stephen Grano
Executive Director

30 September, 2014

Challenges, strategies and priorities

Strategic framework

The Institute for Mineral and Energy Resources (IMER) was formed by the University of Adelaide to focus interdisciplinary research in mineral and energy resources, address globally significant challenges and enhance the impact of research. IMER's mission is to be a globally recognised centre of excellence for interdisciplinary research, innovation and technology transfer in mineral and energy resources.

Global resource and energy challenges

IMER is developing long-term partnerships with its stakeholders and producing world-leading research outcomes that address the following global challenges and trends:

- increasing scarcity of large mineral and energy resource discoveries at, or near, the Earth's surface
- increasing depth of mining and extraction of mineral and energy resources
- decreasing grade and increasing complexity of mineral and energy resources
- increasing energy prices due to competition, constraints on carbon emissions and energy infrastructure upgrades
- increasing global energy consumption while cost-effectively seeking to reduce the resulting emissions
- increasing demand from communities to achieve economic sustainability by enhancing productivity and reducing costs.

Capital and operating costs continue to increase with increasing demand for resources. Mega-scale projects continue to be constrained by the very high capital costs of using existing technology at these large scales. Technologies with lower capital and operating costs are emerging with the potential to unlock otherwise uneconomic resources.

Challenges for South Australia

IMER strives to address the central challenges of South Australia's mineral and energy resource industries through innovative and globally-relevant research outcomes. The global challenges of economic, social and environmental sustainability in mineral and energy resource development are reflected in the following key challenges and opportunities for South Australia.

Mineral exploration under cover

South Australia's mineral and energy resource potential is still largely untapped due to exploration difficulties associated with the thick sedimentary cover overlaying the basement rock. New exploration tools and methods, as well as improved understanding of ore formation and alteration processes are needed to enhance the prospectivity of the State's mineral resources.

High operating costs and impacts in large-scale deep mining

South Australia's deep mines have large volumes of overburden that need to be removed. Operating costs and impacts are increasing, particularly in the State's copper-uranium mines. Strategies are needed to reduce mining of waste rock and waste rock dilution of run-of-mine ore. Costs of transporting run-of-mine ore out of deep pits also need to be reduced.

High operating costs and impacts of complex ore processing

South Australian minerals tend to be fine-grained and complex, with fine intergrowths of different value and gangue minerals at the micron and sub-micron scale and contain some penalty elements which can significantly impede processing. Conventional equipment used for effective mineral separation and concentration has high capital and operating costs. New low capital and operating cost technologies are needed to process these minerals, remove penalty elements and upgrade low-grade ores while minimising environmental impacts.

High costs of extracting unconventional natural gas resources

South Australia has significant resources of natural gas contained in ultra-tight and shale gas deposits. These resources have several advantages over coal bed methane but extraction costs are higher as more drilling and fracturing is required. Regions of high permeability and gas evolution or 'sweet spots' in these unconventional gas reservoirs need to be identified and targeted.

Reliable, low cost, low emission energy

Ensuring reliable electricity supply whilst maintaining ability to meet peak loads and cost-effectively achieve greenhouse gas reduction targets is a major challenge. Research is needed to reduce the cost of renewable energy technologies and manage their integration. New, cost-effective and low-carbon production of liquid transport fuels from alternative feedstocks also needs to be explored.

Socio-economic impacts of mineral and energy resource developments

Mining, energy resource and energy technology developments can have major impacts and present significant opportunities for a community's economy and workforce. Research is needed to inform strategies aimed at sustainable industrial development particularly by commercialising and marketing innovative, value-added products and processes that leverage off our comparative mineral and energy resource strengths to grow our economy.

Interdisciplinary research priority areas and strategy

Based on these global and South Australian challenges, IMER's research priority areas are:

- mineral exploration under cover
- deep mining
- complex ore processing
- unconventional energy resources
- reliable, low cost, low emission energy.

IMER provides leadership in interdisciplinary initiatives that are aligned to these research priority areas by:

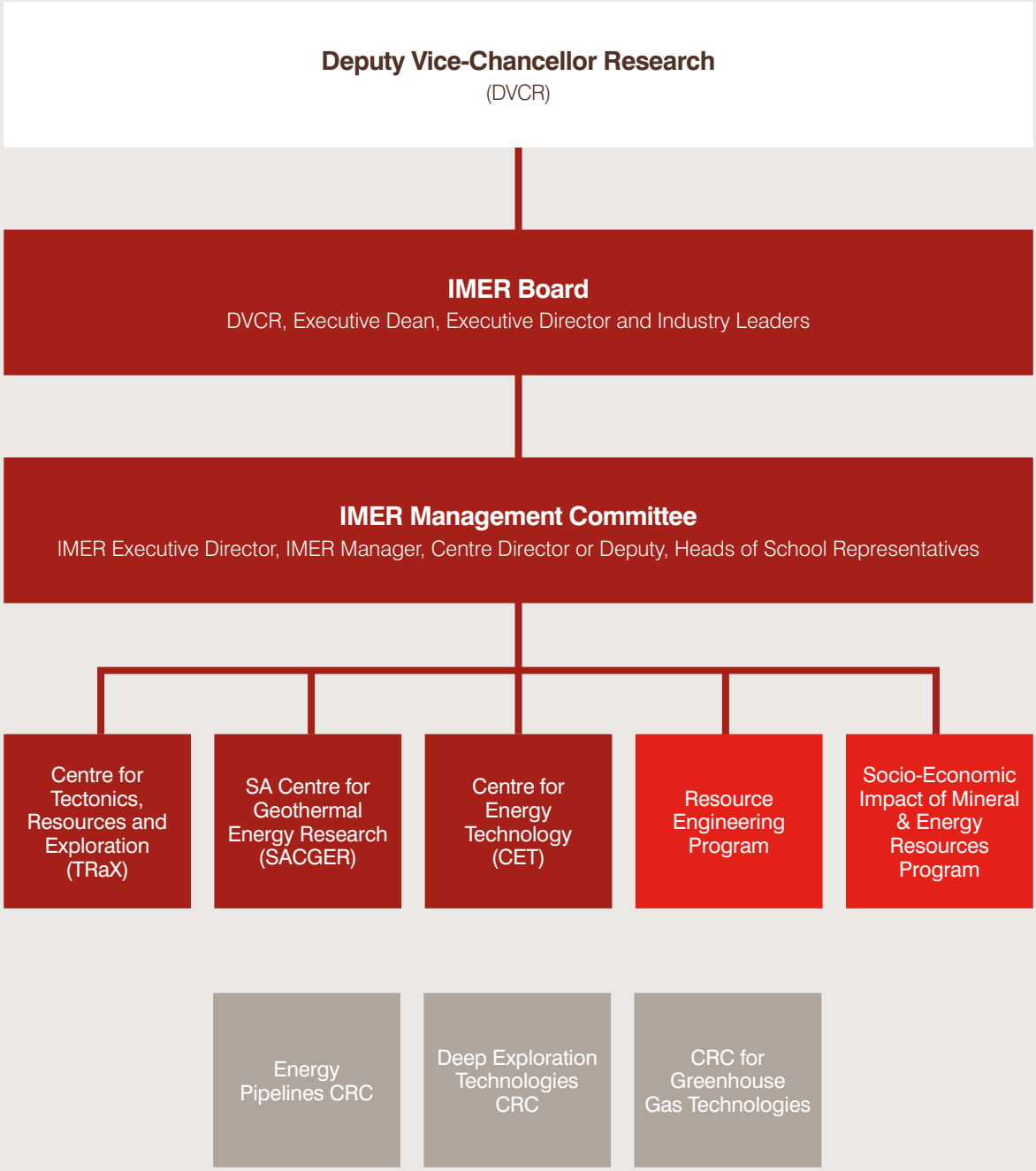
- bringing together interdisciplinary teams from the University of Adelaide and research partners to develop high profile, high value, long-term interdisciplinary projects funded by key industries and stakeholders
- forging new strategic relationships between researchers and the minerals and energy industry as well as related business and professions, including developing relationships with international research institutions and industry
- supporting research leadership by investing in strategic research initiatives that leverage new funding and build IMER's track record for high quality research outputs
- increasing the number, scale and success rate of national competitive grant applications to build research capability and capacity.

Key principles

IMER's mission encompasses the key principles:

- **interdisciplinary research** – reflects the University of Adelaide's objective for IMER to bring together science, engineering and humanities research disciplines to address globally significant challenges
- **global recognition** – reflects the University of Adelaide's intent to be a leading research university by world standards and places global benchmarks on IMER's performance
- **fundamental and applied research** – recognises the critical importance of fundamental research to underpin applied research which will directly address State and global challenges
- **innovation** – recognises the importance of step-change research and the breakthroughs required to make a positive and lasting impact on State, national and global communities
- **technology transfer** – recognises the importance of communication in all its forms to maintain mutually beneficial relationships between the University of Adelaide, industry and society.

Organisational structure



Board and committees

Advisory Board

IMER's ten-member Advisory Board brings together industry and government leaders and internal University of Adelaide members with extensive knowledge or experience of the mineral and energy resource sectors.

Chair
Mr Robert Kennedy
Chairman, Ramelius Resources Limited

Professor John Beynon
Executive Dean, Faculty of Engineering, Computer and Mathematical Sciences, University of Adelaide

Professor Mike Brooks
Deputy Vice-Chancellor and Vice-President (Research), University of Adelaide

Mr Colin Cruickshank
General Manager Unconventional Resources and Exploration Eastern Australia Business Unit, Santos Ltd

Mr John England
Director of Processing Studies and Technology Resource Planning and Development, BHP Billiton

Professor Stephen Grano
Executive Director, IMER University of Adelaide

Dr Paul Heithersay
Chief Executive Olympic Dam Taskforce and Deputy Chief Executive Resources and Energy, Department of State Development (DSD)

Professor Richard Hillis
Chief Executive Officer, Deep Exploration Technologies Cooperative Research Centre

Ms Belinda Robinson
Chief Executive, Universities Australia

Mr Andrew Stock
Non-executive Director, Horizon Oil Ltd, Geodynamics Limited and Clean Energy Finance Corporation

Management Committee

The Management Committee comprises members from IMER's interdisciplinary Centres and Programs, as well as School and research leaders. The group generates research ideas, reviews funding and engagement opportunities and discusses project management issues. Committee members develop IMER's research capability and oversee strategy.

Management Committee members

Chair
Professor Stephen Grano
Executive Director, IMER

Professor Bruce Ainsworth
Deputy Leader, Resource Engineering Program

Professor Alan Collins
Director, TRaX

Mr Simon Firth
Commercial Development Manager, Adelaide Research and Innovation Pty Ltd

Professor Martin Hand
Deputy Director, IMER
Director, SACGER

Mr Simon Ladd
Research Development Manager, Faculty of Humanities and Social Sciences

Professor Gus Nathan
Deputy Director, IMER
Director, CET

Dr Jordan Parham
Manager, IMER

Professor Shizhang Qiao
Chair of Nanotechnology, School of Chemical Engineering

Associate Professor John Spoehr
Executive Director, Australian Workplace Innovation and Social Research Centre (WISeR)

Associate Professor Jennifer Watling
Head of School of Earth and Environmental Sciences

Associate Professor Chaoshui Xu
Program Leader, Resource Engineering Program

Management Committee alternates

Professor
Peter Ashman
Head of School of Chemical Engineering

Associate Professor
Emmanuel Chanda
Deputy Leader, Resource Engineering Program

Dr Simon Holford
Deputy Director, TRaX

Associate Professor
Barry Burgan
Deputy Leader, Socio-Economic Impact of Mineral and Energy Resources Program

Professor
Bassam Dally
Deputy Director, CET

Associate Professor
Yung Ngothai
Deputy Director, SACGER

Key leaders

IMER executive

Executive Director

Professor Stephen Grano

Prof Stephen Grano was appointed Executive Director of IMER in March 2010. He is an internationally-recognised metallurgical engineer with nearly three decades of research experience and a background of delivering successful projects linked to industry.

Manager

Dr Jordan Parham

Dr Jordan Parham combines extensive experience in both research and industrial environments. In his current role, he manages the Institute's strategic research initiatives, business development, outreach activities and internal operations. He holds a PhD from the University of Adelaide in the control and optimisation of mixing and combustion for mineral processing.

Centre directors

TRaX Director

Professor Alan Collins

Prof Collins' research answers geologically significant questions through various aspects of geoscience, including palaeomagnetism, structural geology, geochronology and sedimentology. He was awarded an Australian Research Council Future Fellowship in 2012 and appointed director of TRaX in 2013.

SACGER Director, IMER Deputy Director

Professor Martin Hand

With a PhD focused on the structural and metamorphic evolution of Proterozoic terrains in Antarctica and central Australia, Prof Martin Hand's research expertise is in the thermal evolution of the continental crust. He was the inaugural director of TRaX and was appointed SACGER Director in 2009. His current research focuses on the emerging geothermal energy industry in Australia.

CET Director, IMER Deputy Director

Professor Graham (Gus) Nathan

Appointed as founding director of CET in 2009, Prof Gus Nathan specialises in thermal energy engineering in systems supplied by solar and geothermal and the combustion of fossil and biofuels. His research focuses particularly on novel approaches to integrate and optimise these different energy sources.

Program leaders

Resource Engineering Program Leader

Associate Professor Chaoshui Xu

A/Prof Xu has over 20 years of experience working for mining academic institutions and industry. His research interests cover many areas including geostatistics, mineral resource evaluation, risk assessment of mining projects, optimal mine design, rock fracture mechanics, stochastic rock fracture modelling, particle flow simulation using distinct element method and statistics of porous or fractured media.

Socio-Economic Impacts of Mineral and Energy Resources Program Leader

Associate Professor John Spoehr

A/Prof John Spoehr is the Executive Director of the Australian Workplace Innovation and Social Research Centre (WISeR). He is also leading the establishment of the Stretton Centre, a focal point for integrated economic, industry and urban research and practice in Adelaide's Northern suburbs. His research focuses on the interactions between economic, industry and social policies.

Cooperative Research Centres

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

Chief Scientist
Professor John Kaldi

Energy Pipelines Cooperative Research Centre (EPCRC)

Program Leader
Professor Peter Ashman

Deep Exploration Technologies Cooperative Research Centre (DET CRC)

Research Leader
Professor David Giles

Below: Towering Neoproterozoic granites in central Madagascar, in the heart of the East African Orogen. Prof Alan Collins, Prof John Foden and Donnelly Archibald visited Madagascar in September to collaborate with Prof Theodore Razakamanana (Toliara University) and work on Prof Collins' ARC-funded Future Fellowship.

Major sponsors

IMER researchers have project sponsorship funding from leading local and international companies as well as from South Australian and Australian government departments, in all cases linked to competitive and prestigious research grants.

CRC for Greenhouse Gas Technologies

Core industry and government sponsors

Australian National Low Emissions Coal Research and Development Ltd (ANLEC R&D)
BG Group
BHP Billiton
BP Australia
Brown Coal Innovation Australia
Chevron Australia
Department of State Development, Business and Innovation, State Government Victoria
Department of Mines and Petroleum, Government of Western Australia
Glencore Xstrata
INPEX
Korean Institute of Geoscience and Mineral Resources (KIGAM)
NSW Trade & Investment, NSW Government
Rio Tinto Ltd
SASOL Ltd
The Shell Company of Australia Ltd
TOTAL

Energy Pipelines CRC

Core Industry Sponsor

Australian Pipeline Industry Association Ltd (APIA)
Pipeline Research Council International
European Pipeline Research Group

Deep Exploration Technologies CRC

Core industry and government sponsors

Anglo American
Barrick Australia Pacific Ltd
BHP Billiton
Boart Longyear
Department for Manufacturing, Innovation, Trade, Resources and Energy, Government of South Australia
Geoscience Australia, Australian Government
Gold Fields Australia Pty Ltd
Imdex Ltd
Newcrest Mining Ltd
Olympus
Vale Exploration Pty Ltd

Reservoir architecture and heterogeneity in marginal marine systems – WAVE Consortium

Core industry sponsors

Apache Corporation
Badr Petroleum Co
BG Group
BHP Billiton
BP Australia
Chevron Australia
ConocoPhillips
Nexen Petroleum Australia Pty Ltd
OMV Group
Shell
Statoil
Todd Energy
Woodside Energy Ltd

Major research sponsors

Adelaide Airport Ltd
Adelaide Brighton Ltd
American Association of Petroleum Geologists Foundation
Australian Institute of Nuclear Science and Engineering
Australian Business Foundation Ltd
Australian Society for Exploration Geophysicists
Australian Synchrotron Company Ltd
Barrick Gold of Australia Ltd
Beach Energy Ltd
BG International Limited
Broons Hire (SA) Pty Ltd
Carnegie Wave Energy Ltd
Deep Blue Tech Pty Ltd
Don Dunstan Foundation
EconSearch Pty Ltd
ESSO Australia Pty Ltd
ESSO Exploration Inc
Exxon-Mobil
FCT Combustion Pty Ltd
Halliburton Energy Services Inc
Iluka Resources Ltd
Imperial Oil & Gas Pty Ltd
Iron Road Ltd
Mining Education Australia
Muradel Pty Ltd
Nature Foundation SA Inc
Newcrest Mining Ltd
Newmont Mining Corporation
Oceanlinx Ltd
OzMinerals Prominent Hill Operation
Petratherm Pty Ltd
Playford Memorial Trust Inc
Premium Wine Brands
Public Service Association
QGC Pty Ltd
JRS
Santos Ltd
Science and Industry Endowment Fund
Shell Development Australia Pty Ltd
Sir Mark Mitchell Research Foundation
Society of Exploration Geophysicists
South Australian Research and Development Institute
SQC Pty Ltd
The Sir Ross & Sir Keith Smith Fund
Total E&P Australia
Water Quality Research Australia Ltd
Woodside Energy Ltd
Xstrata Coal Pty Ltd

Commonwealth Government of Australia

Australian Agency for International Development
Australian Renewable Energy Agency
Australian Research Council
Commonwealth Scientific and Industrial Research Organisation
Defence Science and Technology Organisation
Department of Education
Department of Employment
Department of Foreign Affairs and Trade
Department of Industry
Regional Development Australia

State and local government

South Australia

City of Playford
Department for Education and Child Development
Department of State Development
Department of Environment, Water and Natural Resources
Forestry SA
Renewables SA
SafeWork SA
South Australian Museum
South Australian Research and Development Institute
SA Water
Workcover Corporation

Victoria

Department of Environment & Primary Industries
Melbourne Water

Western Australia

Geological Survey of Western Australia

Facts and figures

Over the past five years, IMER's membership, funding and number of publications has continued to grow. This is testament to our collaborative and innovative approach that both anticipates and meets industry's needs.

IMER Members

Both staff and student numbers have grown from 2009 to 2013.

2009

Staff 125

Students 140

2013

Staff 141

Students 218

Research funding

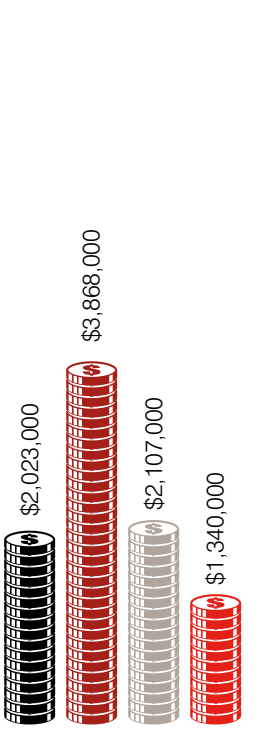
Funding which can be attributed to IMER members has been calculated from the total funding obtained by IMER member researchers for projects and research infrastructure grants that are relevant to IMER.

As IMER is highly inter-disciplinary and encompasses a diverse cross-section of research fields, only projects and infrastructure that relate to core IMER research areas of expertise and priorities have been included in this financial data.

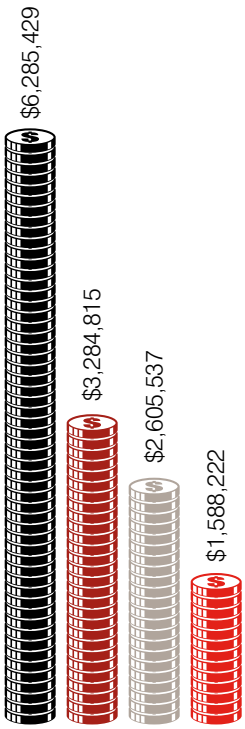
Research funding is shown according to the Australian Higher Education Research Data Collection categories:

- **Category 1**
  Nationally competitive research grants
- **Category 2**
  Other public sector funding
- **Category 3**
  Australian industry, donations and international grants
- **Category 4**
  Cooperative Research Centres

In 2009, IMER's total research funding was $A9,338,000. In 2013 IMER's total research funding was A$13,764,002. This increase is largely due to Category 1 funding in 2013 being more than triple that of 2013.



2009 $A9,338,000



2013 A$13,764,002

Publications

For Publications please visit our website www.adelaide.edu.au/imer/

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- Open file
- Select program from list of installed programs
- Select Endnote

Note: If 'save as' option does not display, right click 'save link as' then open as above with Endnote.

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- On homepage click on 2013 Publications PDF link

Book chapters 0

Conference papers 85

Journal articles 168

2009

Book chapters 18

Conference papers 218

Journal articles 373

2013

Key collaborators

In 2013 IMER researchers continued their strong track record of collaborative research with leading universities across the globe. These collaborations bring together researchers with diverse skills, capabilities and approaches, generating a holistic, innovative and interdisciplinary approach to solving current and future challenges.

Australian

AuScope
Australian National University
Charles Darwin University
Commonwealth Scientific and Industrial Research Organisation
Curtin University
Deakin University
Flinders University
Geological Survey of Queensland
Geological Survey of Western Australia
Geoscience Australia, Australian Government
GeoScience Victoria
GNS Science
Macquarie University
Monash University
Murdoch University
Northern Territory Geological Survey
Queensland University of Technology
RMIT University
South Australian Museum
University of Melbourne
University of Newcastle
University of New South Wales
University of Queensland
University of South Australia
University of Sydney
University of Tasmania
University of Western Australia
University of Wollongong

International

Abo Akademi
British Geological Survey
Chinese Academy of Sciences
Chinese University of Geoscience
Coffey International
Delft University of Technology
Dublin Institute for Advanced Studies
East China University of Science and Technology
ETH Zurich
Federal University of Minas Gerais
Federal University of Rio de Janeiro
Imperial College London
Indian Institute of Technology
Karlsruhe Institute of Technology
Kent State University
Kochi University
Korean Maritime University
Luleå University of Technology
Lund University
Martin Luther University
McGill University
Memorial University
Northwest University
Peking University
PTT Exploration and Production PLC
Purdue University
Royal Holloway University of London
RWTH Aachen University
Scripps Institute of Oceanography
Shanghai University
Simon Fraser University
Stellenbosh University
Tianjin University
Tsinghua University
Tsukaba University
University of Aberdeen
University of Addis Ababa
University of Auckland
University of Birmingham
University of California
University of Cambridge
University of Canterbury
University of Chile
University of Edinburgh
University of Münster
University of Otago
University of Portsmouth
University of Salamanca
University of Sao Paulo
University of Science and Technology
University of St Andrews
University of Utah
University of Wales
University of Western Ontario

Key awards

Dr Stephan Thiel

Winner, *The Australian* Innovation Challenge – Minerals and Energy

Dr Stephan Thiel and fellow geophysicists in IMER's Electrical Earth Imaging group (EEI) won the Minerals and Energy category of *The Australian* Innovation Challenge. The team is developing a low-cost, low-impact approach to assessing the impacts on groundwater from exploration and production of energy resources such as coal seam gas.

The pioneering technique was first trialled in a geothermal fraccing operation in South Australia and changes the way we can view groundwater movement. Real-time electromagnetic techniques can now be used to image underground changes as they occur. Mapping groundwater flow in this way is much less invasive and lower in cost than existing methods such as drilling monitoring wells or using microseismic technologies. The team aim to apply the technique to coal seam, shale and tight gas operations across Australia.

The Australian Innovation Challenge is an annual competition run in association with Shell and supported by the Federal government's Innovation Australia organisation.

Professor Peter Dowd

Georges Matheron Lecturer 2013, International Association for Mathematical Geosciences

Professor of Mining Engineering Peter Dowd received the Georges Matheron Lecturer 2013 award f rom the International Association for Mathematical Geosciences (IAMG). This prestigious award is bestowed on a scientist of international standing for their research contribution to geostatistics. Over his career, Prof Dowd has won approximately $14 million in competitive grants from research councils, industry and government in the UK, EU, published more than 200 papers and supervised 100 postgraduate students.

Prof Dowd presented his lecture *"Quantifying uncertainty for mineral and energy resource exploitation – sources, randomness, scale and structure"* at the 15th annual IAMG meeting (Madrid) in September.

continued next page >

Professor John Kaldi

Society of Petroleum Engineers Distinguished Lecturer 2013–2014

Prof John Kaldi, Chief Scientist of the CO2CRC and Chair of Geosequestration at the University of Adelaide was appointed a Distinguished Lecturer for the Society of Petroleum Engineers (SPE) for 2013-2014.

Prof Kaldi was chosen, along with 29 other experts, from a worldwide peer-nominated pool and this is fantastic recognition of his research and communication skills. As part of the role, Prof Kaldi will share his expertise in carbon capture and storage with other SPE members, highlighting the big issues and opportunities for the petroleum industry through visits to countries including Qatar and Brazil.

Professor Shizhang Qiao

ARC Discovery Outstanding Researcher Award

Prof Shizhang Qiao, Chair of Nanotechnology in the School of Chemical Engineering, won a highly-competitive Discovery Outstanding Researcher Award (DORA) from the Australian Research Council (ARC). Commencing in 2014, Prof Qiao will investigate the use of novel porous silica nanoparticles in biocompatible delivery systems for therapeutic agents. These advanced systems have the potential for co-loading of agents to deliver targeted, sustainable and highly-efficient treatments for complex human diseases such as cancer.

Prof Qiao's nanotechnology expertise is also highly relevant to energy materials for applications such as catalysts, energy storage and conversion.

Emeritus Professor Colin Hansen and Dr Danielle Moreau

High achieving mechanical engineers

Colin Hansen, Emeritus Professor in the School of Mechanical Engineering, was awarded the AGM Michell Medal from Engineers Australia.This award is the highest honour possible for a mechanical engineer in Australia and is recognition of E/Prof Hansen's outstanding service to the field of mechanical engineering over a career spanning more than 40 years. E/Prof Hansen was also made an honorary fellow of the International Institute of Acoustics and Vibration for his outstanding contributions to the science of acoustics and vibration.

Dr Danielle Moreau, Research Associate in the School of Mechanical Engineering was awarded a Fulbright Scholarship. As part of the award Dr Moreau will spend three months at the Virginia Polytechnic Institute using their aero-acoustic facilities to study noise generation by airfoil.

Staff recognised for outstanding contributions to their field

Dr Rosalind King, lecturer in Earth and Environmental Sciences, was awarded the Geological Society of South Australia (SA Division)'s Howchin Medal. The medal is awarded to South Australian early-stage researchers who have a significant publication record.

Dr Paul Medwell won the prestigious Tall Poppy (SA) Award from the Australian Institute of Policy and Science. Dr Medwell is investigating more efficient and cleaner combustion technologies to develop innovative and sustainable combustion systems for the future.

Professor John Sturgul, from the School of Civil, Environmental and Mining Engineering (CEME), won the 2013 Ray Page Lifetime Simulation Achievement Award. The award recognises Prof Sturgul's outstanding contribution to the development of modelling and simulation science.

Dr Abbas Zeinijahromi, lecturer in Petroleum Engineering, was awarded a South Australian Science Excellence Award – the most prominent of its kind in the State. Dr Zeinijahromi is investigating a novel theory for single and two-phase flow in porous media, with potential application in hydrocarbon reservoirs, geothermal resources and groundwater aquifers.

Student awards for best papers

PhD candidate **Peijun Guo** was awarded the Chris Fell Prize for the Best Student Paper at the Australasian Chemical Engineering conference (Chemeca 2013). Co-authored by P Ashman, P van Eyk and G Nathan, Mr Guo's paper was titled *Hybrid Solar Gasification of Biomass in a Dual Fluidized Bed Reactor for the Polygeneration of Liquid Fuels and Electricity*.

PhD candidate **Ernest Swierczek** was awarded Best Paper 2013 by the Petroleum Exploration Society of Australia (PESA) SA. Dr Swierczek's paper was co-authored by C Zhen-Dong, S Holford, G Backe, R King and A Mitchell and titled *Quantifying fault reactivation risk in the western Gippsland Basin using geomechanical modelling*.

Centre for Tectonics, Resources and Exploration (TRaX)

Understanding the evolving Earth and its resource potential

TRaX provides a link between continental and regional-scale geology and deposits of minerals and petroleum to improve our understanding of deposit formation and develop predictive methods for the discovery of new deposits.

Our goal is to be the leading provider of research and teaching in tectonics, resources and exploration in Australia and conduct focused research into South Australia's unique geological characteristics.

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Professor Alan Collins in a rare moment within his office. Prof Collins' work sees him frequently travelling to countries like Pakistan, Madagascar, Oman and Ethopia.

Director's report

Professor Alan Collins

My first year as Director has seen many highlights, including the research symposium held on campus mid-year. The symposium featured geoscience mapping research, ranging from continental-scale reservoir analogues to a microbial map of the continent, with sessions chaired by high-level industry and government representatives. It was a fantastic demonstration of our diverse geoscience research and how it is contributing to our understanding of the Earth. We are now planning to hold the symposium annually.

In 2013, I visited the Chinese University of Geosciences, Beijing and the China Academy of Sciences where I spent time discussing the development of an Australo-Asian tectonics research centre. I had extremely constructive discussions with the university president and academics and a scientific meeting is now planned for 2014 to move this forward.

TRaX members continued to publish industry-focused research in peer-reviewed journals and made a significant contribution to the sector. This is highlighted in part by the major awards won by Dr Stephan Thiel (*The Australian* Innovation Challenge) and Dr Rosalind King (Geological Society of South Australia (SA Division)'s Howchin Medal) as featured in Key Awards (page 21).

Some major staff changes occurred in 2013. We wish Professor Bruce Ainsworth all the best in his new industry role as he leaves the Centre. Dr Stijn Glorie was appointed as a new lecturer in Geology and Geophysics. Dr Khalid Amrouch, a structural geologist was also appointed as a lecturer and researcher in the Australian School of Petroleum and Frank Rarity joined the *WAVE* Consortium as a postdoctoral researcher. I would also like to thank Associate Professor Nigel Cook and Dr Simon Holford for their invaluable advice and support as part of their Deputy Director roles in 2013.

TRaX strengthened its collaboration with the Geological Survey of South Australia (GSSA) in 2013, through a joint Honours program. The first student intake began in 2013, with students supervised by both GSSA and TRaX staff. This is a great opportunity for staff and students alike.

The Centre has recently revitalised its Advisory Board to reflect a spread of researchers and industry professionals across both the petroleum and mineral sectors. This breadth of expertise has enabled us to identify and strategically develop new research opportunities. I look forward to seeing the results of this new focus continue to manifest throughout 2014.

PhD student Morgan Blades gets some assistance sampling Neoproterozoic gneisses in western Ethiopia.

Looking north across the mouthbar of the primary Mitchell River channel, Queensland, Australia.

Project highlights

Deep Exploration Technologies Cooperative Research Centre (DET CRC) Program 3: Deep targeting research to maximise drill hole success

Dr Steven Hill, Dr Caroline Forbes, Dr Cristiana Ciobanu, Dr Robert Dart, Simon van der Wielen and Professor David Giles

DET CRC focuses on mineral exploration technologies. Research within Program 3 aims to ensure that drill holes for mineral exploration are placed to maximise their success, using both seismic and geochemical exploration methods.

Researchers have processed the DET CRC Hillside 3D seismic survey and confirmed the capability of a light weight, rapid and relatively inexpensive seismic survey to identify iron-oxide lithologies and image complex, steeply dipping structures in a hard rock setting.

State-of-the-art microscopic techniques have been used to show that sub-economic iron-oxide copper gold (IOCG) mineralisation in the Craton was affected by a late fluid event associated with hematite and chlorite alteration. A highly-comprehensive atlas has been developed that is a one-stop reference for explorers wishing to maximise exploration value of cover sequence material in the highly prospective but deeply covered Gawler Craton.

Future research across DET CRC will focus on three core technologies – a coiled tubing drill rig capable of rapid, cheap drilling; an autonomous sonde capable of capturing downhole geophysical and rock property data during the drilling process; and a Lab-at-Rig™ system for gathering real time mineralogical and geochemical data from drill cuttings.

Ancient systems help improve characterisation techniques for future

Dr Rachel Nanson, Dr Boyan Vakarelov, Professor James MacEachern (Simon Fraser University) and Professor Bruce Ainsworth (former Lead Investigator now with Chevron Energy Technology Ltd)

The WAVE Consortium Phase II (2011–2014) is an eleven company, industry-sponsored research consortium based at the Australian School of Petroleum. It aims to better characterise mixed-influence coastal depositional environments and analyse potential impacts of heterogeneities on hydrocarbon reservoir connectivity and compartmentalisation.

A key deliverable of the Phase II Project is the characterisation of the modern analogue Mitchell River delta in Queensland, Australia. The 2013 field drilling campaign was highly successful, and results will be communicated to industry via the American Association of Petroleum Geologists (Houston) and Canadian Society of Petroleum Geologists (Calgary) 2014 meetings. Visits were also made to sponsor companies throughout North America and Europe. Visits will be made to Australian and New Zealand offices before completion of Phase II in December 2014.

WAVE Phase III is due to commence in February 2015. Owing to current industry interest in tide-influenced fluvial reservoirs (e.g. McMurray Formation, Canada), it will build upon existing modern analogue WAVE datasets from the Gulf of Carpentaria and Mitchell River delta channels and will investigate the *"Architecture and Heterogeneity of Tide-Influenced Fluvial Channel and Fan-Delta Systems"*.

Microscopic solution to major mining challenges

Dr Frank Reith, Dr Carla Zammit (formerly IMER, University of Queensland), Dr Florian Weiland and Associate Professor Peter Hoffman

As demand for new exploration and processing technologies grows, microbial-based exploration is becoming one of the mining industry's fastest growing research areas. TRaX researchers are leading the charge in investigating the use of microbes in gold exploration.

After discovering a bacterium with an active genetic response to mobile toxic gold, the research team led by Dr Reith developed a prototype of a biosensor capable of measuring gold down to the parts per million level. Building on this cellular-level work, the team are working with the Adelaide Proteomics Centre to identify the specific proteins involved. The aim is to develop a protein-based sensor for gold, similar to those used in blood glucose tests.

By stripping away the cells and working with the pure proteins, the researchers have made significant progress towards understanding the proteins involved in gold detoxification. However, further funding is now required to translate their highly promising research findings into a field-based test.

New insights into magmatic plumbing system of the South Australian Quaternary Basin

Sam Holt, Dr Simon Holford and Professor John Foden

Many oil fields are closely related to faults and magma can interfere with their structural integrity. Magmatism can also be associated with an influx of CO_2 which can make fields uneconomic.

The Newer Volcanic Province in the South Australian Quaternary Basalt (SAQB) is the site of the most recent phase of volcanic activity in Australia. Large volumes of seismic data have been collected during gas exploration in the region, making it a natural laboratory for examining magma transport through the Earth's crust.

The research team used a combination of geochemical modelling, 3D seismic data and volume visualisation to investigate magma transport. Results showed that magma in the SAQB underwent approximately 34–41 per cent fractional crystallisation as a result of approximately 200°C cooling during ascent. This indicates a residence time of days to weeks, inferring that the magma took a direct path through the crust.

The research insights into the magmatic plumbing system of the SAQB are helping to discriminate between competing magma transport theories and aid oil exploration. The results indicate a potential correlation between the size and volume of the magmatic system, with small-scale systems like the SAQB adhering to traditional vertical models of magma ascent.

Crustal electrical resistivity heterogeneity – a potential vector to mineralisation

Dr Stephan Thiel, Professor Graham Heinson, Paul Soeffky, Kate Robertson and Sebastian Schnaidt

The eastern Gawler Craton and Stuart Shelf region is one of the most prospective mineral provinces on Earth. However, as the prospective rocks are covered by sediments, the deep mineral system and the crustal architecture that provide its framework are poorly understood. Magnetotellurics (MT) is an electromagnetic geophysical technique that is able to penetrate the cover sequences and image to depths of several hundred kilometres.

Using an array of approximately 200 long-period MT sites, the team has developed a new three dimensional crustal resistivity model for an area of approximately 30 000 square kilometres and to

a depth of 50 kilometres. Three-dimensional models of this type provide a new approach to defining regional prospectivity.

In 2013, an 80-site broadband MT survey was also centred over the Olympic Dam deposit and provided much higher resolution of upper and mid-crust than ever seen before. Conductive pathways were imaged through the resistive basement, connecting the highly conductive surface sediments with a large conductive zone approximately 20 kilometres deep. The conductive heterogeneity of the crust helps constrain regions of potential mineralisation indicating that these conductive upper-crustal pathways may be a vector to mineralisation.

Investment highlights

IMER invests in research projects to advance our leadership in strategic research priority areas aligned to industry and community needs. Here we highlight the research projects supported by IMER.

More advanced geochemical and isotopic tools improve tectonic analysis and mineral exploration

Dr Justin Payne, Professor Martin Hand, Professor Alan Collins and Associate Professor Nigel Cook

Dr Payne has supervised the growing use of the Laser Ablation Multi-Collector ICP-MS in 2013. Researchers have been taking full advantage of the rapid sample throughput and increased data quality in uranium-lead geochronology and trace element analysis available through the facility. Sample throughput increased by approximately 50 per cent compared to previous instrumentation and demand remains extremely high.

Dr Payne shared his expertise with University of Adelaide and DSD researchers through a user's course on laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). Dr Payne and colleagues have also developed a method to quantify the influence of isobaric and molecular interferences on LA-MC-ICP-MS analysis of Lu–Hf isotopes in zircon, which will help to increase the accuracy and precision of isotope ratio measurements used to determine the age of mineralising events.

TRaX's capability will also be boosted by the commissioning of a new thermal ionisation mass spectrometer, purchased through an Australian Research Council Linkage Infrastructure Equipment and Facilities grant. This will also play a vital role in tracing Australia's ancient evolution and securing our future groundwater resources.

Using iron isotopes in exploration of hydrothermal ore deposits

Professor John Foden and Chris Wawryk

IMER researchers are amongst only a few in the world examining the use of iron isotopes to decipher magmas, fluids, modes of ore deposition and ore fluid transport. This novel research aims to characterise the iron isotopic composition of ore minerals precipitated from fluids discharged from cooling, crystallising granite magmas. The iron isotope signatures reflect the oxidation state of the parental granite body, and our research on the Tasmanian Renison tin deposit confirms the source of the ore fluids from a reduced, sedimentary-source granite.

The team analysed bulk samples of granite and separates of pyrrhotite, pyrite, arsenopyrite, magnetite, chalcopyrite and siderite. The pyrite, magnetite and chalcopyrite from the hottest ore fluids (>300-400°C) at Renison are isotopically heavier than minerals from comparator deposits derived from more oxidised intrusions. The partitioning of the iron isotopes between different coexisting ore mineral has a potential to provide a useful geothermometer, reflecting the temperature of ore precipitation. Outcomes from this research have led to further research funded by BHP Billiton Ltd which will apply the same techniques and concepts to deposits at Olympic Dam.

Understanding the iron isotope ratios that are associated with different granites could potentially lead to development of geochemical tools for mineral exploration of hydrothermal ore deposits.

ARC Future Fellowship investigates origins of petroleum deposits

Professor Alan Collins

Prof Alan Collins was recognised as one of Australia's best and brightest mid-career researchers with the award of a highly competitive Australian Research Council Future Fellowship in 2012.

Prof Collins is investigating the geography of Australian Gondwana between 850 and 500 million years ago – a period of major climatic extremes, rapid evolution and the deposition of some of the oldest petroleum source rocks. This year marked the first year of his fellowship, and saw the appointment of two PhD students and the beginning of their associated field programs in Madagascar, Ethiopia and Oman. A new collaboration with the Sultan Qaboos University in Oman has begun and collaborations with the Geological Survey and Ministry of Mines in Ethiopia are being established. Prof Collins also hosted a visiting fellow from Perth, Western Australia, to work on paleomagnetic reconstruction.

The commencement of student recruitment, field programs and international relationship-building signal the start of a highly successful fellowship.

Research Highlight

Geochronology & thermometry techniques reveal thermal structure of central Australia's architecture

Mountain ranges are formed when lateral compression leads to folding and deformation of the Earth's crust. Called orogeny, this deformation commonly occurs at the margins of continental plates. However, central Australia is home to an exceptional example of intraplate orogenesis – the Ediacaran-Cambrian Petermann Orogeny.

PhD student Alec Walsh.

The Petermann Orogeny is located in central Australia's Musgrave Inlier (about the size of Victoria), and led to the current day structural architecture of the Inlier. The major tourist attractions of Uluru and Kata Tjuta define the northernmost preserved part of the Petermann Orogeny. The age span of the Petermann Orogeny is relatively well known for the Musgrave Inlier (600-550 million years ago) but the rate of metamorphism and cooling that occurred in the most deeply exhumed parts of the orogeny has been the subject of competing theories.

The 'cold' theory proposed by Camacho *et. al.* (2001, 2009) suggests that deformation in the core of the Petermann Orogen occurred in cold, strong crust over very short periods of time; approximately 1 million years. Alternatively, Raimondo *et. al.* (2009, 2010) proposed the 'hot' theory, whereby weak and hot crust involved lateral flow of ductile lower crustal material (called a channel-flow regime). The timescale associated with this type of deformation is comparatively long – more than 20 million years.

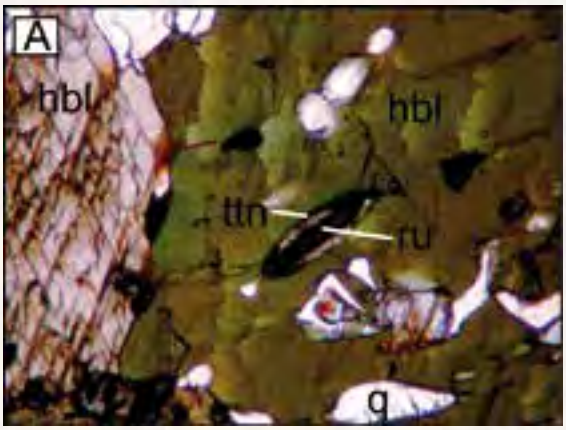
PhD student Alec Walsh analysed seven samples from the legacy collections of the Northern Territory Geological Survey, taken from the core and proximal foreland of the central Petermann Orogeny. These samples were selected because they originated from between the widely separated study areas of Camacho et al (2001, 2009) and Raimondo et al. (2009, 2010). Sensitive High Resolution Ion Microprobe (SHRIMP) uranium (U)–lead (Pb) geochronology was conducted on zircon, to determine the age of metamorphism – the highest temperature part of the rock's history and on titanite and rutile, to determine the age at which the (same) rocks cooled through

certain temperature windows. The temperature at which zircon grew was determined using zircon trace element thermometry, which is based on the temperature-sensitive concentration of tiny amounts of titanium (Ti) in zircon. The concentration of Ti was measured using the University of Adelaide's laser ablation–inductively couple–mass spectrometry (LA–ICP–MS).

U–Pb zircon analysis and Ti-in-zircon thermometry indicated that the highest metamorphic temperatures of 720–760°C occurred 544 ± 7 million years ago. Closure of Pb diffusion in titanate showed that subsequent cooling to 600–660°C had occurred by approximately 521 million years ago, giving a cooling rate of 2.6–7.0°C every million years. Pb closure in rutile suggested that further cooling to 585–560°C occurred by 498–472 million years ago, implying a potential slowing of the cooling rate to about 0.9–4.8°C every million years for this lower temperature part of the rock's exhumation history.

The results of this research indicate that metamorphism and deformation in the Petermann Orogeny occurred for much longer than that allowed by the proposed 'cold' mechanism. This study demonstrated that metamorphism and deformation in the central and western parts of the orogen lasted for more than 40 million years in crust characterised by higher, hotter thermal gradients between 17 and 26°C per kilometre.

Mr Walsh's research supports the hypothesis that the Petermann Orogeny formed over a comparatively long period, dramatically increasing the spatial footprint of 'hot', weak crust. The thermal gradients that characterise the Petermann Orogeny are comparable to those of typical collisional orogens, suggesting that the rheological development and thermal evolution of intraplate orogens may be similar to orogens that develop at plate margins.



A: Thin titanite (ttn) corona developed around rutile (ru) during retrogression from high-grade metamorphism.

Characterising the thermal structure of the crust – how rapidly temperature changes with depth – is critical to defining prospective or barren regions for mineral explorers.

Reference

Walsh AK[a], Raimondo T[b], Kelsey DE[a], Hand M[a], Pfitzner HL[a] and Clark C[c] (2013) *Duration of high-pressure metamorphism and cooling during the intraplate Petermann Orogeny.* Gondwana Research 24, 969–983.

[a] Centre for Tectonics, Resources and Exploration (TRaX), School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia

[b] School of Natural and Built Environments, University of South Australia, Adelaide, South Australia

[c] Department of Applied Geology, Curtin University, Perth, Western Australia

South Australian Centre for Geothermal Energy Research (SACGER)

Working towards efficiently and sustainably managing the world's energy resources for the benefit of society, industry and the environment

SACGER's mission is to establish a world-class centre for practical, high-priority geothermal energy research with a focus on enhanced (engineered) geothermal systems and geothermal power systems that will result in widespread benefits at a state, national and international level.

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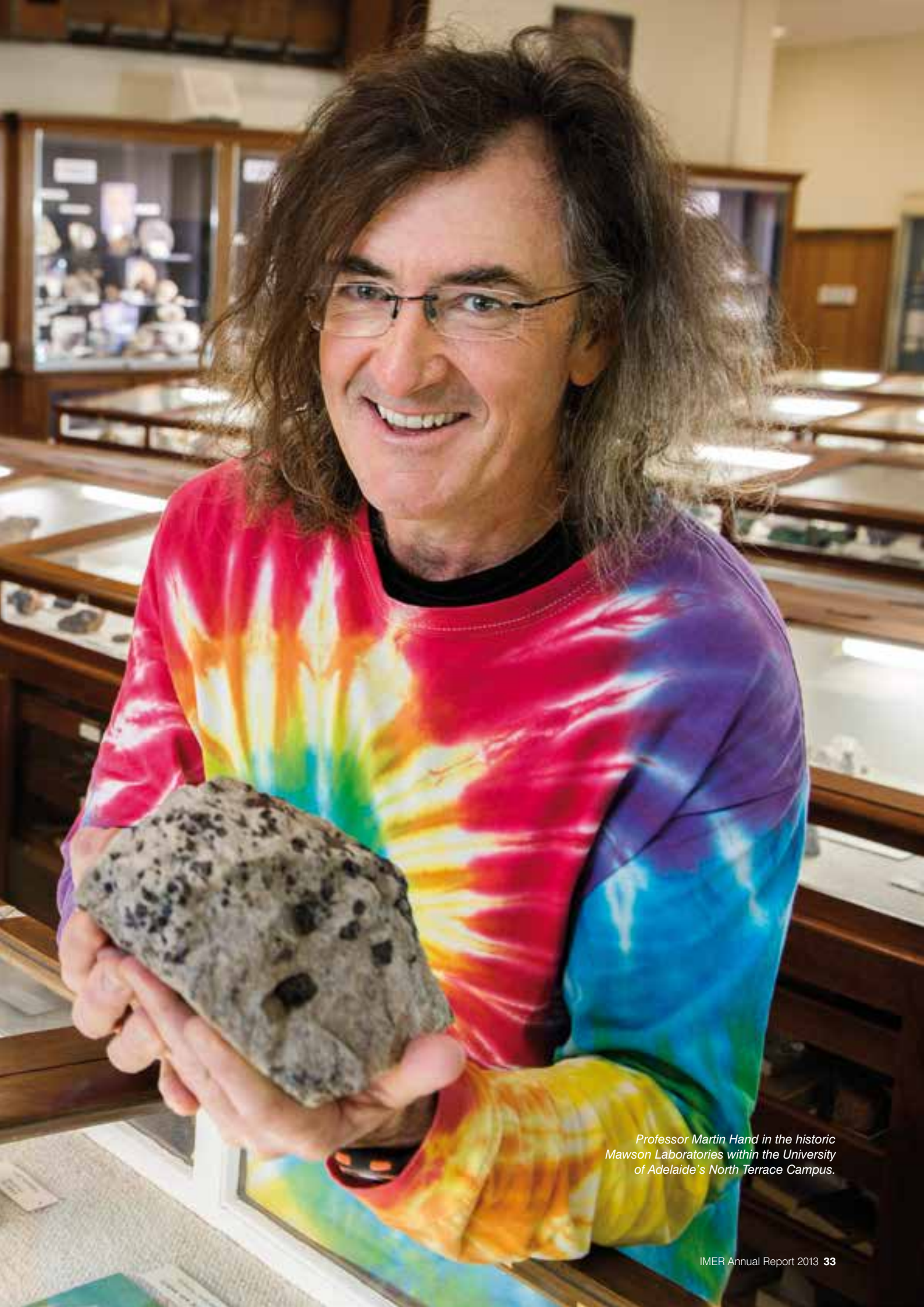


Professor Martin Hand in the historic Mawson Laboratories within the University of Adelaide's North Terrace Campus.

Director's report

Professor Martin Hand

Since the inception of the South Australian Centre for Geothermal Energy Research (SACGER) our industry-focused research and interdisciplinary approach have underpinned our success. We have helped develop collaborations between research groups at the University as well as externally with industry and other research institutions, allowing us to deliver enhanced research outcomes.

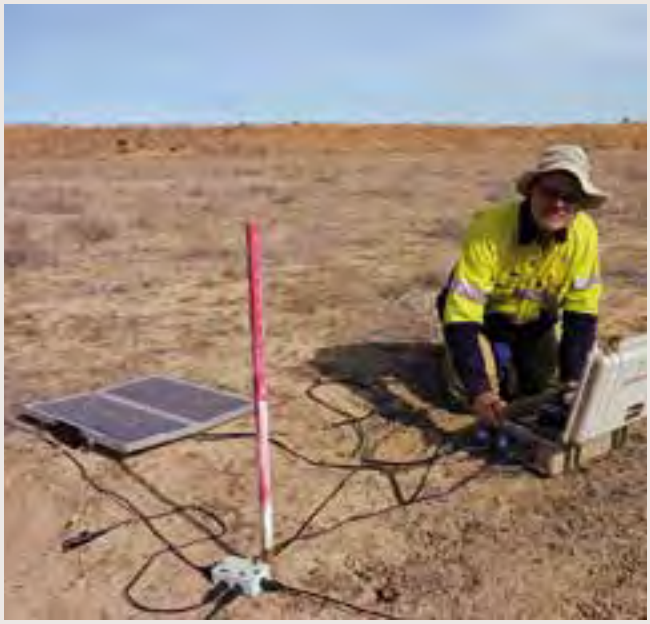
A great example of this is our four-dimensional magnetotelluric monitoring conducted at the Paralana geothermal energy project. For the first time, we have been able to comprehensively map sites before, during and after fluid movement – critical information to realise the potential of geothermal energy. Congratulations to Dr Stephan Thiel and the geophysics team who received an innovation award for developing this technique (Key Awards page 21). The use of this novel technique has the potential to lead to millions of dollars of ongoing research and revolutionise geothermal energy as well as the monitoring of unconventional gas extraction, including coal seam gas.

The first phase of our $3.7 million Australia-wide geothermal collaboration with CSIRO, DSD and industry partners Panax Geothermal Ltd and Geodynamics Ltd was completed in 2013. This research program, co-funded by the Australian Renewable Energy Agency (ARENA), is analysing the only two wells drilled in hot sedimentary aquifers in Australia and has found that diagenetic factors and formation damage may explain why fluid flow rates were lower than expected in these reservoirs.

Another exciting development in 2013 was the setting up of a petrophysical laboratory with an emphasis on measuring the petrothermal properties of drill core. After six months of testing and calibration, we established a quality assurance and control program for the laboratory. This facility is now being used to measure rock samples collected as part of our research funded by AuScope's Australian Geophysical Observing System (AGOS). The results of this research are significantly increasing our understanding of the South Australian shallow crust by examining in situ stress, migration mechanisms of ore-bearing paleofluids and maturation and migration processes in shale-hosted and coal seam gas resources.

The SACGER team has also been forging international connections through conference presentations around the world. Jo Varney presented a paper on using geothermal energy to preheat feedwater in a traditional steam power plant at the 38th Workshop on Geothermal Reservoir Engineering, Stanford University, United States. SACGER was also well represented at the American Geophysical Union Fall Meeting in San Francisco, United States, with presentations by Jared Peacock and Dr Hani Abul Khair on modelling time-varying magnetotelluric responses measured during a fluid injection and natural fracture networks enhancing unconventional reservoir production respectively.

With SACGER funding coming to an end in 2014, we have begun an important transition into the broader field of unconventional energy resource research. Keeping our eye on common research questions in the geothermal, oil and gas industries has enabled us to identify opportunities to adapt to changing industry, government and funding priorities. The significant analytical capabilities in fluid permeability and hydraulic fracturing developed within SACGER and complementary capabilities across IMER should facilitate a smooth transition into unconventional energy resource research.



The Electrical Earth Imaging team deploying magnetotelluric equipment in the Cooper Basin.

Project highlights

Determining the resource and energy potential of the northern Gawler Craton, Officer and Arckaringa Basins, Musgrave Domain and Torrens Hinge Zone, South Australia

Professor Martin Hand, Dr Betina Bendall (DSD), Jeremy Schulz and Cameron Bowker

Prof Martin Hand is leading this AuScope Australian Geophysical Observing System (AGOS) funded project, to increase our understanding of the mineral and energy resource potential of under-explored regions of the South Australian shallow crust.

The research team is gathering a comprehensive dataset of petrophysical and complementary wireline log data from existing and new wells across the northern and eastern Gawler Craton, Officer and Arckaringa Basins, Musgrave Domain and Torrens Hinge Zone. Eleven wells, belonging to seven different companies, have been logged at various project locations throughout South Australia. Most of these wells were co-funded by DSD's Plan for Accelerating Exploration (PACE) program. The team is currently negotiating access to another three sites.

Data collected in this project is being used to materially constrain *in situ* stress, geophysical inversions, geological and geothermal models and regional interpretation. The results of these models will improve the understanding of the migration mechanisms of ore-bearing palaeofluids such as uranium mineral systems and iron oxide copper gold deposits, as well as maturation and migration processes in shale-hosted and coal seam gas resources. The data will also be made publicly available for further research.

Project highlights continued

Reservoir quality in sedimentary geothermal resources

Professor Martin Hand, Professor Pavel Bedrikovetski and Professor Allan Pring

SACGER is leading an Australia-wide, ARENA-funded collaboration with CSIRO, Department of State Development, Panax Geothermal Ltd, Geodynamics Ltd and the South Australian Museum to analyse the only geothermal wells drilled in hot sedimentary aquifer reservoirs in Australia. The aim is to evaluate why the actual fluid flow rates achieved were significantly lower than expected.

Two programs were undertaken that used a combination of petrology; scanning and transmission electron microscopy; QEMSCAN® mineral analysis; cathodoluminescence; and seismic attribute analysis. Laboratory experiments were used to simulate secondary mineral growth and fines production under different conditions as well as model reservoir behaviour.

The first program evaluated the primary reservoir quality of the two target formations – the Pretty Hill Formation in the Otway Basin and the Hutton Sandstone in the Cooper-Eromanga Basin. The second program evaluated formation damage that may have been caused during the drilling of the two wells and subsequent production tests.

The research team found that diagenetic factors may have made the deep, hot water reservoirs less permeable than expected. However, these effects are not uniform basin-wide, and more permeable zones could potentially be identified using seismic analysis and petrology. The research also showed that formation damage is more likely in geothermal settings with hot water than hydrocarbon reservoirs under production, which may have restricted fluid flow.

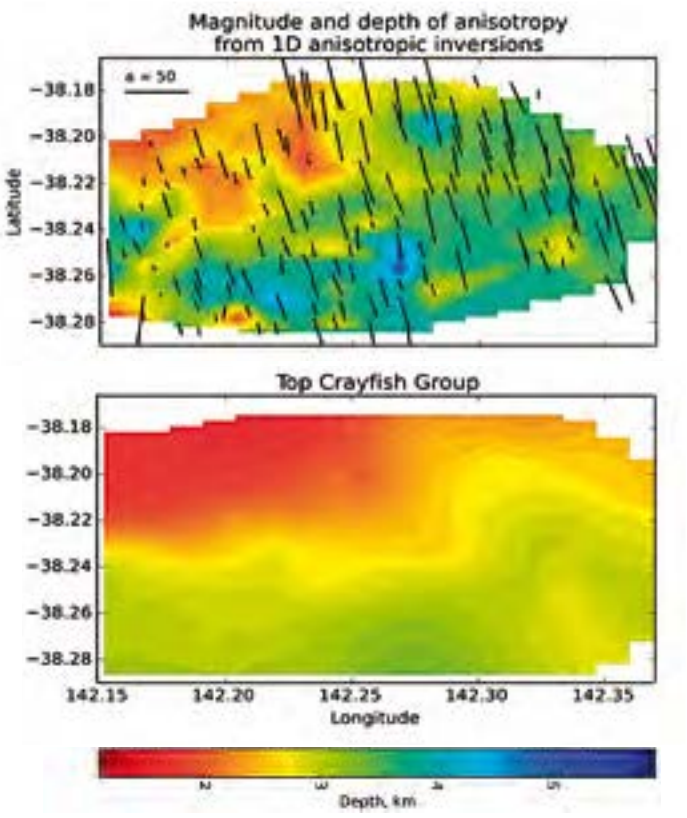
Mapping stress orientations, temperature and permeability with electromagnetic geophysics

Dr Simon Carter, Professor Graham Heinson, Dr Simon Holford, Dr Stephan Thiel, Alison Kirkby, Jake Macfarlane and Yohannes Didana

Electrical resistivity of upper crustal rocks could potentially be used to ascertain temperature, porosity and permeability for geothermal energy resource development. The research team is investigating the relationship between the direction of electrical current flow in the crust and regional stresses in order to determine if this is possible.

Using existing industry data sets from various geothermal prospects in Australia, the team has developed new maps that indicate fracture alignment based on the anisotropy of electrical current flow. These fracture alignment maps at depths of several kilometres, may be very significant for geothermal source stimulations and for shale gas developments.

In 2014, a new three dimensional magnetotelluric data set of more than 100 sites is planned for the Otway Basin, south of Penola – covering an area of about 200 km^2. *See figure below.*



The top pane shows the depth of maximum electrical anisotropy from our surface EM measurements (in colour), which we interpret as fractures, and the bars represent the amount and orientation of anisotropy. The lower figure shows the depth to the same formation determined from drilling and seismic methods. The axes are in latitudes and longitudes, it is about 10 km north south by 20 km east west.

Optimisation of enhanced geothermal systems

Professor Nigel Bean and Jo Varney

Power plants associated with enhanced geothermal systems (EGS) often operate in remote, outback locations in Australia. Due to the lack of water in these regions, the plants may be air-cooled. Mathematical modelling was used in this research to examine the impact of ambient air temperature on the power output of air-cooled power plants and the performance of EGS and hot sedimentary aquifer plays in Australia.

The research team is investigating revenue by modelling the link between temperature, production and electricity price. Their analysis suggests that the effect of ambient design temperature should be carefully considered, because for every 14°C increase above the ambient temperature used for design purposes there is approximately 20 per cent loss in brine efficiency. Conversely, there is no gain in efficiency for any drop in ambient air temperature. Using temperature distribution data from 12 sites across Australia, the team's analysis showed that an optimally designed geothermal plant can produce around six per cent more energy annually than a plant designed using the mean ambient temperature. This is important as in summer the ambient temperature reduce electricity production from an air-cooled geothermal plant, when market prices are at their highest.

The team is now investigating the efficiencies that can be gained by integrating geothermal preheating of feedwater into traditional steam power plants that are predominantly coal fired. Initial results show that geothermal preheating can lead to up to six per cent extra power than a traditional steam plant and up to double the total efficiency compared to a geothermal plant alone.

Research Highlight

Fines migration research in geothermal reservoirs has impacts for oil and gas industry

Clogging due to fines migration has long been a worldwide problem in the oil and gas industry. In more recent times it has been discovered that geothermal reservoirs also experience the same problem. Prof Pavel Bedrikovetsky from the Australian School of Petroleum is investigating the impact of fines migration in geothermal reservoirs. This research has the potential to improve prospectivity in geothermal reservoirs but will also have wider reaching impacts, including in the oil and gas industries.

Professor Pavel Bedrikovetsky

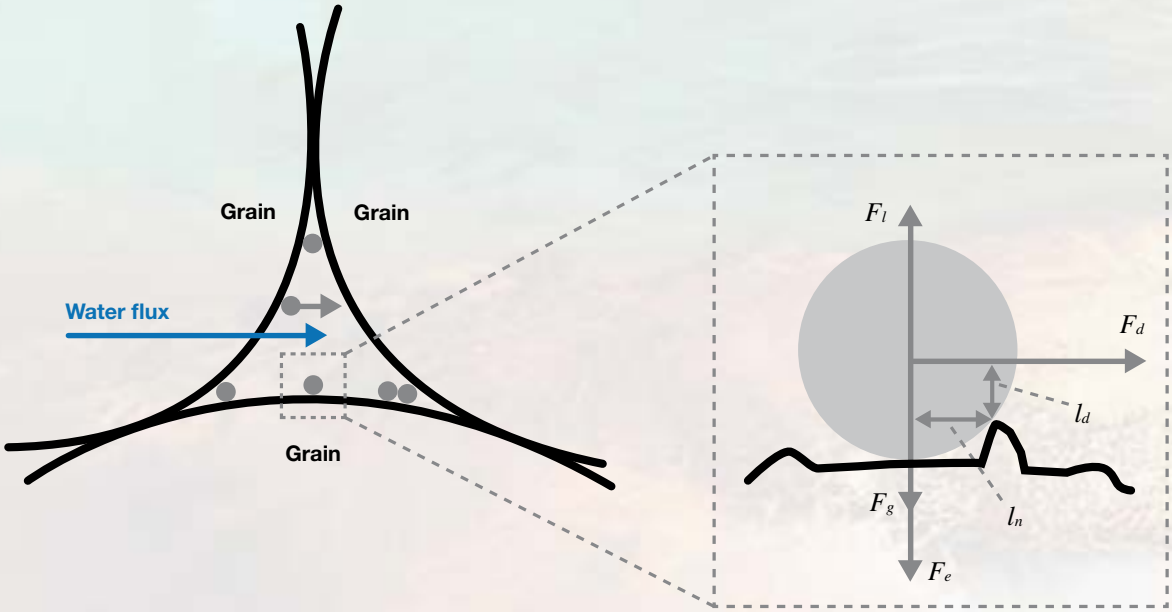
Fine particles on pore walls in reservoirs are subject to a number of forces. These particles mobilise when extraction disturbs the equilibrium between the electrostatic and gravitational forces that attach particles and the drag and lifting forces that detach particles (see figure). Mobilised particles become trapped in thin pores, reducing permeability and decreasing productivity.

Prof Bedrikovetsky and his colleagues have developed a new mathematical model that takes into account fines mobilisation, migration and clogging of production wells. The model uses empirical proportionality coefficients obtained by tuning laboratory data. The maximum concentration of attached particles is determined as a function of factors like velocity, salinity, pH and temperature, instead of the kinetic expression for detachment rates that is used by classical models.

The model uses a basic system of equations for water production in geothermal reservoirs with fines migration, including a pressure diffusivity equation for water; conservation mass for suspended, attached and strained forces; rate equation for mobilised fines straining and the critical retention function. Two typical stages of well impairment were demonstrated with modelling – a quasi-steady state with gradual straining of mobilised fines and asymptotical stabilisation of well productivity.

The research team's model was evaluated using field data from an Australian geothermal reservoir. The production well was discharged for five hours during which the rate decreased from 15.5 litres per second to 5 litres per second. Impedance gradually increased during discharge as straining of mobilised fine particles caused a decline in permeability near the wellbore. There was excellent agreement between the field data and mathematical modelling (coefficient of determination $R^2=0.99$).

Sensitivity analyses from laboratory data and model predictions show that geothermal reservoirs are particularly vulnerable to fines migration due to reduced electrostatic particle-grain attraction at high temperatures. At higher temperatures there are less attached fines, more mobilised fines and higher well impairment compared to conventional oil and gas reservoirs. Analyses also demonstrated that high flow rates resulted in more mobilised fines which increased impedance.



Cross-section of a pore throat and the forces acting on the attached particles where F_l is lifting force, F_e is electrostatic force, F_d is drag force and F_g is gravitational force.

Further analysis is needed to validate the model for geothermal well clogging by fines, as water samples were not taken and temperature, depth, porous media permeability, rock type and porosity were given. For full characterisation of particle flow behaviour and clogging, electrostatic potentials need to be measured from rock samples and attached particle and maximum retention levels determined from laboratory samples.

With geothermal reservoirs already more susceptible to fines migration than conventional reservoirs, the researchers are also looking strategies to reduce clogging, such as nanoparticle injection. When injected into wells, nanoparticles stick to fine particles, making them less susceptible to mobilisation and reducing clogging of pores.

In the past, companies have lost prospectivity almost instantly due to fines migration and clogging. Prof Bedrikovetsky's modelling research can help to anticipate the likelihood and scale of fines migration in different resources and allow industry to take steps to alleviate the problem where possible. A better understanding of fines migration and potential production rates will help to enhance the productivity of resources into the future.

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[1] Australian School of Petroleum, Centre for Tectonics, Resources and Exploration, The University of Adelaide, Adelaide, South Australia

[2] Panax Geothermal Ltd, Milton, Queensland

Centre for Energy Technology

We support the sustainable economic development of Australia through innovative clean energy technologies.

The CET integrates the science and technology of thermal-fluids, advanced energy materials and energy systems to generate cost-effective pathways to cleaner power and fuels, especially through hybridisation.

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Home Schools

School of Chemical Engineering
School of Chemistry and Physics
School of Earth and Environmental Sciences
School of Economics
School of Electrical and Electronic Engineering
School of Mathematical Sciences
School of Mechanical Engineering

Professor Gus Nathan, CET Director, within one of CET's laser diagnostic laboratories. The team have developed a novel laser based technique, referred to as Non-Linear Two Line Atomic Fluorescence, to achieve the world's first planar measurement of temperature in turbulent flames with soot.

Director's report

Professor Graham 'Gus' Nathan

It's been another exciting year for CET, with strong progress in all of our research priority areas and growing linkages with industry. In particular, we have now established a strong partnership for our Energy Storage Knowledge Bank and Test Platform proposal with the support of with SA Power Networks, Solar Storage, Energy Networks Association, State Government of South Australia, Zen Energy Systems, Power and Drive Renewable Solutions and Regional Development Australia.

Three new patents are pending from our team's innovative research and development program, which align well with our vision to support Australia's sustainable economic development. One of these patents describes a novel airfoil technology that decreases noise and increases performance from wind turbines, fans and aeronautical devices. The other two patents describe two complementary solar hybrid technologies that will help reduce the cost of solar thermal power plants.

We have also seen a growth in interdisciplinary activities with the establishment of a program in solar fuels that embraces the Schools of Chemistry and Physics, Chemical Engineering and Mechanical Engineering. This team is addressing the full path of the process from the solar resource, through the syngas production to the downstream processing to Fischer Tropsch liquid fuels. This program includes CET's work as a key partner in the Australian Solar Thermal Research Initiative, an $87 million collaboration led by the CSIRO and funded by ARENA, to lower the cost of solar power and fuels to reach 12 cents per kilowatt hour by 2020.

I was proud to see CET's wide-ranging interdisciplinary research showcased during our research day in December which was attended by Chair of the ARENA Board, Greg Bourne. CET had strong representation at many conferences in 2013, including the Australian Symposium on Combustion and the Acoustics 2013 conference, contributing 15 and 19 papers respectively. Prof John Abraham, who holds a joint appointment at the Universities of Adelaide and Purdue, also gave the Bilger Keynote Lecture at the Australian Symposium on Combustion on recent progress in modelling reacting diesel sprays. PhD candidate Peijun Guo was awarded the Chris Fell Prize for the Best Student Paper at the Australasian Chemical Engineering conference (Chemeca 2013). In total, CET researchers published 180 journal articles and 132 conference papers as well as two book chapters throughout the year.

Our international engagement is growing with two visiting fellowships awarded to CET members from the Japan Society for Promotion of Science (JSPS). A/Prof Chris Sumby, Deputy Dean (Research), Faculty of Sciences, was awarded an International Invitational Fellowship while A/Prof Christian Doonan, also affiliated with the Centre for Advanced Nanomaterials, was awarded a Visiting Fellowship.

We welcomed several new staff members to the CET team in 2013. Of particular note are Dr Woei Saw, who brings specialist expertise in twin-bed gasification of biomass; Dr Yunpeng Xue who is investigating novel approaches to lower the cost of heliostat fields by aerodynamic design; and Dr Zhiwei Sun who is making an outstanding contribution to our laser diagnostics program.

Recovering liquid and gaseous energy from microalgae biomass – a major research focus within the School of Chemical Engineering.

Project highlights

Alternate combustion technology to reduce greenhouse gas emissions

Dr Paul Medwell and Professor Bassam Dally.

Moderate or intense low oxygen dilution (MILD) combustion technology uses recirculated heat and exhaust gases to achieve stable volumetric combustion at moderate temperatures. This combustion regime can increase thermal efficiency, while reducing greenhouse gas emissions.

The research team of Dr Medwell and Professor Dally investigated the combustion of natural gas, ethylene and liquid petroleum gas under MILD conditions using a Jet in Hot Coflow burner and modelled the reaction zone using laminar flame calculations. A similar reaction zone structure was found for all three fuel types and the different fuels also showed similar combustion characteristics. This work suggests that MILD combustion can be readily adapted to different fuel types – a major advantage for incorporating MILD combustion into industrial systems.

In conjunction with research into the combustion of liquid and solid fuels like ethanol and coal, the MILD combustion research will help to progress the development of advanced combustion technology that can be commercially deployed.

Industrial scale development of energy from microalgae

Associate Professor David Lewis, Professor Peter Ashman, Dr Andrew (Kwong) Lee, Michael Jureidini, Wynand van den Berg, Quang Doan, Blessing Eboibi, Mason Erkelens, Amir Forghani, Theo Kalaitzidis, Daniel Lane and Andrew Ward.

Recovering liquid and gaseous energy from microalgae biomass is a major research focus in the School of Chemical Engineering and includes hydrothermal liquefaction, gasification and anaerobic digestion. Energy recovery and resource recycle (carbon, nitrogen and phosphorus) are being used to assess the suitability for commercial application of the three technologies.

The researchers completed a life cycle assessment of an integrated microalgae to 'green' crude process incorporating hydrothermal liquefaction and anaerobic digestion. Based on an annual biomass productivity of 25 grams ash free dry weight, per square metre per day, the yield of green crude from the *Tetraselmis* species of microalgae is typically more than 45 per cent weight per volume – well above the target of 30 per cent. The 'green' diesel fractionated from the green crude produced an energy returned over energy invested (ERoEI) ratio 20 per cent higher and greenhouse gas emission 30 per cent lower than a conventional fossil diesel reference pathway.

The research outputs from this work are assisting Muradel Pty Ltd (University of Adelaide, Murdoch University and SQC Pty Ltd) with the commercialisation of biofuels from halophytic microalgae.

Pipeline implications of future energy media, Energy Pipelines CRC

Dr Neil Smith, Professor Peter Ashman, Professor Gus Nathan and Mark Coates (Hatch Pty Ltd).

Australia's pipeline industry carries natural gas, oil and water, but this may change in the future as different fuels are introduced and/or greenhouse gas emissions are captured.

The research team is identifying fluids with the greatest potential for pipeline transport over the next ten years to provide the most relevant information to the pipeline industry. Researchers are using a scenario modelling method to identify the likely commercial opportunities surrounding pipelines. The scenario modelling is also identifying and assessing pipeline technologies and opportunities with a competitive advantage, including the use of cheaper raw materials; unlocking stranded resources; building on existing infrastructure; reuse of old pipelines; value-adding to existing fluids; and providing storage capacity to even out peaks in supply/demand.

This work will be used to help the pipeline industry prepare for the future. For example, future fluid composition and pipeline operating conditions may require additional research into corrosion resistance and pipeline design to prevent fractures.

Improving wind farm design to increase efficiency

Associate Professor Nesimi Ertugrul, Anthony Pemberton (Parsons Brinckerhoff) and Thomas Daly (ElectraNet).

Optimising design of on-shore wind farms is critical to efficiency, reliability and economic-viability as well as keeping installation and running costs low to attract investment.

A/Prof Ertugrul and his team have developed a genetic algorithm-based optimisation method for wind farm design. The software employs computing power and mathematical algorithms to test hundreds or even thousands of potential cable network options for standard on-shore wind farm layouts. Through this software users can employ mathematics to optimise design rather than a time-consuming iterative manual calculation process. Users can select from a range of design components, including underground, overhead, single or triple-core cables as well as allow for inaccessible areas of a site (e.g. rivers, or locations with ownership or access issues). Decisions can also be made to maximise reliability or minimise costs.

Industry is already saving significant time and money through increased efficiency of wind farm design assessment using this software.

Project highlights continued

Developing new graphene-based catalysts and cathodes to replace precious metals

Professor Shizhang Qiao and Professor Mietek Jaroniec (Kent State University).

Renewable energy technologies like fuel cells and metal-air batteries rely on oxygen reduction and oxygen evolution reactions. Traditionally, the catalysts used in these reactions are the precious metals platinum or iridium.

The large surface area and conductivity of graphene make it a good potential catalyst and the research team has found that this low cost, abundant and readily-available product has comparable activity to traditional catalysts.

The team are also working on a carbon-based replacement for the platinum cathodes in hydrogen production. Based on theoretical predictions, they designed and synthesised graphene doped with nitrogen and phosphorus as an alternate electrocatalyst for sustainable and efficient hydrogen production. The nitrogen and phosphorus heteroatoms could coactivate the adjacent carbon atom in the graphene matrix by affecting its valence orbital energy levels, which induced a synergistically enhanced reactivity toward the hydrogen evolution reaction (HER). As a result, the dual-doped graphene showed higher electrocatalytic HER activity than single-doped graphene and comparable performance to some of the traditional metallic catalysts.

With research on track to increase the activity, efficiency and stability of graphene-based cathodes, the team are making a significant contribution to improving renewable energy technologies.

Investment highlights

IMER invests in research projects to advance our leadership in strategic research priority areas aligned to industry and community needs. Here we highlight the research projects supported by IMER.

Using wakes to design better wind farms

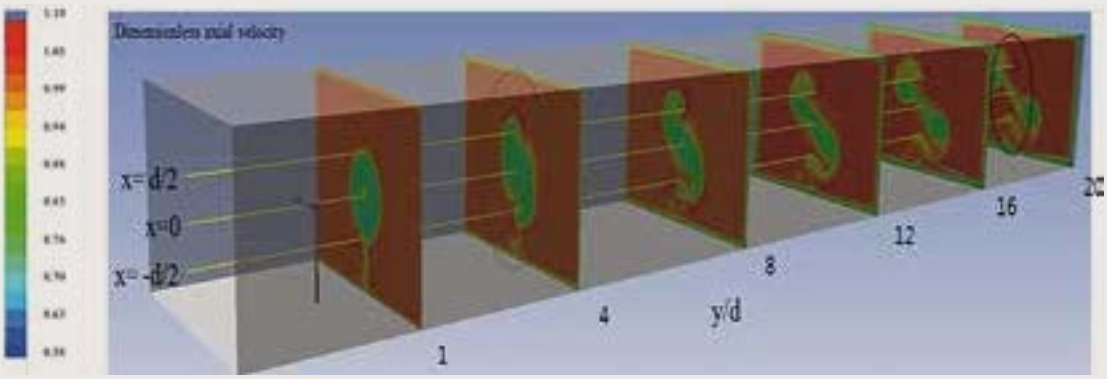
Dr Maziar Arjomandi, Associate Professor Richard Kelso, Associate Professor Benjamin Cazzolato, Amanullah Choudhry, Alex Laratro, Nima Sedaghatizadeh, Professor Young Ho Lee (Korean Maritime University) and Dr Jang-Oh Mo (Korean Maritime University)

The majority of wind farms are clusters of horizontal axis wind turbines. Clustering makes practical and economic sense but it means that most turbines operate in the wake of other turbines. This can impact on power output, dynamic loads, fatigue life due to turbulence and potentially noise levels.

Dr Arjomandi and the team investigated the impact of wake interactions using multi-processor computers. They simulated a high fidelity numerical model of the wake characteristics of a single turbine and compute the dynamics of the near-wake and far-wake. The team found that wake turbulence intensity can reach 10 per cent for a turbine operating in a low-turbulence wind which can reduce performance through excessive dynamic loading on the blade. Vortex structures generated in the wake of an upstream turbine can also interact with the blade of a downstream turbine and produce the low frequency 'thumping' noise sometimes reported near wind farms.

The team will now use a large scale wind tunnel to investigate wake propagation by multiple turbines and improve wind farm efficiency. *See figure below.*

Using wakes to design better wind farms



Instantaneous dimensionless velocity contours in the wake of the National Renewable Energy Laboratories (NREL) Phase VI wind turbine enclosed inside a virtual wind tunnel after ten revolutions of the turbine blade demonstrating the formation of pairwise vortex patterns in the wake. Details of the research can be found in: Laratro A.J., Arjomandi M., Kelso, R.M. and Cazzolato B.S. On wake-rotor interaction contributions to wind farm noise, Wind Engineering and Industrial Aerodynamics Volume 127, 2014, Pages 1-10.

Adelaide Airport.

Hybrids research to reduce the cost of solar thermal power

Professor Gus Nathan, Dr Maziar Arjomandi, Professor Bassam Dally, Professor Peter Ashman, Dr Woei Saw, Associate Professor Greg Metha and Associate Professor Christian Doonan

The Australian Solar Thermal Research Initiative (ASTRI) is an Australia-wide, international collaboration that brings together leading researchers and industry bodies in concentrated solar power (CSP) technologies. This eight-year, $87 million program, supported through ARENA, is investigating options for increasing the adoption and cost-effectiveness of CSP technologies

The University of Adelaide is leader of ASTRI's *Node 4 – Adding product value*. CET's contribution to the initiative includes investigating hybrids that combine solar energy with conventional combustion systems to lower the cost of continuous production of alternative liquid fuels with solar-based gasification.

In parallel with the work in ASTRI, CET researchers are establishing a globally-unique facility for developing solar fuels and solar hybrid technologies that includes a 15 kW thermal solar simulator. Located at the University of Adelaide's Thebarton research precinct, the simulator will be a highly sought after research tool for a diverse range of CSP-based projects. This will complement the laser-based systems in North Terrace that are used to probe the heat transfer and reactions within solar and solar-hybrid reactors and receivers. One of CET's novel hybrid technologies is a patent-pending hybrid solar-chemical looping combustion technology, which can provide a 60 per cent solar share, significantly more than the 3–10 per cent provided by current generation hybrids. A separate patent is also pending for a hybrid solar receiver-combustor technology.

Adelaide Airport Limited partnership pays off

Dr Timothy Lau, Dr Lei Chen, Associate Professor Eric Hu, Professor Gus Nathan and Professor Bassam Dally.

CET's platinum three-year partnership with Adelaide Airport Limited (AAL) concluded successfully in 2013, reducing total electricity consumption in the main terminal building (T1) by two per cent each year. Control methods were developed and implemented to optimise the heating, ventilation and air-conditioning systems through a 'smart plant room' project. The team also developed Australia's first fully validated thermodynamic model of a large, complex, multi-use building and identified and replaced faulty or underperforming devices.

The research undertaken in the Partnership has helped AAL become a recognised leader in sustainability as the first airport in Australia to achieve Airports Council International Airport Carbon Accreditation. The partnership also significantly increased AAL staff awareness of sustainable energy management and carbon emission reduction strategies.

Beyond the airport, the partnership has invested in a number of novel clean energy technologies with strong potential to make a long term step-change in clean energy use, including solar thermal hybrids, alternative fuels and clean combustion.

Ocean energy – understanding its potential

Associate Professor Ben Cazzolato, Professor David Walker, Dr Maziar Arjomandi, Dr Boyin Ding, Fantai Meng, Professor Gus Nathan, Dr Zebb Prime and Peter Hardy

CET researchers are involved in a number of projects that are investigating the vast potential of ocean energy. In this project, A/Prof Cazzolato and his team are partnering with Carnegie Wave Energy Ltd to see if the team's non-linear control systems can be used with Carnegie Wave Energy Ltd's submerged hydraulic heaving buoy system.

Researchers will model an electro-mechanical system coupled to incoming waves and use techniques like impedance matching to optimise power generation. Both numerical and experimental methods will be used to assess the system and help us to better understand the most efficient approach to harness the potential energy from wave power.

Research Highlight

Novel hybrid solar system to decrease the cost of solar thermal power

The low intensity and intermittent nature of solar radiation is one of the major barriers to economic viability of solar power systems. Concentrated solar thermal power (CSP) technology has the potential to supply economically viable power, but systems need storage capacity or back-up from auxiliary power so they can continue to supply electricity when solar radiation is below a threshold. Combining conventional combustion with renewable energy technology in a hybrid system eliminates the need for separate storage and can significantly decrease the cost of solar thermal power.

PhD student Mr Mehdi Jafarian.

PhD student Mr Mehdi Jafarian and colleagues from CET investigated combining solar technology with chemical looping combustion (CLC) technology. The aim was to develop a hybrid system that retained base-load capability and increased the solar thermal energy share. The research team designed a hybrid solar CLC (Hy-Sol-CLC) system, as shown in the figure below, in which concentrated solar thermal radiation from the solar collector field is captured and stored in oxygen carrier particles within the solar fuel reactor at a constant temperature. Using CLC process components – oxygen carrier particles, fuel and air reactors – the heat stored in oxygen carrier particles is released into the air reactor at a higher temperature resulting in a steady power output despite intermittent solar radiation input.

The research team developed mathematical models to compare the Hy-Sol-CLC system with other solar technologies. They have shown that the system is able to maintain a constant operating temperature at the air reactor outlet despite the variations in solar thermal energy input to the hybrid system. Simulations predict that the majority of the absorbed solar energy in the solar fuel reactor is stored in the oxygen carrier particles as sensible and chemical heat.

The Hy-Sol-CLC system is estimated to provide a 60 per cent solar share. This is significantly higher than the 3-10 per cent of solar share provided by current generation hybrids. Of the total energy input to the system – fuel plus absorbed solar energy – 95 per cent is released at a constant temperature and flow rate. This means the Hy-Sol-CLC system is suitable for base load power generation.

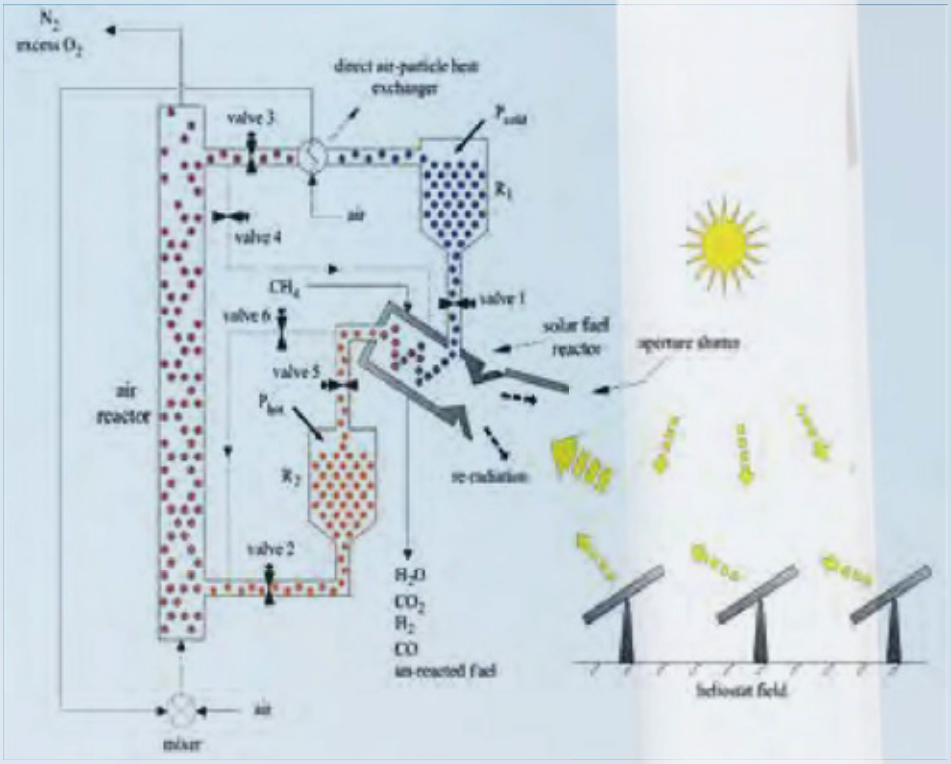
CLC technology is under development worldwide to capture CO_2 from the combustion of hydrocarbon fuel. However, this research is the first to investigate the potential for using CLC in conjunction with solar thermal systems. CLC technology is highly conducive to partnering with CSP technology – solar energy can be stored as chemical energy within the CLC process and facilitate a continuous CSP power supply. An added bonus is that the CO_2 produced in CLC is less diluted than that from conventional combustion systems meaning it can be sequestered more easily.

The proposed solar-CLC hybrid system. Reservoirs R1 and R2 are used to store the hot and cold particles produced in the solar fuel reactor and in the air reactors, respectively.

A direct air-particle heat exchanger is employed to further cool the particles to the OC particle storage temperature in reservoir R1.

Valves 1 and 2 are used to control the flow rate of OC particles to the solar fuel and air reactors, respectively.

The system can be also operated as a conventional CLC system using streams 13 and 14 and valves 3, 4, 5 and 6.



With a patent now pending for the Hy-Sol-CLC system, the researchers are on track to build the first prototype within three to five years. Their Hy-Sol-CLC system has the potential to contribute to step change in integrating renewable energy technologies into conventional power generation systems because the inherent variability of solar power can be managed within the one system which significantly reduces costs. Solar energy can be stored but their Hy-Sol-CLC can also be run as a conventional CLC system during extended periods of low solar radiation.

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Jafarian M[a], Arjomandi M[b] and Nathan GJ[b] (2013) *A hybrid solar and chemical looping combustion system for solar thermal energy storage.* Applied Energy 103, 671-678.

Jafarian M[a], Arjomandi M[b] and Nathan GJ[b] (2014) *A hybrid solar chemical looping combustion system with a high solar share.* Applied Energy 126, 69-77.

[a] School of Mechanical Engineering, The University of Adelaide, South Australia

[b] Centre for Energy Technology. School of Mechanical Engineering, The University of Adelaide South Australia

Associate Professor Chaoshiu Xu in one of the University of Adelaide's rock strength testing facilities.

Resource Engineering Program

Providing pathways to low-cost, low-impact and high yield mining, petroleum and energy resources exploration and extraction

Program Leader's Report

Associate Professor Chaoshui Xu

The Resource Engineering Program brings together capability in geostatistics, operations research, rock mechanics and geotechnical engineering through the mining/geotechnical engineering and petroleum engineering research clusters. In 2013, we continued to focus on delivering world-class research outcomes that provide pathways to low-cost, low-impact and high-yield, mining, petroleum and energy resource exploration and extraction.

Our program received significant industry investment during 2013. Prof Peter Dowd and I were able to secure more than half a million dollars over three years from Newcrest Mining Ltd. This investment will sponsor research to develop a technical management system to optimise the value chain from mine to mill. The need for improved technical management systems is becoming increasingly important across the industry as mining moves to lower grade and more complex ore bodies.

Prof Steve Begg and Dr Matt Welsh have also secured further industry support for the highly regarded Centre for Improved Business Performance within the Australian School of Petroleum. Woodside Energy Ltd and British Gas have now joined Santos and Exxon-Mobil as sponsors of the Centre and recognise its unique contribution to the decision-making research area. Australian School of Petroleum staff have continued their close relationship with industry partners as is evidenced by increased levels of contract research and consulting and the delivery of short courses to industry during 2013.

Prof Begg is to be congratulated on his appointment to the Society of Petroleum Engineers' information management discipline committee and distinguished lecturer series selection committee. Congratulations also to Prof Dowd, who was recognised for his contribution to geostatistics research with the Georges Matheron Lecturer 2013 award from the International Association for Mathematical Geosciences.

Looking ahead, the program's research direction is broadening to include more research applicable to unconventional resources. Extraction of unconventional resources depends primarily on the fracture network within the reservoir created using hydraulic stimulations. It shares many common modelling issues with other engineered reservoirs such as the hot dry rock enhanced geothermal systems (EGS) that have been a focus of our program and the SA Centre for Geothermal Energy Research. Many algorithms and methods for fracture network modelling developed by the group are equally applicable to unconventional reservoirs. Together with expertise from across the University of Adelaide, this changing focus to unconventional resources will significantly expand our research capability as an interdisciplinary research strength in IMER.

Home Schools

Australian School of Petroleum

School of Chemical Engineering

School of Civil, Environmental and Mining Engineering

Project highlights

Rock fractures and mineral and energy resources

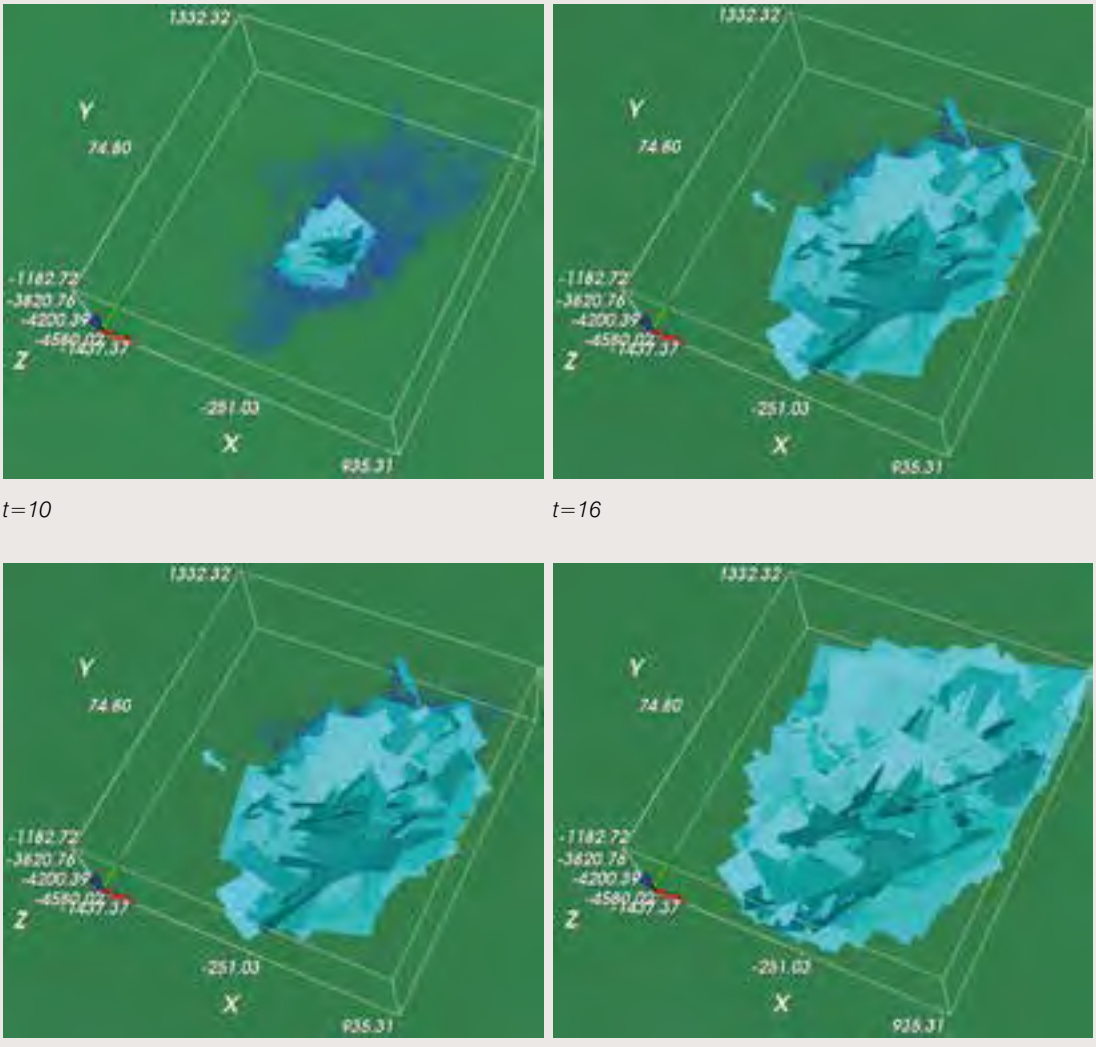
Associate Professor Chaoshui Xu, Professor Peter Dowd, Sattar Seifollahi, Younes Fadakar and Doone Wyborn (Geodynamics Ltd)

A detailed understanding of rock fractures and their spatial distribution is crucial to modelling and predicting fluid or gas flow in engineered reservoirs.

The team has developed a stochastic rock fracture propagation modelling algorithm which significantly advances rock fracture modelling conditioned on seismic data. This algorithm is capable of producing a fracture network that closely follows fracture propagation during the reservoir stimulation process and was able to reproduce all of the major features of Geodynamics Limited's Habanero geothermal field. A model such as this provides a reliable foundation for subsequent analysis in flow or heat transfer within the reservoir.

The team's research also has implications for *in situ* leaching of ores; design and control of block caving mining operations; heat extraction modelling and prediction for enhanced geothermal systems and the stability of rock excavations more generally. *See figure below.*

Rock fractures and mineral and energy resources



Stochastic rock fracture propagation modelling for Geodynamics Limited's Habanero field, which shows the fracture network model generated by the algorithm at four different time steps during the hydraulic stimulation process.

CO2CRC Otway Project – Stage 2 drilling. Over 176 metres of core was obtained during drilling. Image © CO2CRC.

CO2CRC's progress in carbon capture and storage recognised locally and globally

Reducing greenhouse gas emissions to the atmosphere is a key environmental issue and major challenge for Australia and the world. Carbon capture and storage (CCS) is vital as it is the only technology that can limit CO_2 atmospheric emissions from fossil fuel and biomass combustion. The CO2CRC, a collaboration of more than 150 researchers from Australia and New Zealand, is Australia's primary organisation for developing CCS technology as well as building local application knowledge.

Over the last ten years the CO2CRC has achieved international prominence by developing, with partners, some of the most sophisticated CCS research and development programs. Achievements include building of the CO2CRC Otway Project – the southern hemisphere's only active CO2 injection, storage and monitoring program. An outstanding collaborative research team with strong international linkages was formed in this project and innovative concepts, comprehensive datasets and first of a kind experiments developed.

In recognition of the CO2CRC's significant contribution to CCS technology development, the Federal Government has recently allocated a further $25 million to continue work on the Otway Project through 2020. For 2015 to 2020, the focus of future technology development will be on driving down costs and securing more efficient operational, monitoring and regulatory outcomes, all of which will be trialled at the Otway Project.

Decision-making research attracts worldwide interest

Professor Steve Begg and Dr Matthew Welsh

The Centre for Improved Business Performance (CIBP), within the Australian School of Petroleum, has pioneered a new research frontier that has attracted oil and gas companies from all over the world. It brings together research on how people should make decisions with research on how people actually make decisions.

Typically, people are rewarded or penalised based on the outcome of a decision. Good outcomes, even if a result of good luck or a poor decision-making, are valued over good decision-making. Neutrality is key to good decision-making and the CIBP helps members identify a whole range of significant cognitive and motivational biases that influence decision-making such as overconfidence, optimism and the illusion of control. Funded for the first nine years by Exxon-Mobil and Santos Ltd, another two major companies joined in 2013 – Woodside and British Gas. This is testament to the high value industry places on research outcomes. Interest in the CIBP's work is now increasing amongst the mining industry, with Prof Steve Begg an invited keynote speaker at GeoMet 2013.

Research over the next two years will focus on staff behavioural surveys for new members; individual differences and associated biases; methods for assessing judgement quality and the economics of decisions; and using incentives to improve decision-making.

Investigating the risk of geological CO_2 sequestration

Ernest Swierczek, C. Zhen-dong, Dr Simon Holford, Dr Guillame Backé (BP), Dr Rosalind King and Andy Mitchell

Geological carbon dioxide (CO_2) sequestration is now being considered as an option to reduce greenhouse gas levels in the atmosphere. Depleted oil and gas reservoirs typically have the natural conditions required for sequestration, but injection of liquids into these sites may change their structural integrity.

As part of his PhD research, Mr Ernest Swierczek is using seismic data and a geomechanical approach to examine the risk of fault reactivation on structural integrity in the western Gippsland Basin – a target area for CO_2 sequestration. A best and worst case scenario was investigated to give the team a range of fluid pressures that could impact on structural stability. Hybrid strike-slip to reverse and reverse fault scenarios were found to have a higher risk of reactivation.

The extensive modelling work conducted has emphasised the important role that fault surface geometry has on fault reactivation. More detailed structural models will be needed to accurately assess the risks to reservoir integrity, as this research has shown that each potential CO_2 sequestration site will have its own unique geomechanical characteristics.

New, inexpensive, simple and accurate method for estimating rock strength

Dr Jiayi Shen, Dr Murat Karakus, Associate Professor Chaoshui Xu and Associate Professor Rafael Jimenez (Technical University of Madrid)

Many engineering projects require excavation through rock. Engineers need to estimate rock strength under different loading conditions – known as rock failure criteria. Traditional rock failure criteria require complex, time-consuming and expensive triaxial tests.

The research team has proposed an alternative failure criterion based on rock type and uniaxial compressive strength (UCS). The criterion was developed after collecting and analysing an extensive database of intact rock strength, which includes more than 1500 triaxial tests corresponding to 28 rock formations worldwide. The proposed method outperforms strength prediction of other failure criteria when validated against experimental data for eight rock types.

The new method developed by the team allows quick, easy and more accurate estimates of intact rock strength - a distinct advantage in the early stages of a project or where timelines and/or budgets are of concern. It uses tools that are readily available and can be easily incorporated into existing failure assessment methods.

Investment highlights

IMER invests in research projects to advance our leadership in strategic research priority areas aligned to industry and community needs. Here we highlight the research projects supported by IMER.

Understanding uranium mineralisation at Olympic Dam

Associate Professor Yung Ngothai, Kan Li, Dr Joël Brugger, Professor Allan Pring, Dr Barbara Etschmann, Associate Professor Brian O'Neill and Associate Professor Tony Hooker (EPA)

Olympic Dam is the world's largest uranium deposit in terms of metal endowment, but no specific study on the genesis of its uranium mineralisation has been conducted until now.

The research team led by Associate Professor Ngothai has shown that uranium is scavenged during the replacement of hematite by chalcopyrite under hydrothermal conditions. Researchers also discovered that the presence of uranium influences the reaction pathway, resulting in different textures and sulfide assemblages. Synchrotron-based micro-spectroscopy measurements conducted at the Diamond light source (United Kingdom) showed that uranium is present as U^{4+} rather than U^{6+} in the reaction products, even when U^{6+} was the source of uranium. The ability of the highly soluble U^{6+} to be reduced at the reaction front is key to developing an efficient scavenging mechanism.

The research undertaken in this project will lead to a better understanding of the distribution of uranium in iron oxide copper gold (IOCG) deposits and also aid metal recovery during ore leaching. *See figure below.*

Consortium increasing recovery and decreasing costs and impact of unconventional gas resources

Dr Dennis Cooke and Dr Hani Abul Khair

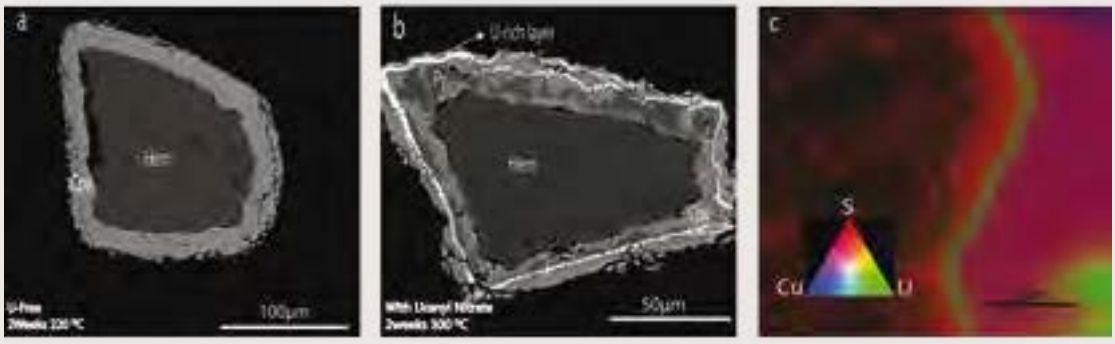
The GeoFrac Consortium project aims to increase productivity in unconventional gas resources by understanding the effects of geomechanics and geological structures to identify and target areas of enhanced prospectivity or 'sweet spots'. Industry members of the Consortium are Beach Energy Ltd, Halliburton Energy Services, JRS, QGC Pty Ltd/BG Group and Santos Ltd.

The team has used seismic techniques to constrain existing fracture networks within the Cooper Basin. Studies were based on 3D seismic cubes – the Moomba Big Lake survey in the south western part of the Cooper Basin. This research detected possible fractures from seismic data in the Cooper Basin.

Image logs, well logs and formation tests have also been analysed, and orientation and magnitudes of the three principal stresses were calculated. Modelling indicated potential sweet spots driven by geomechanical results which correlates to high gas production.

The Geofrac project is providing new insights into sedimentary basin structure as well as parameters that are crucial for developing tight gas reservoirs. Targeting sweet spots and understanding stresses will help increase recovery and minimise drilling, hence reducing costs and the environmental impacts of developing unconventional gas reservoirs.

Understanding uranium mineralisation at Olympic Dam



Results of different reaction runs:
(a) In the absence of uranium, the sulfidation reactions resulted in the replacement of hematite by chalcopyrite.
(b) Uranium nanoparticles were precipitated with the chalcopyrite when uranium was added in the system.
(c) Chemical map of an experiment where U was added in the form of uraninite.

Research Highlight

Mapping and modelling to improve field development in unconventional gas resources

Successful field development of unconventional gas resources relies on finding and aligning wellbores to the most prospective area, or 'sweet spot'. These geomechanical sweet spots are controlled by current day *in situ* stresses, ancient stresses and pre-existing natural fractures.

Dr Hani Abul Khair

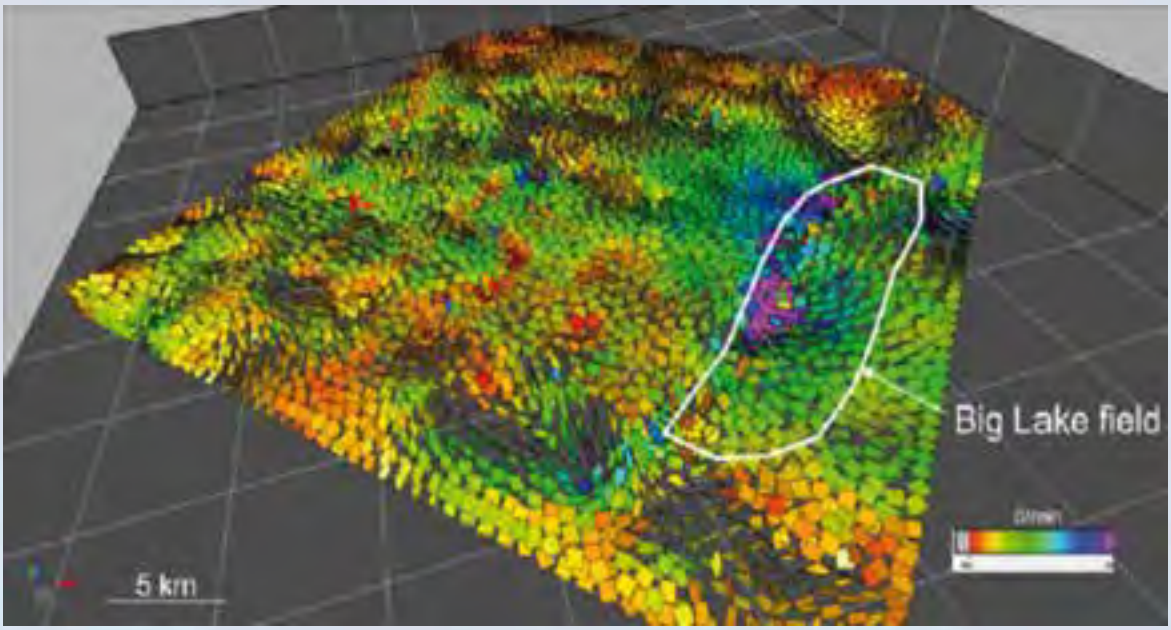
Dr Hani Abul Khair, Australian School of Petroleum, and his colleagues have mapped natural fractures in the area covered by the Moomba-Big Lake 3D seismic survey, in the southwest termination of the Nappamerri Trough of the Cooper Basin. The large amount of survey data available – approximately 300 oil and gas wells over 800 square kilometres – enabled the team to measure the curvature of the surface and identify anticlines or faults where there should be lots of fractures.

Three horizons – the Murteree, Roseneath and Toolachee Formations – were interpreted in the survey. The most positive and negative curvature attributes permitted careful mapping of the most subtle structural features which were interpreted as faults and fracture networks. The survey interpretation indicated that as the shale volume increased, the density of the mapped features by curvature attributes also increased. This correlation was also noticeable along a given time slice, where high shale ratios always corresponded to high values of curvature, suggesting that curvature signatures can locate regions of increased fracturing.

The morphology and rock properties of two of the horizons were also compared in extensive detail, with differences found in responses to stress. The Rosneath Fomation is expected to respond in a brittle way whereas the Toolachee Fomation will likely respond in a more ductile way. Generally, shales are hard to fracture compared to the sandstones that hold conventional gas reserves, but the Cooper Basin shales are stiff and so fracture easily. The outcomes of this research suggest that horizons with the highest fracture density should be targeted first for exploration as they would respond well to hydraulic stimulation. Open fractures are also good corridors for gas in shale.

Modelling can also be used to locate sweet spots, based on present day *in situ* stresses, pore pressure and the mechanical properties of rocks, to improve our understanding of rock behaviour during fracturing. The research team examined magnitudes and orientations of present day stresses; interpreted faults and horizons from 3D seismic data and used computer models to apply these stresses to existing structures. Using 3D modelling software the team identified a highly permeable domain or sweet spot in the Big Lake field. However, the modelling did not detect any potential sweet spots in the Moomba field.

Geomechanical restoration software packages based on the finite element method (FEM) and boundary element method (BEM) were also used to model fold, fracture and fault behaviour in the basin. FEM-based results correlated well with the orientation of the image log fractures, with a potentially stressed fracture set identified in current Big Lake sweet spot, as shown in



Fracture network predicted using finite element method (FEM) solver in Dynel 3D software. Purple regions correspond to highly strained fractures which indicate geomechanical sweet spots.

the figure. BEM-based results correlated well to the Big Lake fault, but no correlations were found away from the major fault.

For locations where no direct stress measurements are available, this type of modelling can help predict stress and locate possible sweet spots. The relative importance of paleo-stress compared to current-day stress in gas field development is an ongoing research question. In this research the fractures predicted by FEM modelling agreed best with the fractures interpreted on image logs.

Mapping methods used in this research could be applicable to other basins where good quality 3D seismic surveys and geophysical well data are available. Modelling work is continuing, to correlate predicted stress and fracture density with gas production rate. The mapping and modelling techniques used by Dr Abul Khair and colleagues in this research program are helping to identify exploration priorities for unconventional gas resources and increase collection efficiency.

References

Abul Khair H[a], Backé G[b], King R[c], Holford S[a], Tingay M[c] and Cooke D[a] (2012) *Factors influencing fractures networks within Permian shale intervals in the Cooper Basin, South Australia.* AAPEA Journal 52, 213-228.

Abul Khair H[a], Cooke D[a] and Hand M[d] (2013) *The effect of present day in situ stresses and paleo-stresses on locating sweet spots in unconventional reservoirs, a case study from Moomba-Big Lake fields, Cooper Basin, South Australia.* Journal of Petroleum Exploration and Production Technology 3, 207-221.

[a] Australian School of Petroleum, Centre for Tectonics, Resources and Exploration, The University of Adelaide, Adelaide, South Australia

[b] BP, United Klngdom

[c] Geology and Geophysics, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia

[d] South Australian Centre for Geothermal Energy Research, The University of Adelaide, Adelaide, South Australia.

Socio-Economic Impact of Mineral and Energy Resources Program

Understanding the social and economic dimensions of growth and change in mineral and energy resource development

Program Leader's Report

Associate Professor John Spoehr

With industrial diversification becoming increasingly important for Australia and South Australia in particular, it is critical that we understand the needs of our community, economy and the marketplace now and into the future. Our role is to undertake the economic and social research needed to identify those needs as well as opportunities and strengths and put in place strategies aimed at sustainable industrial development.

With the closure of the car industry in Australia we have been focusing particularly on diversifying Northern Adelaide's economy. Many companies are now searching for alternative opportunities that are closely linked to the mineral and energy sectors; areas where there is likely to be growth and demand for products and services over the next ten years. We have continued to work closely with the South Australian Government's Department of State Development (DSD) in projects designed to support the State's advanced manufacturing agenda. Now more than ever we need to develop, commercialise and market innovative, value-added products and processes to protect jobs and grow our local economy.

We are key players in a national bid for the Innovative Manufacturing CRC which if successful, would be supported by $40 million of Federal funding, matched by $40 million from industry as well as $2 million from the South Australian Government. This CRC is a major investment in the growth of advanced manufacturing and will focus on applying new technologies and modernising existing processes in industries such as medical devices, assistive technologies, minerals and energy and cleantech. A node of the CRC will be based in Adelaide working collaboratively with several IMER researchers.

A highlight of 2013 was the publication of *The Engaging State: South Australia's Engagement with the Asia-Pacific*. This book highlights the State's complex diverse, complex and dynamic economic ties with the Asia-Pacific region and the critical role played by subnational governments in developing and establishing these relationships. It was a pleasure to edit and co-author this publication which is the result of almost nine years of interdisciplinary effort by University of Adelaide researchers.

Socially and economically it is a tricky time for South Australia – negotiating it successfully will rely on combining innovative and interdisciplinary approaches with a solid foundation of workplace, industry and urban development research. This will enable us to identify and seize opportunities to retrain workforces and develop manufacturing capabilities that will benefit communities and the economy and help our State remain productive and progressive long into the future.

Home Schools

Australian Workplace Innovation and Social Research Centre

Business School

School of Economics

School of Geography and Environmental Studies

School of History and Politics

Associate Professor John Spoehr.

Project highlights

Accredited to Marketing and Communications – The University of Adelaide.

Whole of ecosystem study in Great Australian Bight

A $20 million, four-year collaboration between BP Developments Australia, CSIRO and Marine Innovation South Australia (MISA) partners the University of Adelaide, Flinders University and South Australian Research and Development Institute, is investigating the environmental, economic and social value of the Great Australian Bight.

Studies of the oceanography, ecology and geochemistry of the Bight are being combined with socio-economic research to provide a holistic picture of the region. The maiden voyage of the study was conducted in April using the research vessel Southern Surveyor. Depths between 200 and 2000 metres were sampled – the deepest ever in this area – collecting fish, crustaceans, echinoderms, amphipods and phytoplankton. An integrated coring platform was used to collect sediment cores and acoustic measurements were also taken that will help map the seabed and identify any oil seeps. The University of Adelaide's role will be to investigate the economic and social value of the project.

BP Developments Australia's significant investment in this research confirms their commitment to environmentally responsible exploration and extraction. Information collected will inform future decision-making and sustainable development in the region.

Investment highlights

IMER invests in research projects to advance our leadership in strategic research priority areas aligned to industry and community needs. Here we highlight the research projects supported by IMER.

The Stretton Centre

Artist's impression pictured opposite

The Australian Workplace Innovation and Social Research Centre (WISeR), in partnership with the City of Playford, was awarded an $11.3 million grant to establish the Stretton Centre in the new Playford Alive development, South Australia.

Construction will begin on the centre in 2014 and will be completed by May 2015. In the wake of the closure of Australia's car manufacturing industry WISeR researchers are working on identifying opportunities for diversifying Northern Adelaide's economy. Outcomes from IMER's diverse and innovative research platforms have many potential applications for future industries in the region. WISeR and IMER are continuing to work closely with the SA government and DSD in projects aiming to support advanced manufacturing in the State.

The Centre will be a hub for interdisciplinary problem solving and act as a catalyst for innovative projects designed to link industry, workforce and urban development objectives. It will play a major role in informing policy and planning at a local, state and national level and help South Australia take full advantage of growth in the mining and clean technology sectors.

Organisational change facilitated in Adelaide Airport Limited partnership

CET's platinum three-year partnership with Adelaide Airport Limited (AAL) aimed to reduce energy consumption in the main terminal building by identifying areas for improvement and implementing organisational change.

WISeR staff brought together technical researchers from IMER with AAL staff as part of a co-design process. A combination of good communication, teamwork and shared leadership helped everyone engage with the project's aims; understand the need for change; and take ownership of the process. By listening to staff, researchers were able to identify faulty or underperforming devices and develop optimal strategies for implementing changes in operational processes and staff attitudes. Likewise, staff were able to understand the motivation behind changes which greatly helped facilitate implementation. Energy usage in the terminal reduced by two per cent each year due to a raft of introduced changes. AAL's staff significantly improved their awareness of sustainable energy management and carbon emission reduction strategies.

The co-learning environment created in this project is a model that will be well suited to a wide range of IMER projects in the future. As a result of this partnership, AAL has become a recognised leader in sustainability as the first airport in Australia to achieve Airports Council International Airport Carbon Accreditation.

Outcomes from IMER's diverse and innovative research platforms have many potential applications for future industries in the Northern Adelaide region.

Focus on
Adelaide Microscopy: Centre for Advanced Microscopy and Microanalysis

Dr Animesh Basak using the TEM high resolution transmission electron microscope at Adelaide Microscopy. This equipment is often used by IMER scientists to characterise mineralogical samples.

Adelaide Microscopy at the University of Adelaide is a vital partner to IMER's research.

The Centre boasts a broad range of highly technologically advanced instruments for microscopy and microanalysis. Director Angus Netting leads a team of more than ten specialist microscopists who advise and train students, staff and industry professionals on the most appropriate equipment and techniques to answer their research questions. Adelaide Microscopy staff also help users with data analysis, interpretation and discussion.

There are more than 17 specialist instruments at Adelaide Microscopy that provide a vast range of services, including biological and physical science imaging; laser dissection; high-resolution microscopy; elemental analysis of liquids in the parts per billion range; elemental mapping of materials; and nano-scale fabrication of devices.

Much of the equipment at Adelaide Microscopy works in tandem to provide increasing layers of information. The equipment used most by IMER researchers includes the FEI Helios NanoLab DualBeam FIB/SEM, Phillips CM200 TEM and Laser Ablation ICP.

FEI Helios NanoLab DualBeam FIB/SEM (FIB/SEM)

The FIB/SEM is a high performance scanning electron microscope, coupled with a gallium (Ga+) ion gun. Dr Animesh Basak, Dual Beam Engineer, manages the FIB/SEM and helps users with preparing samples, processing materials, imaging samples and nano-scale fabrication. The FIB/SEM can provide:

- cross-sectional (sub-surface) structural view and feature size measurements
- identification, quantification and mapping of elements in a solid sample
- 3D microscopy and analysis
- orientation imaging microscopy
- site specific sample selection, sample placement and shaping
- high resolution secondary electron imaging
- nano-scale fabrication
- sample preparation for atom probe tomography
- ultra-thin sample preparation for transmission electron microscope analysis or synchrotron experiments.

Phillips CM200 TEM (TEM)

The TEM is a high resolution transmission electron microscope with imaging and analytical capabilities that can operate up to 200kV. It can achieve 0.2 nanometre resolution and magnification of 2,000,000 times, making it ideal for high resolution imaging and analysis. It is routinely used by IMER researchers to quantify and characterise mineralogical samples. The samples must be thin enough for the electron beam to pass through (<100 nanometres) – the FIB/SEM is used to prepare such samples for the TEM.

Microscopy techniques in action

IMER researchers use Adelaide Microscopy's services for a variety of research, including to:

- identify and map the elemental properties of samples, such as uranium deposit distribution within rock cracks and veins
- measure rock strength
- investigate the structure and mechanics of breaks, including mapping fractures within samples placed under varying stress.

Understanding graphene structure key to reaping benefits for SA

Prof Dusan Losic leads a Nano research group focused on exploring nanoscale materials and their properties for emerging applications. Their recent focus is on harnessing the opportunities created by increasing demand for South Australia's graphite and development of graphene-based products. Adelaide Microscopy's equipment is helping the researchers understand the properties of graphite and graphene at the nanoscale. They use the FIB/SEM to examine the structural properties of the different forms and examine cross sections of material, which allows them to gain a detailed understanding of how graphite and graphene-based products are formed. This knowledge will help them to develop new, low cost and environmentally-friendly methods for graphite extraction and allow them to explore a broad range of uses, including biomedical, microelectronic and environmental applications.

Dr Animesh Basak and PhD student Walter Costin on the FIB/SEM high performance scanning electron microscope. Walter is using the FIB/SEM to investigate the mechanical properties of samples using nano-machined micro-cantilevers.

Dating of hematite at Olympic Dam

Hematite, the main ore of iron, incorporates a variety of trace elements that are used to fingerprint deposit types and help to identify new exploration targets.

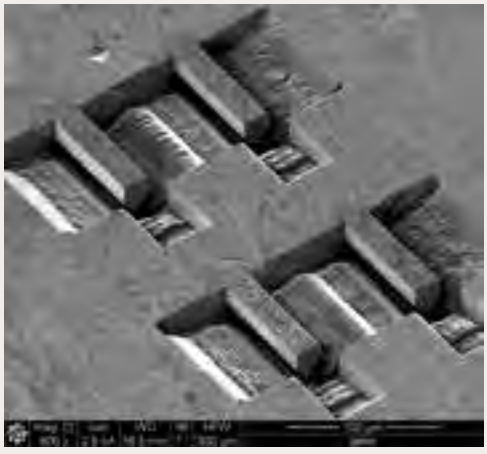
Dr Cristi Ciobanu's research investigated the mineral composition of hematite on the nanoscale to find out if it contained uranium that could also be used to age the mineral and increase our understanding of how and when the minerals were formed. Dr Ciobanu used Adelaide Microscopy's FIB/SEM and TEM to examine the structural and elemental properties of hematite from Olympic Dam. Her research showed for the first time that low levels of uranium were present in hematite (as inclusions and incorporated into the lattice) that could be used to establish the geochronology of the rock. This research enabled the development of a new tool to date iron-oxide bearing ores and will help us to understand exactly when and how these important economic mineral deposits are formed.

Adelaide Microscopy, located in the University buildings off Frome Road, offers a wide range of consultancy services to industry as well as University staff and students.

Nano-machining – creating micro-cantilevers to measure material properties at micro-scale

The FIB/SEM equipment in the experienced hands of Dr Animesh Basak, can be used to fabricate samples in micro-scale, at site-specific area, and then investigate their mechanical properties. This gives researchers an idea of the strength of the material at this particular microstructure and also an image of any resulting fractures induced by mechanical loading. Once the underlying mechanisms are identified, these results can then be extrapolated to a larger scale.

Cantilever construction is detailed work and incredibly time consuming, with each micro-cantilever taking around 50 hours to fabricate.



Key major projects active in 2013

IMER researchers gained support from prominent global companies, government and research partners in a large number of projects during 2013.

Here are details of key projects either initiated in 2013 or continuing as active projects through the year.

Centre for Tectonics, Resources and Exploration

Earth Imaging and Structure
Sponsor: Department of Industry
Chief Investigator: Prof Graham Heinson

Contemporary stress and tectonics of Australia
Sponsor: Australian Research Council
Chief Investigator: Dr Mark Tingay

Constraining conditions and timing of orogeny and reworking in the west Musgrave Province
Sponsors: Australian Research Council, Curtin University, Geological Survey of Western Australia
Chief Investigators: Dr David Kelsey, Prof Martin Hand, A/Prof Alan Collins

Deep and smelly: exploring the roles of pressure and sulphur in hydrothermal metal transport
Sponsors: Australian Research Council
Chief Investigators: Dr Joël Brugger

Detachments in evaporites and shales: their controls on fold-thrust belt style and wedge geometry
Sponsor: Australian Research Council
Chief Investigators: Dr Rosalind King, Prof Alan Collins, Dr Mark Tingay, Dr Guillaume Backe

Development of biosensors and bioindicators for gold exploration and processing in Australia
Sponsors: Australian Research Council, Barrick Gold of Australia Ltd, CSIRO Land and Water, Flinders University, Martin Luther-University Halle-Wittenberg, Newmont Australia, South Australian Museum, University of Nebraska-Lincoln
Chief Investigators: Dr Frank Reith, Dr Joël Brugger, Prof Joseph Shapter, A/Prof Claire Lenehan

Experimental studies on hydrothermal reaction processes at the molecular level: the role of mineral replacement reactions in ore formation
Sponsor: Australian Research Council
Chief Investigators: Prof Allan Pring, Dr Joël Brugger

Funding to support, develop and diversify educational and research programs associated with the Centre for Mineral Exploration Under Cover
Sponsor: Primary Industries and Resources SA
Chief Investigator: A/Prof Jennifer Watling, Prof David Giles

Iron isotope variation in subduction magmas: links to fluid flux and oxidation of the mantle wedge
Sponsor: Australian Research Council
Chief Investigator: Prof John Foden

Reservoir architecture and heterogeneity in marginal marine systems – WAVE Consortium Phase 11
Sponsors: Apache, Badr Petroleum Co, BG, BHP Billiton, BP, Chevron, ConocoPhillips, Nexen, OMV, Shell, Statoil, Todd, Woodside
Chief Investigator: Dr Rachel Nanson, Dr Boyan Vakarelov, Professor Bruce Ainsworth

South Australian State Chair of Petroleum Geology
Sponsor: Department of State Development, Government of South Australia
Chief Investigator: Prof Bruce Ainsworth

The geomicrobiology and (bio) geochemistry of platinum, palladium and rhodium
Sponsor: Australian Research Council
Chief Investigator: Dr Frank Reith

The origin of Australian Gondwana – using isotopic proxies for subduction to reconstruct ancient oceans
Sponsor: Australian Research Council
Chief Investigator: Prof Alan Collins

PhD Student, Sara Moran Polanco working in the special core analysis laboratory

South Australian Centre for Geothermal Research

Machine learning for geothermal exploration
Sponsor: Australian Renewable Energy Agency
Chief Investigator: Prof Martin Hand

Funding for South Australian Centre for Geothermal Energy Research
Sponsor: RenewablesSA
Chief Investigator: Prof Martin Hand

Reservoir quality in sedimentary geothermal resources
Sponsor: Australian Renewable Energy Agency
Chief Investigators: Prof Martin Hand, Prof Allan Pring, Prof Pavel Bedrikovetski, Prof Martin Kennedy

Stochastic modelling of fractures in crystalline rock masses for hot dry rock enhanced geothermal systems
Sponsor: Australian Research Council
Chief Investigator: Prof Peter Dowd

Centre for Energy Technology

Energy storage initiative
Sponsor: Regional Development Australia
Chief Investigator: Prof Gus Nathan

Controlled radiation facility to investigate turbulence-radiation-chemistry interactions in high-flux solar
Sponsor: Australian Research Council
Chief Investigator: Prof Gus Nathan

Energy from microalgae – industrial scale development and downstream processing of co-products
Sponsors: Australian Research Council, SQC P/L Partnership
Chief Investigators: Dr David Lewis, Dr Stephen Clarke, Prof Peter Ashman

Enhanced mixing of turbulent jet flames via side lateral injection
Sponsor: Australian Research Council
Chief Investigator: Prof Bassam Dally

Green cool wine: Solar powered solid adsorption refrigeration system with ice storage to provide cooling capability for wine industry
Sponsor: Australian Research Council
Chief Investigators: A/Prof Eric Jing Hu, Prof Mark Biggs, Dr Chen Lei

Internally decorated discrete metallo-supramolecular assemblies and infinite metal-organic frameworks as molecular containers
Sponsor: Australian Research Council
Chief Investigator: A/Prof Christopher Sumby

Investigation of the coupled dependence of concentrated solar radiation and combustion in a novel solar hybrid technology
Sponsors: Australian Research Council, FCT-Combustion Pty Ltd
Chief Investigators: Prof Gus Nathan, Prof Bassam Dally, Dr Zeyad Alwahabi

Materials characterisation facility for a sustainable future
Sponsors: Australian Research Council
Chief Investigator: Prof Shizhang Qiao

Mechanisms of sound absorption at the nanoscale
Sponsor: Australian Research Council
Chief Investigators: A/Prof Anthony Zander, Dr Carl Howard, A/Prof Ben Cazzolato

Metal-organic frameworks as heterogenous catalytic systems
Sponsor: Australian Research Council
Chief Investigators: Dr Christian Doonan, Dr Christopher Sumby

Multiscale models of nanoporous carbons for a sustainable future
Sponsor: Australian Research Council
Chief Investigator: Prof Mark Biggs

Nanostructured non-precious Metal and Metal-free Catalysts for Sustainable Clean Energy Generation
Sponsor: Australian Research Council
Chief Investigator: Prof Shizhang Qiao

New understanding of the heat transfer in compact, two-phase solar and solar hybrid reactors by advanced laser diagnostics and modelling
Sponsor: Australian Research Council
Chief Investigator: Prof Gus Nathan

New understanding of turbulent flames with soot and particulate fuels
Sponsor: Australian Research Council
Chief Investigator: Prof Gus Nathan

Novel vibro-acoustic technologies for detecting bearing and wheel defects in rail vehicles
Sponsor: Australian Research Council
Chief Investigator: Dr Carl Howard, E/Prof Colin Hansen

Open framework organic materials for CO_2 capture and conversion
Sponsor: Australian Research Council
Chief Investigator: Dr Christian Doonan

Quantifying the impact of wind farm noise on rural communities
Sponsor: Australian Research Council
Chief Investigator: E/Prof Colin Hansen

Resolving flame stabilisation mechanisms in the transition to MILD combustion
Sponsor: Australian Research Council
Chief Investigator: Dr Paul Medwell

Resolving the mechanics of quiet wind turbine noise production
Sponsor: Australian Research Council
Chief Investigators: Dr Con Doolan, E/Prof Colin Hansen

Responsive nanoporous organic cages
Sponsor: Australian Research Council
Chief Investigator: Dr Christian Doonan

Self-assembling nanoporous graphene with dialable pore sizes for green energy
Sponsor: Australian Research Council
Chief Investigator: Prof Mark Biggs

Solar gasification - using renewable energy to produce lower-carbon, high value liquid transport fuels using low grade carbonaceous feedstocks
Sponsor: ARENA
Chief Investigator: Dr Philip van Eyk

Solving the energy waste roadblock
Sponsor: Science & Industry Endowment Fund
Chief Investigator: A/Prof Christopher Sumby, Dr Christian Doonan

The Adelaide Airport Limited industry partnership
Sponsor: Adelaide Airport Limited
Chief Investigator: Prof Gus Nathan

Tools for design and scale-up of solar thermochemical reactors
Sponsor: ARENA
Chief Investigators: Prof Gus Nathan, Prof Bassam Dally, A/Prof Zeyad Alwahabi, Dr Paul Medwell

Ultrasound for control of cyanobacteria
Sponsor: Australian Research Council
Chief Investigators: Dr Carl Howard, E/Prof Colin Hansen, A/Prof Anthony Zander

Understanding and predicting submarine hydrofoil noise
Sponsor: Australian Research Council
Chief Investigators: Dr Con Doolan, E/Prof Colin Hansen, A/Prof Anthony Zander, Dr Laura Brooks

Resource Engineering Program

Development of innovative technologies for oil production based on the advanced theory of suspension flows in porous media
Sponsors: Australian Research Council, Santos Ltd, University of South Australia
Chief Investigators: Prof Pavel Bedrikovetski, Prof Anthony Roberts, Dr Andrei Kotousov

Impact of rolling dynamic compaction
Sponsor: Australian Research Council
Chief Investigator: Prof Mark Jaksa

Novel technology for enhanced coal seam gas production utilising mechanisms of stimulated cleat permeability through graded particle injection
Sponsor: Australian Research Council
Chief Investigator: Prof Pavel Bedrikovetski, Prof Anthony Roberts, Dr Andrei Kotousov

Variations in wellbore productivity from unconventional reservoirs – the GeoFrac Consortium project
Sponsors: Beach Energy Ltd, Department of State Development, Government of South Australia, Halliburton Energy Services, JRS, QGC Pty Ltd, BG Group, Santos Ltd
Chief Investigator: Prof Dennis Cooke

Cooperative Research Centre for Greenhouse Gas Technologies

Reactive rocks and their impact on CO_2 storage potential trapping
Sponsor: Cooperative Research Centre for Greenhouse Gas Technologies
Chief Investigator: Dr Ulrike Schacht

Geochemical impacts and monitoring of CO_2 storage in low salinity aquifers
Sponsor: Cooperative Research Centre for Greenhouse Gas Technologies
Chief Investigator: Dr Ulrike Schacht

Energy Pipeline Cooperative Research Centre

RP3-04B Future Energy Fluids
Sponsor: Energy Pipelines Cooperative Research Centre
Chief Investigator: Prof Peter Ashman

Deep Exploration Technologies Cooperative Research Centre

Acoustic emission monitoring during drilling/rock cutting for optimising drilling performance
Sponsor: Deep Exploration Technologies Cooperative Research Centre
Chief Investigator: A/Prof Chaoshui Xu

Borehold stability assessment for deep drilling
Sponsor: Deep Exploration Technologies Cooperative Research Centre
Chief Investigator: A/Prof Chaoshui Xu

Geochemical sampling of deep cover
Sponsor: Deep Exploration Technologies Cooperative Research Centre
Chief Investigator: Prof David Giles

Joint inversion of 3D seismic data and magnetotelluric (MT) data
Sponsor: Deep Exploration Technologies Cooperative Research Centre
Chief Investigator: Prof Graham Heinson

Public events and seminars

IMER members shared key research findings, outcomes and benefits with business leaders, government and the wider community. Here is a selection of key public presentations by IMER members or events hosted by IMER during 2013.

DSD and IMER co-host meeting to discuss unconventional energy resources

A meeting of the Roundtable for Unconventional Gas Projects in South Australia was held in December 2012 with representatives from industry, government and research providers discussing research, technology and policy needs to assist the unconventional gas industry in South Australia. The three-day meeting on Unconventional Energy Resources – Research and Technology needs included discussions of the leading practices and research capabilities in unconventional petroleum projects as well as meetings of the roundtable working groups.

On the first day, representatives from Santos Limited, Beach Energy and Strike Energy presented updates on Cooper Basin projects, while discussions were also held on stakeholder engagement, water management, logistics and resource estimation. A service company panel on best practice technologies for unconventional development was also held with representatives from Halliburton, Schlumberger, Baker Hughes and Condor Energy.

Prof Stephen Grano welcomed participants on day two and chaired a session on exploration and targeting including presentations from IMER researchers Dr Kathryn Amos, Dr Hani Abul Khair, Prof Martin Kennedy and Dr Rosalind King.

On the final day IMER hosted tours of The University of Adelaide campus and the Ian Wark Research Institute at the University of South Australia before a closing dinner, where participants reconnected with old friends and forged new connections.

This roundtable forum is a great example of IMER facilitating collaboration between industry, government and research organisations to identify research goals, coordinate research activity, share information and create opportunities for developing joint industry programs.

Information and communications technology showcase

Companies and researchers from around Australia were treated to a tour of the Centre for Energy Technology, the Institute for Photonics and Advanced Sensing and the Australian School of Petroleum as part of an IMER showcase on information and communications technology (ICT) held in October. Participants were able to speak to researchers and see the University of Adelaide's outstanding infrastructure for developing the latest in optical sensing tools and resource analysis and characterisation.

The day also gave participants an insight into the capabilities of complementary researchers, including:

- geophysical monitoring – Electrical Earth Imaging (EEI) group
- statistical optimisation of systems and networks; geostatistical modelling for resource characterisation and optimisation; and rock fracture modelling – Mining Engineering
- data processing and modelling for exploration and environmental monitoring – Teletraffic Research Centre
- Visual information processing, computer graphics, machine learning, robotics, control and automation – Australian Centre for Visual technologies.

The showcase was part of the ICT Roadmap for Minerals and Energy Resources Project, led by industry and driven by the Australian Information Industries Association in partnership with DSD. This project is working towards establishing Adelaide as a national ICT hub to provide cutting edge ICT solutions for the mineral and energy resources sector.

Centre for Tectonics, Resources and Exploration (TRaX) on show

The Centre for Tectonics, Resources and Exploration (TRaX) held a research symposium in July that was attended by more than 80 people, including researchers, industry and government representatives. The symposium highlighted the geoscience research being conducted by TRaX and was a fantastic demonstration of the breadth of research into understanding our continent.

Topics covered during the symposium ranged from mapping of reservoir analogues on a continental-scale to the creation a microbe map of the continent to assist future microbial-facilitated mineral exploration. Researchers are also electrically mapping the lithosphere and unravelling the tectonic evolution of the continent's basement. Presentations covered both fundamental and applied research and highlighted new opportunities that could be created through interdisciplinary research approaches.

Support from high-level industry and government representatives was extremely strong, with sessions chaired by Ned Stoltz, Geoscience Australia; Peter Vincent, Santos Limited; Ted Tyne, DSD; Frank Bierlein, AREVA Resources Australia Pty Ltd; and Malcolm Altmann, Beach Energy Limited. The symposium was a great opportunity to demonstrate TRaX's research capability, update attendees with new information and foster linkages between industry participants. Feedback from participants was overwhelmingly positive and organisers aim to make the symposium a yearly event.

TRaX seminar series

The Centre for Tectonics, Resources and Exploration (TRaX) also continued with its well-attended and stimulating seminar series in 2013. Weekly presentations throughout the semesters included presentations on:

- Conditions and durations of high-temperature metamorphic events
- A taxonomy of mass extinctions based on new geobiological research in the Gondwana Continents
- Climate variability in the tropical Pacific: beyond El Niño
- The tectonic evolution of the Southern Granulite Terrane, India and its role in the amalgamation of Gondwana
- Assessing future drought and megadrought risk
- Tate, Howchin, Mawson and other geological pioneers of SA.

TRaX Director presents to Royal Society of South Australia

TRaX Director Prof Alan Collins presented at the Royal Society of South Australia's May meeting where he discussed his geoscientific research into the evolution of regions. This research forms part of Prof Collin's Future Fellowship research which is investigating the geography of Australia between 850 and 500 million years ago – a period of major climatic extremes. Prof Collins has recently led field trips to Madagascar, Ethiopia and Oman as part of the fellowship and shared his knowledge and experiences with the Royal Society members.

Centre for Energy Technology hosts ARENA Chair during research day

In December 2013, the Centre for Energy Technology hosted an internal research day which showcased the exceptional breadth of the research being conducted.

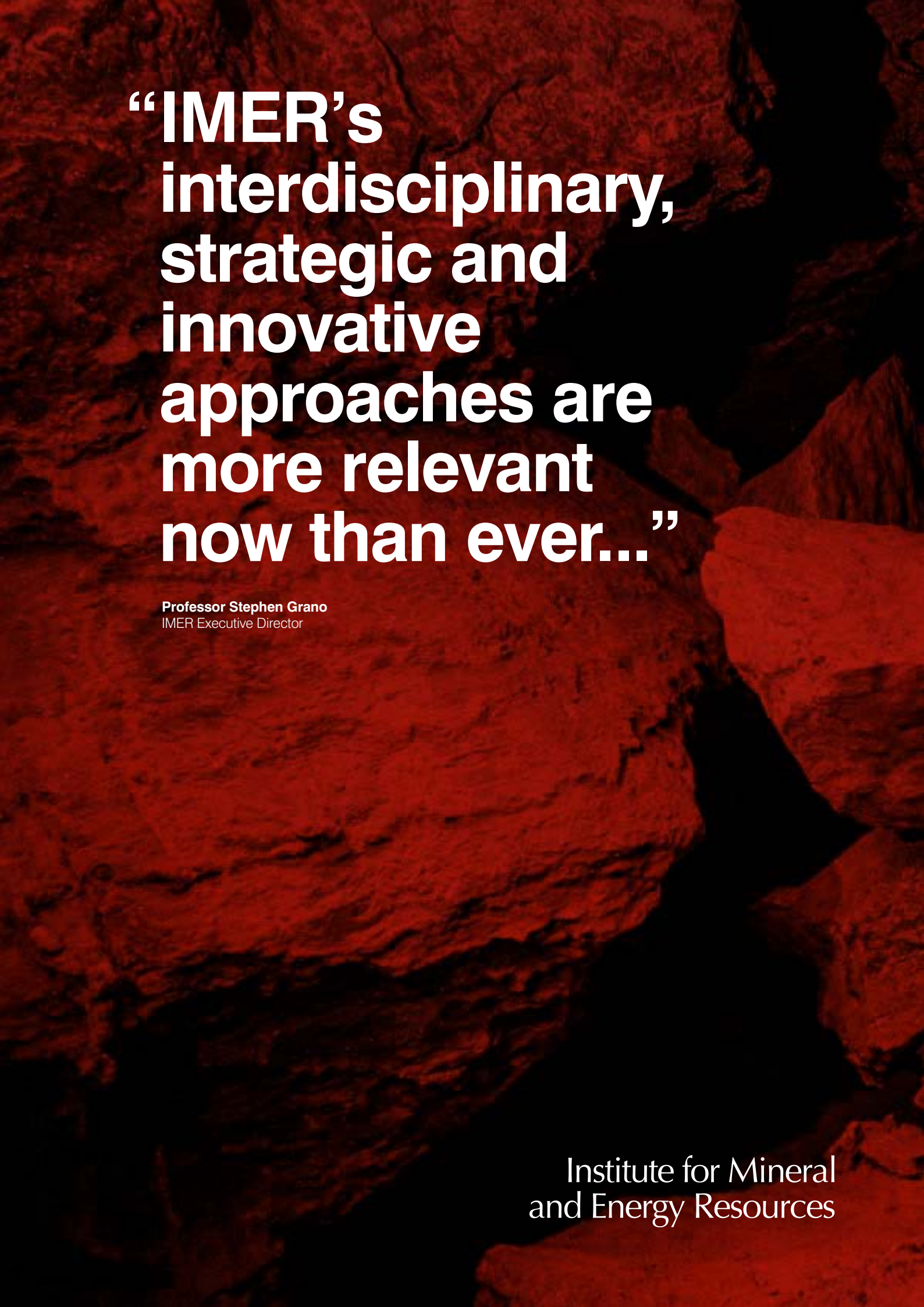
The keynote session was presented by Greg Bourne, Chair of the ARENA board who spoke about the profound impact on him of the optimism, vision and drive of the renewable energy sector. He highlighted ARENA's focus on linking research to commercial application and explained the factors motivating ARENA's funding decisions. Mr Bourne also discussed ARENA's focus on knowledge sharing – a fundamental aspect of ARENA's core business that is designed to grow the renewable energy sector, encourage investment and facilitate new projects.

CET projects highlighted on the day included:

- solar hybrids, Prof Gus Nathan and Dr Phillip van Eyk
- ocean energy technologies, A/Prof Ben Cazzolato's collaboration with Carnegie Wave Energy Ltd
- noise and health impacts of wind energy, A/Prof Anthony Zander
- geothermal, Chris Matthews
- biofuels from microalgae, A/Prof David Lewis
- energy storage, A/Prof Nesimi Ertugrul
- laser diagnostic techniques, Dr Zhiwei Sun.

Research Tuesday seminar series – Where will we source our energy?

CET Director Prof Gus Nathan was a panel member debating 'Where will we source our energy?' as part of the University of Adelaide's Research Tuesday seminar series. The event was facilitated by the Hon. Trish White (FAICD FIEAust), chair of the CET Advisory Board and involved leading figures in the fields on environmental science, energy and resources. Prof Nathan's contribution highlighted the need for low-carbon energy technologies to embrace economic and social sustainability as well as generate global 'first mover' opportunities for Australian industry. Prof Barry Brook, Sir Hubert Wilkins Chair of Climate Change in the School of Earth and Environmental Sciences and Director of Climate Science at the University of Adelaide's Environment Institute argued the need for worldwide transformation of energy systems, focusing on the key role of next-generation nuclear and related technologies. A/Prof David Lewis from the School of Chemical Engineering discussed the potential of microalgal biofuels as viable renewable energy source and the new processing technologies that are under development. Stephanie Bolt, Environment Manager at Adelaide Airport Limited, outlined steps taken by the local and international aviation sector to reduce energy use while protecting growth.



“IMER’s interdisciplinary, strategic and innovative approaches are more relevant now than ever...”

Professor Stephen Grano
IMER Executive Director

Institute for Mineral and Energy Resources

For further enquiries

Institute for Mineral and Energy Resources

The University of Adelaide
South Australia 5005, Australia

Telephone: +61 8 8313 1448
Email: imer@adelaide.edu.au

www.adelaide.edu.au/imer

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