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The University of Adelaide

Institute for Mineral and Energy Resources

Annual Report 2014

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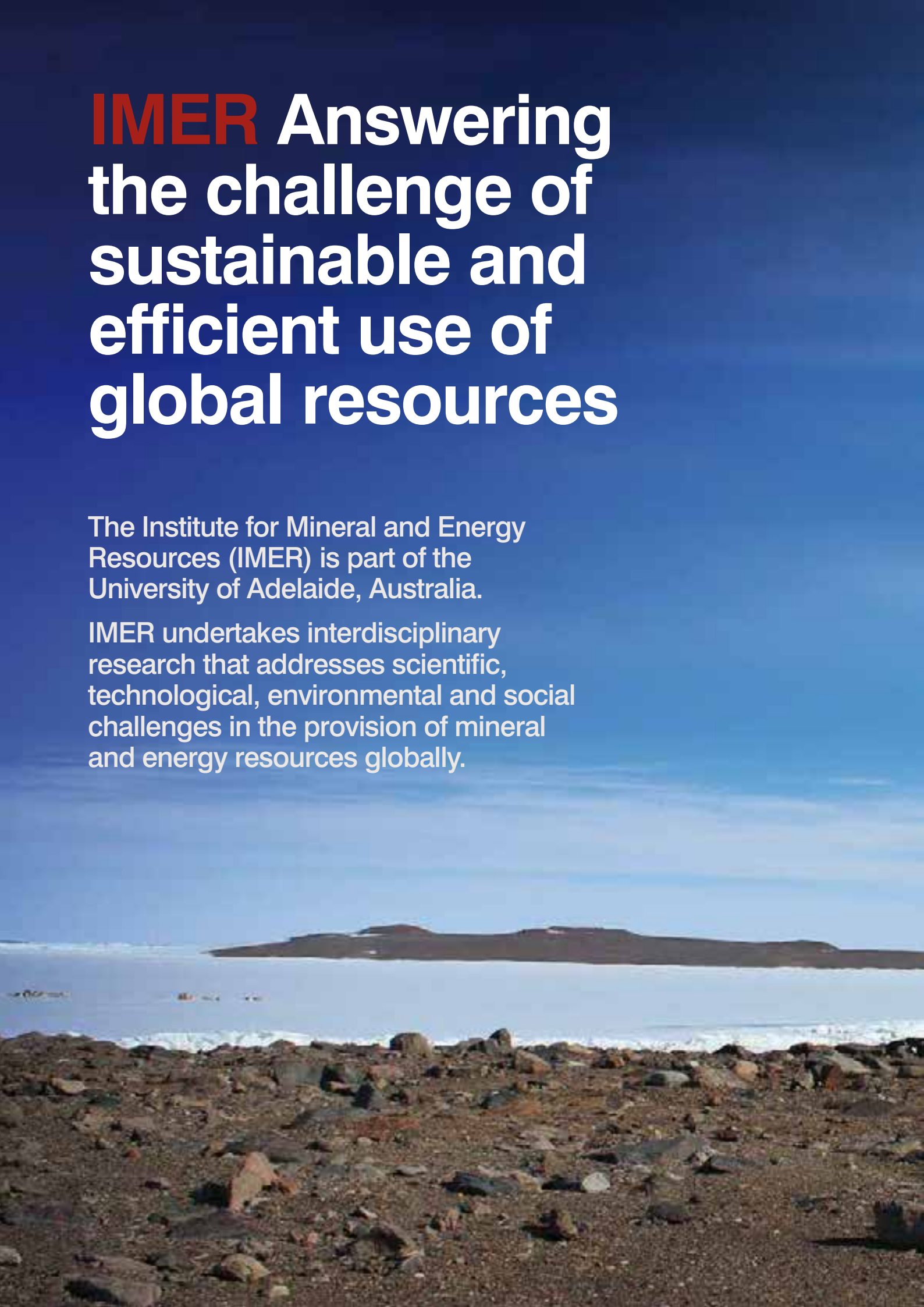
seek LIGHT

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 resources globally.



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, petroleum and geothermal resources.
- Advance the science and technology needed to lower the cost and facilitate 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's schools and faculties involved with IMER include the Australian Workplace Innovation and Social Research Centre (WISeR); the Australian School of Petroleum; the Adelaide Business School; the School of Chemical Engineering; the School of Chemistry and Physics[1]; the School of Civil, Environmental and Mining Engineering; the School of Earth and Environmental Sciences[1]; 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.

Institute for Mineral and Energy Resources

[1] In 2015 the Earth Scientists moved from the former School of Earth and Environmental Sciences to the new School of Physical Sciences.

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Deputy Vice-Chancellor (Research)’s Report

Professor Mike Brooks

The Institute for Mineral and Energy Resources (IMER) is one of the University of Adelaide’s five innovative research institutes, each of which is tasked with solving ‘grand challenges’ of importance to our communities. IMER addresses one of the biggest challenges facing Australia – maintaining growth in the critical mineral and energy resource industries in a technically, economically, socially and environmentally sustainable manner.

IMER has an interdisciplinary and collaborative approach, addressing research priorities closely linked to industry needs. This research supports activities not only in our State, but more widely across Australia and beyond. Practical research outcomes are readily being adopted by industry, and new commercial ventures are being developed in concert with training the next generation of strategic and collaborative thinkers.

As you read through the stories within this report, you will appreciate the incredibly diverse suite of interdisciplinary research being undertaken within IMER. I commend IMER members on their outstanding work this year, and I have no doubt that this success will continue.

Professor Mike Brooks
Deputy Vice-Chancellor and
Vice-President (Research)

"IMER celebrated some excellent funding success in 2014 totalling more than $12 million."

Mr Andrew Stock
Chair

Chair's Report

Mr Andrew Stock

As incoming Chair I am delighted to preside over my first IMER Annual Report. On behalf of all IMER members I would like to sincerely thank Mr Robert Kennedy for five years of dedicated and passionate service. His valuable contribution and leadership have ensured IMER's innovative and interdisciplinary research continues to provide real-world solutions for industry and the community, locally and globally. I look forward to building on this great foundation.

IMER celebrated some excellent funding success in 2014 totalling more than $12 million. Our impressive record of winning Category 1 funding continued – over $4.1 million which included two Discovery Early Career Research Awards (DECRA) and two Discovery Projects (DP). IMER was also awarded $2.5 million over five years from the ARC's Industrial Transformation program to establish a Research Hub in transforming Copper-Uranium production. This Hub is backed by significant industry support from BHP Billiton and OZ Minerals.

The IMER team is also recruiting world-class research talent thanks to $1 million from the Premier's Research and Industry Fund (PRIF) for a Research Fellow in Unconventional Energy Resources (Geomechanics of Fracture Stimulation). Industry partners Beach Energy, Santos, Senex Energy and Halliburton are also supporting this position. These are just a few examples of IMER funding achievements during the year and I invite you to read more about our ongoing research throughout this report.

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. I would also like to extend a warm welcome to our new Board Member, Greg Waters, Chief Executive Mining from Arrium Mining, who recently accepted our invitation to join the IMER Advisory Board.

IMER focuses on delivering innovative interdisciplinary research outcomes for the benefit of local and global industries, communities and the environment – I look forward to advancing this work in 2015 and beyond.

"It's an exciting time at IMER, with the establishment of three new research initiatives."

Professor Stephen Grano
Executive Director

Executive Director's Report

Professor Stephen Grano

Interdisciplinary, innovative and collaborative research for the minerals and energy resources sectors continued to be IMER's core business in 2014.

IMER's research initiatives address real challenges faced by these sectors. We are developing tools to locate the next world class mineral systems; investigating tectonic processes to help us better understand the resource potential of our State and global environment; developing efficient and sustainable solar hybrid systems; and investigating technologies that will help our State take advantage of advanced manufacturing opportunities arising from the minerals and energy sector.

It's an exciting time at IMER, with the establishment of three new research initiatives – the Research Hub in Transforming Copper-Uranium Production, the Graphene Research Centre and the Australian Energy Storage Knowledge Bank. These facilities will bring together diverse research skills and funding opportunities to produce research that will make an immense contribution to the minerals and energy sectors.

Skilling the next generation of strategic and collaborative thinkers is key to meeting future challenges for the mineral and energy resources industries. The University of Adelaide supervised 350 research postgraduate students in the minerals and energy resources fields in 2014, up from 218 in 2013. We congratulate 48 of these students for successfully completing their studies during 2014.

An incredible 415 journal articles, 100 conference papers, 7 book chapters and 1 book were produced by University of Adelaide staff working in the minerals and energy resources research fields. These research outcomes don't just sit on the shelf – we put them out there where they can make a real difference to industry and the community as well as spark opportunities for future collaborative and interdisciplinary research.

Challenges continue to evolve in the mineral and energy resources sector and we are working to increase the competitiveness of these industries. IMER's innovative approach is more relevant now than ever and I am confident IMER members will continue to make practical and positive contributions towards this goal.

Challenges, strategies and priorities

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
- increasing depth of mining and extraction of mineral and energy resources
- decreasing grade and increasing complexity of mineral and energy resources
- increasing energy competition and constraints on carbon emissions and energy infrastructure
- increasing global energy consumption while simultaneously reducing carbon emissions
- increasing demand from communities to achieve economic sustainability by enhancing productivity and reducing costs.

Challenges for South Australia

IMER strives to address the challenges for South Australia's mineral and energy resource industries through innovative and globally-relevant research. The global challenges of triple bottom line outcomes 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 remains uncertain due to exploration difficulties associated with the thick barren cover overlying most mineral resource regions. New exploration tools and methods, as well as improved understanding of ore formation and alteration processes are needed to assess 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 mineral ores are complex, sometimes at microscopic levels. Processing such minerals into value-added material for export is not a trivial operation. Equipment used for effective mineral separation and concentration has high capital and operating costs.

South Australia needs to develop new technologies to process these minerals, remove impurities, and produce value-added products for export, while minimising environmental impacts.

High costs of extracting unconventional natural gas resources

South Australia has significant resources of natural gas contained in shale and deep coal deposits. These resources have several advantages over shallow coal bed methane but extraction costs are higher as deeper drilling and earth engineering is required. Developers target regions of high flow and gas concentration or 'sweet spots' in these unconventional reservoirs.

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

Resource developments can bring significant opportunities for a community's economy and workforce, but will also bring social change. Research is needed to inform change, policy and strategies for resource development.

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 facilitates interdisciplinary initiatives aligned to these research priority areas by:

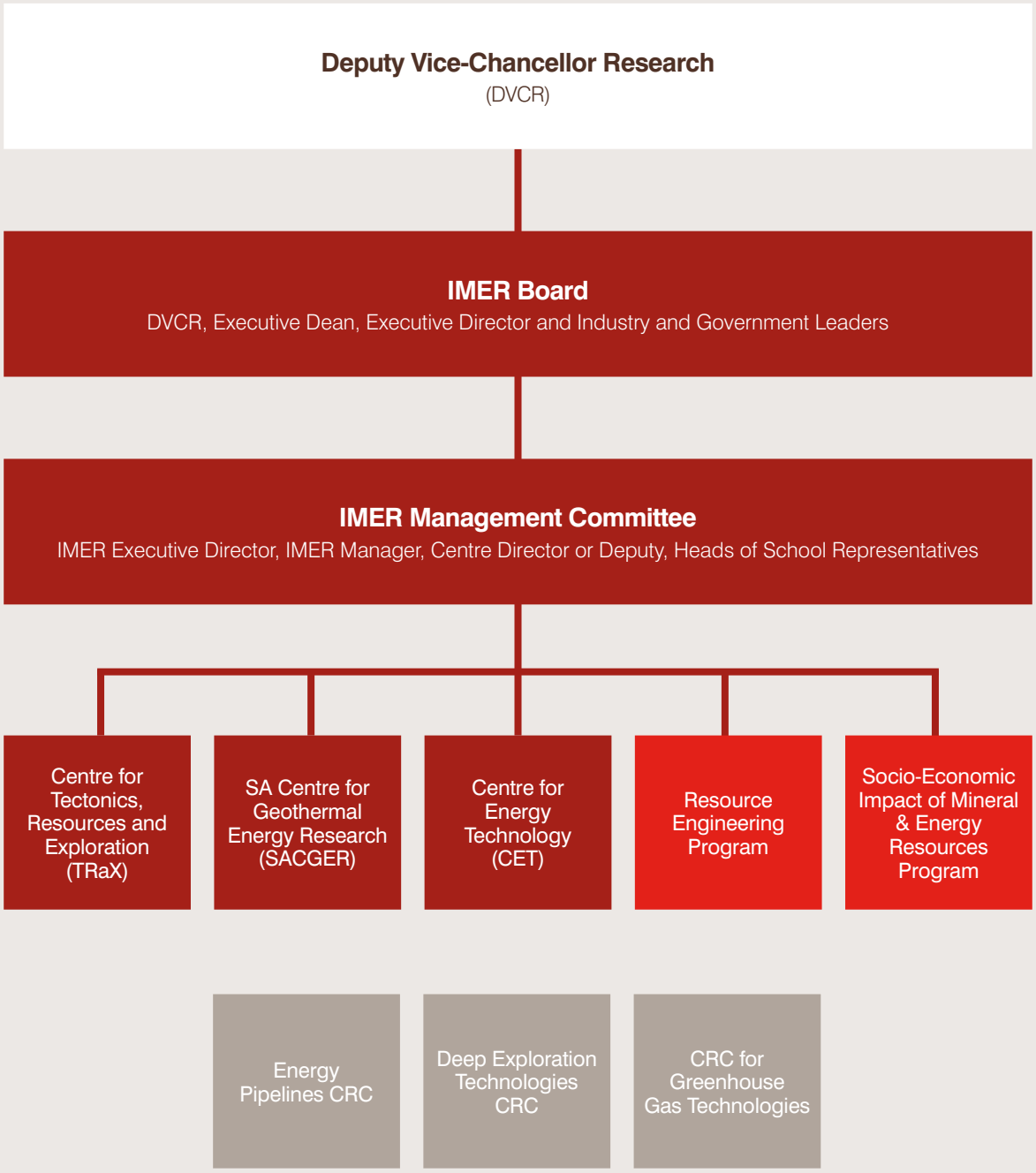
- bringing together interdisciplinary teams from across the University of Adelaide and external partners
- forging new strategic relationships between researchers and industry, including developing relationships with international research institutions and industry
- supporting research leadership by investing in strategic research initiatives that leverage new funding and build capability 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** – brings together science, engineering and humanities research disciplines to address globally significant challenges
- **global recognition** – positions the University of Adelaide to be a leading research university by world standards
- **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
- **outreach** – recognises the importance of communication in all its forms to maintain mutually beneficial relationships between the University of Adelaide, industry and society.

Organisational Structure



Institute for Mineral and Energy Resources

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Non-Executive Director, Horizon Oil Ltd, Geodynamics Limited and Clean Energy Finance Corporation

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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
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Mr John England
Project Director, Process Technology and Studies, BHP Billiton

Professor Stephen Grano
Executive Director, Institute for Mineral and Energy Resources, University of Adelaide

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

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

Ms Belinda Robinson
Chief Executive, Universities Australia

Mr Greg Waters
Chief Executive, Mining, Arrium Limited

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Chair
Executive Director, Institute for Mineral and Energy Resources

Professor Alan Collins
Director, TRaX

Mr James Deed
Manager, Research Business Development Faculty of Sciences

Mr Simon Firth
Commercial Development Manager, Adelaide Research and Innovation

Professor Mike Griffith
Associate Dean (Research), Faculty of Engineering, Computer and Mathematical Sciences

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Deputy Director, IMER, Director, SACGER

Professor Peter McCabe
Deputy Head of School, Australian School of Petroleum

Professor Gus Nathan
Deputy Director, IMER, Director, CET

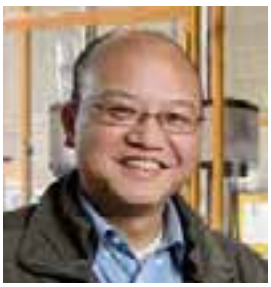
Dr Jordan Parham
Manager, Institute for Mineral and Energy Resources

Professor Shizang 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, School of Earth & Environmental Sciences

Management Committee
continued



Associate Professor
Chaoshui Xu
Leader, Resource
Engineering Program

IMER Executive

Professor
Stephen Grano
Executive Director

Dr Jordan Parham
Manager

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.

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.

TRaX research groups

- Reservoir Analogues Research Group (RARG)
- Electrical Earth Imaging (EEI)
- Continental Evolution Research Group (CERG)
- Stress, Structure, Seismic Group (S3)
- Metals, Ores, Minerals and Solutions (MOMS)
- Deep Exploration Technologies CRC (DET CRC)

Professor Alan Collins
Director, TRaX

Board Members

Dr Frank Bierlien (Chair)
Manager, Global Project Generation, Areva Resources Australia Ltd

Professor Bruce Ainsworth
Senior Staff Research Scientist, Clastic Stratigraphy Research Team, Chevron Australia

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Director, TRaX

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Professor Janet Hergt
Senior Executive, Science, University of Melbourne

Dr Steve Hill
Director/Chief Government Geologist, Department of State Development

Dr Simon Holford
Deputy Director, TRaX

Professor Stephen Grano
Executive Director, IMER

Professor Steven Reddy
Applied Geology Western Australian School of Mines, Curtin University

Dr Ned Stoltz
Senior Geophysicist Resources Division, Geoscience Australia

Mr Peter Vincent
Chief Geoscientist, Exploration and Subsurface, Santos Ltd

"Trace element mapping can help us understand where valuable potential by-products or unwanted contaminants are present."

Associate Professor Nigel Cook
Deputy Director, TRaX

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.

SACGER research areas

- Geophysical tools
- Fluid rock interactions
- Fracture modelling
- Crustal stress characteristics

Professor Martin Hand
SACGER Director, IMER Deputy Director

Board Members

Ms Susan Jeanes (Chair)
Advisor, Jeanes Holland and Associates

Mr Peter Barnett
Managing Director, Hot Rock Limited

Dr Betina Bendall
Principal Geothermal Geologist, DSD

Professor Peter Dowd
Professor of Mining, University of Adelaide

Professor Martin Hand
Director, SACGER

Mr Robert Hogarth
Reservoir Development Manager, Geodynamics Limited

Mr Heinz Holl
Senior Geologist, Geodynamics Limited

Mr Peter Reid
Exploration Manager, Petratherm Limited

> "We can see how well we're doing as researchers. If the results are good, mining and geothermal companies will apply them directly in their operations and they will get direct benefits from the research."
>
> **Professor Martin Hand**
> SACGER

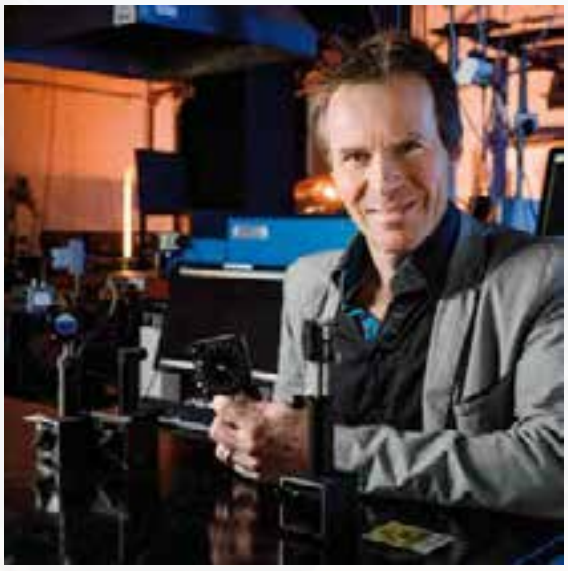
Centre for Energy Technology (CET)

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.

CET research areas

- Biomass/waste to energy
- Chemistry
- Combustion
- Electrical technologies
- Energy analysis and optimisation
- Energy efficiency
- Geothermal energy
- Mathematical modelling
- Solar energy
- System integration
- Transmission and storage
- Wind, wave and tidal power



Professor Gus Nathan
CET Director, IMER Deputy Director

Board Members

Ms Susan Jeanes (Chair)
Advisor, Jeanes Holland and Associates

Professor Bassam Dally
Deputy Director, CET

Ms Ros deGaris
Principal, Ros deGaris Consulting

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Executive Director, IMER

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Director, CET

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Director – Wholesale Markets Branch, Australian Energy Regulator

Dr Jordan Parham
Manager, IMER

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

Mr Richard Turner
Chief Executive Officer, Zen Energy Systems

1. In 2015 The School of Earth & Environmental Sciences combined with the School of Chemistry and Physics to form the School of Physical Sciences.

Resource Engineering Program

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

Resource Engineering Program research areas

- Geostatistics
- Rock fracture modelling
- Mine planning and optimisation
- Geomechanics
- Resource assessment and development
- Decision-making under uncertainty
- Fractured reservoir characterisation
- Mathematical modelling
- Analytical, physical and computational models

Associate Professor Chaoshui Xu
Resource Engineering Program Leader

"The research clusters within this program have continued to perform strongly in attracting external research funding and generating high quality research publications."

Associate Professor Chaoshui Xu
Resource Engineering Program Leader

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.

Research in this program is focused on developing new impact assessment and stakeholder engagement tools as well as developing better ways of measuring the demand for skills.

Resource developments can bring significant opportunities for a community's economy and workforce, but will also bring social change.

Associate Professor John Spoehr
Socio-Economic Impacts of Mineral and Energy Resources Program Leader

Cooperative Research Centres

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

Professor John Kaldi
Chief Scientist

Energy Pipelines Cooperative Research Centre (EPCRC)

Professor Peter Ashman
Program Leader

Deep Exploration Technologies Cooperative Research Centre (DET CRC)

Professor David Giles
Research Leader

Many companies are searching for alternative opportunities that are closely linked to the mineral and energy sectors – areas where there are likely to be growth and demand.

IMER in 2014

Over the 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.

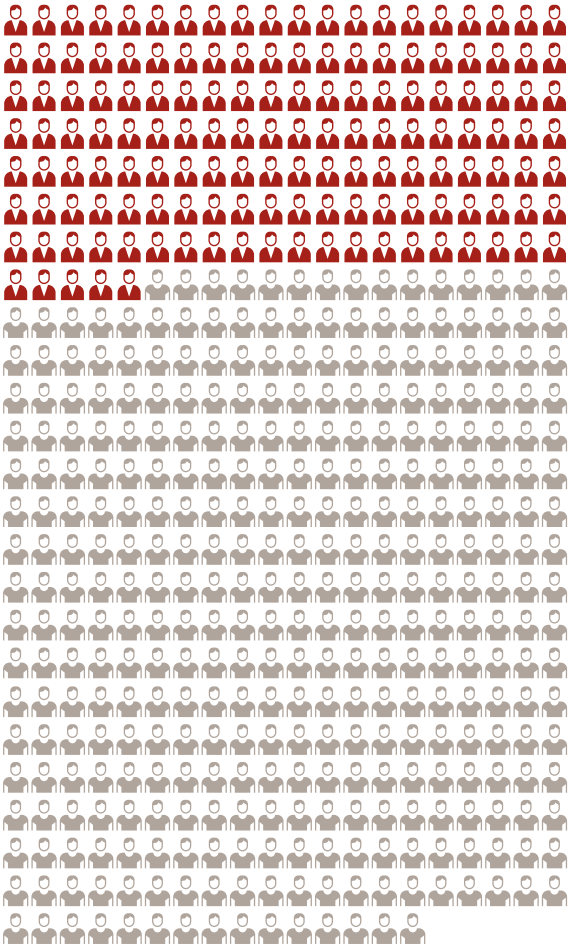
IMER Members

Both staff and student numbers have grown from 2009 to 2014.

2009

Staff 125

Students 140



2014

Staff 145

Students 350

Research funding

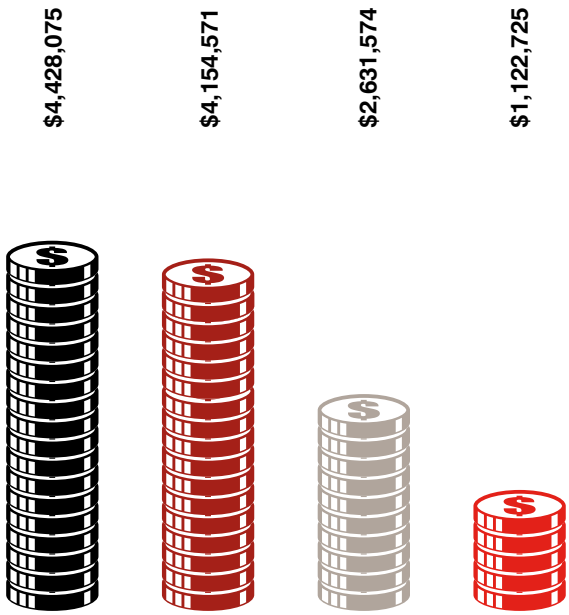
Research funding is shown according to the Australian Higher Education Research Data Collection categories:

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



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Publications

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2014

IMER's scientists and students are immensely talented, with prolific research and publication outputs recognised internationally by their peers.

Here we recognise some of their achievements in 2014.

$3.46M in funding from the Australian Research Council from Discovery and Linkage Projects and Linkage Infrastructure, Equipment and Facilities grants.

$1 million from the South Australian Research Fellowship Program

to recruit a world-class researcher in geomechanics and fracture stimulation.

The successful applicant will join our internationally-recognised unconventional energy resources research program. This position is also supported with significant investment from partners Beach Energy, Halliburton, Santos Ltd, Senex Energy and Department of State Development.

$6.7 million ARC Research Hub for Copper-Uranium Transformation established at IMER

Awarded as part of the ARC's Industrial Transformation Program in partnership with BHP Billiton, OZ Minerals and the State Government of South Australia. This will help to position Australia as a world leader in copper production and associated technologies.

Prof Steve Begg elected to the board of Society of Decision Professionals

Three Endeavour Research Fellowships for IMER researchers.

Dr Yunpeng Xue, Dr An Deng and Ms Bita Bayatsarmadi won fellowships that will enable them to further their research careers by spending 4-6 months overseas.

Dr Cris Birzer wins 2014 Tall Poppy Award for his outstanding achievements in science.

$800,000 investment in graphene research from Valence Industries.

Led by Professor Dusan Losic a Graphene Research Centre will be established at the University placing Valence Industries and the University at the forefront of global graphene markets and innovation.

Sam Holt (2014 Honours student) wins David I Groves Medal from the Geological Society of Australia (GSA).

Professor Gus Nathan awarded the inaugural Australian Institute of Energy (AIE) South Australia Energy Professional of the Year Award.

“We believe that interdisciplinary research is essential to enable the sustainable use and development of the world’s mineral and energy resources.

The following research highlights are examples of this in action – with a clear focus on delivering practical solutions for industry.”

Professor Stephen Grano
Executive Director

Institute for Mineral and Energy Resources

Magnetotellurics for mapping mineral prospectivity

Magnetotellurics (MT) is a technique that images the Earth's electrical properties and maps geological structures

MT is being used to map mineral systems deep into the earth

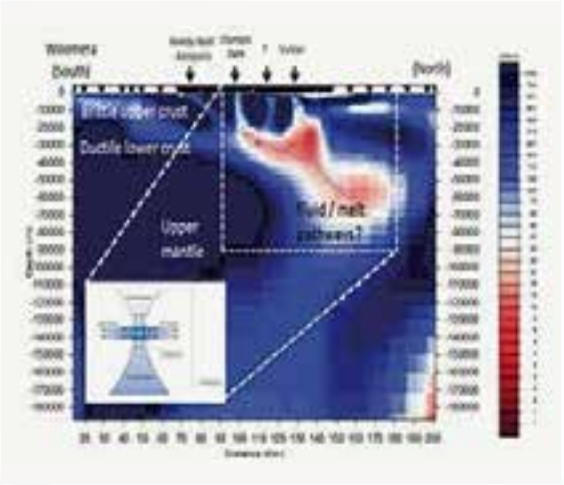
Research led by Professor Graham Heinson at IMER is creating new models of crustal mineral systems. The team is using MT to measure the electrical properties of the Earth to depths of several hundred kilometres.

The Electrical Earth Imaging Group is conducting a survey of 150 new MT sites across the lower half of South Australia from border to border, spaced at intervals of 50 km. The approach is expected to shed light on the evolution of the South Australian crust, and inform mineral exploration.

The eastern Gawler Craton and Stuart Shelf region is one of the most prospective mineral provinces on Earth. However, because younger rocks cover the older geological layers of interest, understanding the deep undercover systems is difficult. The efficiency of locating mineral deposits in South Australia will be vastly improved with better knowledge of the mineralising systems that are found in the layers of rock that lie deep underground.

> "It's exciting because we think MT can be used to find big mineral deposits in South Australia."

Professor Graham Heinson
Leader, Electrical Earth Imaging Group



Like fingers reaching up to the surface, MT modelling detected conductivity relating to three known mineral deposits, which all appear to arise from a single conductive zone in the upper mantle.

The group's current activities are founded on several years of MT research. Previously the team created three dimensional crustal resistivity models for the eastern Gawler Craton and Stuart Shelf – covering an area of approximately 30,000 km^2 and to a depth of 50 km. The models showed structures within the crust that were associated with mineralisation.The team also set up a line of 70 MT stations spaced 1 km apart beginning south of Olympic Dam at Wirrda Well, running right through to the north of Olympic Dam. MT detected areas of high and low conductivity and 'a giant conductive body' at about 100 km deep with four 'conductive fingers' rising to the surface (see figure). Three of these four 'fingers' point to known mineral deposits including Olympic Dam – part of the Olympic Domain that is classified as a Tier 1 globally significant mineral region.

New research will focus on understanding why deposits like Olympic Dam can be detected with MT. The most abundant mineral at Olympic Dam is haematite, which is not responsible for the conductivity. In a system that is essentially dry, it is unlikely to be water either. Developing a sensitive and specific technique for finding new mineral deposits relies on understanding what exactly MT is detecting in existing deposits.

Questions like this are at the heart of IMER's success – bringing together the right people and technologies to tackle a research question and provide answers that will have a positive and long-lasting impact for industry. The Uno Fault Zone on Central Eyre Peninsula is South Australia's only other Tier 1 region – a new region where low impact and cost-effective methods like MT have real potential.

Antarctic expedition helps understand geology of southern Australia

Crustal geology analysis in northern Antarctica can offer insights into rock formation processes in southern Australia

Antarctic research expedition to assess the geological nature of rocks in the region

Mineral prospecting in Australia to benefit

A team led by Professor Martin Hand, SACGER Director has recently returned from a world first expedition to assess the geology of northern Antarctica.

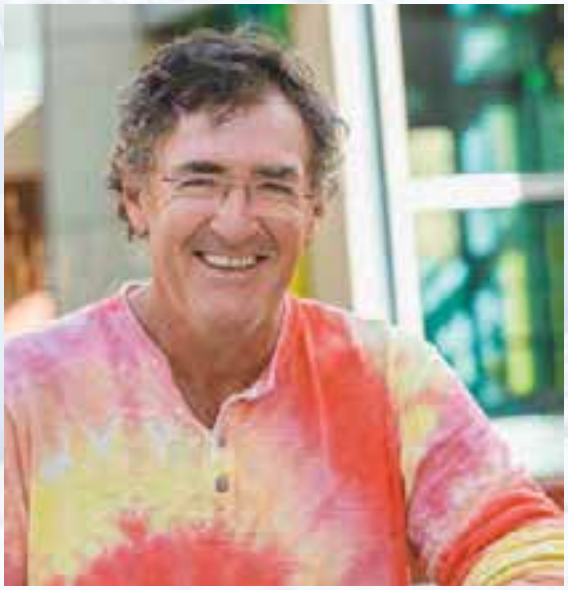
The work is part of the UNCOVER Initiative – an Australia-wide collaboration between industry, government and research organisations. The goal of the initiative is to develop innovative geophysical, geochemical and geological methods to increase Australian mineral discoveries into the future.

Geological surveys in Antarctica are not a precursor to minerals exploration on the continent. Instead, the approach allows scientists to access rock layers that are common to both southern Australia and northern Antarctica due to a shared geological history. Antarctica and Australia were once part of the same continental system until about 70 million years ago when the Southern Ocean formed. Studying surface geology in Antarctica offers a direct, cost-effective and environmentally-sound approach to understanding the geology of southern Australia.

To date, much of Australia's strong minerals resources industry has relied on locating and mining ore deposits located at, or relatively close to, the surface. For continued prosperity in the minerals industry in the future, new techniques are required to better locate ore deposits hidden under cover. Prospecting in deep undercover geological systems usually relies on expensive, hit-or-miss drilling.

Professor Hand and his team spent over two months collecting approximately 150 rock samples in remote northern Antarctica in cooperation with the Australian Antarctic Division. Researchers are now analysing these samples and generating large volumes of good quality data. Initially researchers will begin assessing the isotope geochemistry of around 30 samples. Samples will be prepared and processed using equipment at the University of Adelaide as well as geochemical and geochronology analysis at Curtin University in Perth.

Thanks to a technology revolution in analytical and processing equipment, data that would have taken two to three years to analyse in the 1980s will now only take a week. Extrapolation of these findings should help improve knowledge about the formation of minerals deposits and feed into a 'forward modelling' body of knowledge that will allow better prediction of where minerals deposits lie in Australia.



"Studying processes that shape crustal geology helps us to understand mineral formation, and more accurately identify areas that have high potential to be mineral systems – this is a different way of understanding prospectivity."

Professor Martin Hand
SACGER Director

Mapping and measuring trace elements to unlock secrets of ore formation

Mineral trace elements are measured and mapped with microanalytical methods

Used to help predict trace element patterns in rock and ore

Potential valuable mineral by-products or contaminants identified

Just about all minerals contain trace elements – minor impurities substituted atom for atom in the crystal structure. Their presence, absence, or concentration range can provide valuable information about how a rock or an ore formed.

Although we have known about or predicted these trace element concentrations for decades, the rapidly expanding microanalytical capabilities at Adelaide Microscopy mean they can now be accurately measured and spatially mapped at much smaller scales – often just fractions of a part-per-million.

TRaX researchers began investigating trace elements in minerals nearly ten years ago, measuring the concentrations in common sulphide minerals, such as pyrite and sphalerite. Associate Professor Nigel Cook and his team investigate which elements are present and at what concentration as well as why and how they are incorporated in minerals. There are also impacts for the growing field of geometallurgy, which can show what valuable potential by-products (such as indium or germanium) or unwanted contaminants (including thallium, mercury and arsenic) might be present in minerals.

The research has now expanded to other sulphides and mineral groups, most recently galena, the common lead sulphide. PhD student Luke George is examining the laws of nature that govern the so-called partitioning of trace elements between different minerals when they crystallise together. It is hoped this research will help to predict trace element distribution patterns.

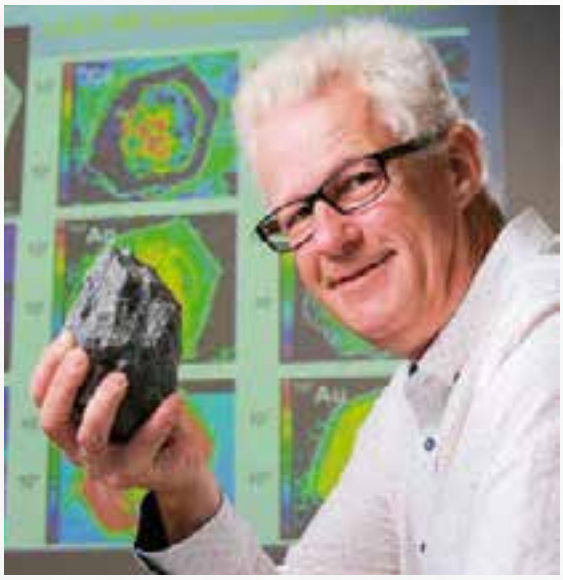
Two other PhD projects began in 2014 that apply the same approach to two very different minerals. Sasha Krneta is addressing the textural and chemical signature of apatite in and around the Olympic Dam deposit, compared with other ore systems. The aim is to assess the potential to use apatite to trace the magmatic-hydrothermal evolution of the ore, with potential for developing new exploration indicators. Alkis Kontonikas-Charos is looking at feldspar minerals in iron-oxide-copper-gold systems for evidence of fluid-rock reaction during ore genesis.

Dr Cristiana Ciobanu and the iron-oxide or 'FOX' team were awarded a new project 'Trace elements in iron oxides: deportment, distribution and application in ore genesis, geochronology, exploration and mineral processing' at the end of 2014. This project will look at trace elements in the two most common iron-oxide minerals, hematite and magnetite and is an interdisciplinary program of research funded through the SA Mining and Petroleum Services Centre of Excellence, and BHP Billiton.

Reference
George L, Cook NJ, Ciobanu CL and Wade BP (2015) Trace and minor elements in galena: A reconnaissance LA-ICP-MS study. *American Mineralogist* 100: 548–569.

"Rapidly expanding microanalytical capacity at Adelaide Microscopy is helping us accurately measure and map trace elements in minerals."

Associate Professor Nigel Cook
Deputy Director, TRaX



"If we can understand what the landscape looked like millions of years ago, then we can better predict where hydrocarbon reservoirs are located."

Alex Robson
Australian School of Petroleum

Research Highlight **TRaX**

3D seismic data reveals fault growth in Great Australian Bight

Evolution of geological systems can be better understood by examining fault lines

3D seismic reflection data used to identify faults from economically significant Ceduna Sub-Basin

Fault modelling used to help inform oil and gas exploration activities

The structure of a listric fault system in the Ceduna Sub-Basin, Great Australian Bight, has been described by PhD candidate Alex Robson. His results were obtained using 3D seismic reflection data, and suggest that the fault system grew in six stages according to the 'isolated fault model'.

This study highlights the need to look at fault growth in three dimensions demonstrating that seismic analysis can be used to visualise deep geological structures under the sea.

The Ceduna Sub-Basin trends west-northwest in the eastern Great Australian Bight, lying in water 200 to 5200 metres deep. It contains more than 12 kilometre thickness of sediments, hopefully comprising large deposits of oil and gas. Exploration in the Bight is extremely difficult because of the deep water and a lack of geological information.

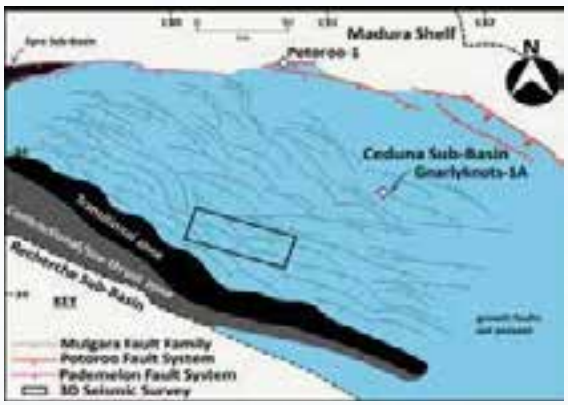
Understanding the evolution of geological features can provide insight into the structure of potential oil and gas reservoirs at depth. Economic and environmental outcomes can be improved by simplifying and informing the processes involved in tapping into these systems and successfully bringing reserves to the surface.

Alex Robson from the Australian School of Petroleum used 3D seismic reflection data to examine the growth history of listric faults in the Basin using displacement-distance plots and displacement backstripping.

Two vertically connected fault systems of differing structural style were identified, as well as fault growth via independent normal faulting and dip-linkage. The results are consistent with the isolated fault model, a formation theory whereby unique faults grow radially, accumulate displacement and then combine to form a larger fault system. In the Great Australian Bight this occurs as a gravity-driven process, as the area between Australia and Antarctica is under subsidence.

This research is helping improve our understanding of the size and shape of petroleum reservoirs and more accurately predict fault reactivation in petroleum settings on the southern Australia offshore basins and elsewhere. IMER researchers are also examining fault systems in the Otway Basin (southern Australia) and the North Sea (northern Europe) to better understand the relationship between fault growth and mineral resource formation over geological time.

Reference
Robson A, King R and Holford S (2015) 3D seismic analysis of normal fault growth and interaction within a gravitational detachment delta system in the Ceduna Sub-Basin, Great Australian Bight. ASEG 2015 Conference, Perth, Australia.



A map of the central Ceduna Sub-basin, illustrating the extensional, transitional and compressional zones as well as the location of the 3D seismic survey (modified from Totterdell and Bradshaw, 2004).

‘Artificial photosynthesis’ creating solar fuel

A research team led by Professor Greg Metha is using novel catalysts to carry out solar-induced photocatalytic conversion of carbon dioxide (CO_2) and water (H_2O) into methanol and methane fuels. A type of artificial photosynthesis, the process uses titanium dioxide (TiO_2), an inert and abundant photo-active substrate.

The researchers have improved the catalytic performance of well-known and studied reactions. Their novel co-catalyst is made of nanoscale gold clusters embedded into TiO_2 and is up to 40 times more efficient than the same quantity of traditional platinum catalysts. Similarly, by using nanoparticle ruthenium catalysts embedded into TiO_2 the team were able to produce a mixture of methanol and methane at 80˚C – significantly lower than the 200–250˚C required by current commercial catalysts.

Using a simple, purely chemical approach has many advantages compared to other solar conversion methods. The process is space-efficient, scalable and can be built anywhere in sunlight. Researchers are currently working on optimising the process even further.

“Our novel technique combines two ideal virtues – carbon neutral solar energy harvesting and storage as well as reduction of atmospheric CO_2.”

Professor Greg Metha
Centre for Energy Technology

"AusStorageBank will allow us to test energy storage systems under simulated Australian conditions both on and off the grid."

Associate Professor Nesimi Ertugrul
Centre for Energy Technology

Research Highlight **CET**

New AusStorageBank to support rapid deployment of energy storage technology

The Centre for Energy Technology will establish the first Australian Energy Storage Knowledge Bank (AusStorageBank) thanks to a collaboration between IMER, the Australian Renewable Energy Agency (ARENA) and industry.

Led by Associate Professor Nesimi Ertugrul, the project brings together industry partners SA Power Networks and Solar Storage as well as the Department of State Development and the Energy Networks Association Australian Strategic Technology Program. Total project funding of $3.2 million over two years includes $1.4 million from ARENA and $650 000 from industry and government partners. Along with SA Power Networks and Solar Storage, two local companies ZEN and Power and Drive will provide significant in-kind support. Financial and in-kind support has also been contributed by lead partner and custodian of the AusStorageBank, the University of Adelaide.

Commencing in 2015, the project will establish the Australian Energy Storage Knowledge Bank (AusStorageBank) to provide a single repository for the collection and storage of data, reports and case studies relating to the operation of energy storage systems in Australia. In addition to sourcing data from other projects, the AusStorageBank will perform its own testing and generate independent test data on the operation of energy storage systems through a specially designed, mobile Australian Energy Storage Platform (AusStoragePlatform).

The AusStoragePlatform will enable energy storage systems to be tested under real and simulated grid and off-grid conditions in Australia. It will also be used as a training aid to develop the industry and build the capacity needed to support rapid deployment of future systems.

The high resolution and independent data generated by AusStorageBank will benefit renewable energy and energy storage technology developers, energy utilities, energy users, training providers and regional communities throughout Australia. AusStorageBank will also develop links to existing energy storage deployments and centres of expertise to build a comprehensive and co-ordinated one-stop-shop for energy storage knowledge and information.

World-first hybrid reaction chain develops liquid fuel from solar energy

Environmental and cost concerns are driving innovative development of liquid fuels

Generation of liquid fuels from biomass-derived gases is energy intensive

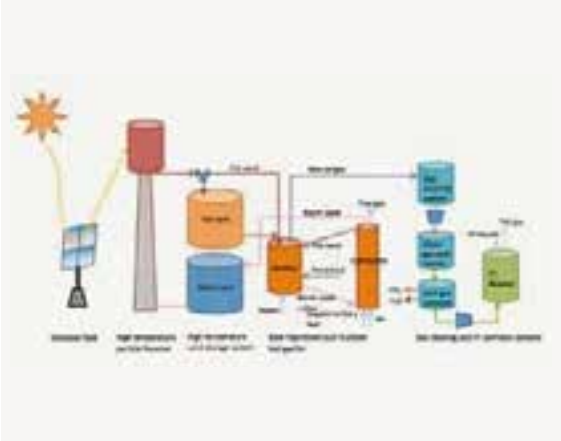
Concentrated solar thermal energy can produce liquid fuels via a realistic and cost-effective pathway

A world-first hybrid reaction chain for developing liquid fuels using concentrated solar thermal energy has been developed by CET scientists. Compared to other fuel generating systems, CET's solar receiver, solar hybridised gasifier and combustor, and high temperature energy storage system procedures are highly unique.

High production costs and negative environmental impacts of diesel and petrol distilled from crude oil are driving growing interest in alternative liquid fuels. One potential approach is to chemically convert gaseous hydrogen and carbon monoxide into liquid hydrocarbons using a process known as Fischer–Tropsch (FT). Transportation liquid fuels made using this method can be used in existing diesel and petrol engines.

Production of liquid fuels is energy intensive and expensive due to a reliance on conventional energy sources to drive reactions. Dr Woei Saw and colleagues from the Schools of Chemical and Mechanical Engineering have shown that solarised production of liquid fuels can be achieved cost-effectively. Their system consists of a solar-energy capturing array; a solar receiver; a high temperature storage system; a biomass solar hybridised gasifier and combustor; a series of gas cleaning and gas conditioning systems; a FT synthesis system; a heat recovery steam generator; and a gas and a steam turbine.

Now that the process has been shown to be economically viable, continuing research efforts are focused on fine-tuning each of the steps involved.



Solarised production of liquid fuels – a general schematic.

To improve the efficiency of the system, each aspect is now being experimentally tested and further refined through process modelling developed in-house at the University of Adelaide.

The overall aim of the research is to produce an industry-ready, fully hybridised and efficient system in which solar energy is captured, stored and used to convert biomass into gaseous molecules that are then chemically converted into liquid fuels. Biomass sources may include wood, macro-algae or agricultural by-products. In effect this will mean a liquid fuel production system that can be run on direct solar energy during the day and on stored energy at times when solar is not available. The capacity to retro-fit infrastructure for capturing, storing and releasing solar energy for liquid fuel production in existing systems is also being developed.

Reference
Performance Assessment of Fischer–Tropsch Liquid Fuels Production by Solar Hybridized Dual Fluidized Bed Gasification of Lignite. Peijun Guo, Philip J. van Eyk, Woei L. Saw, Peter J. Ashman, Graham J. Nathan, and Ellen B. Stechel. Energy & Fuels 2015 29 (4), 2738-2751
DOI: 10.1021/acs.energyfuels.5b00007

"Our hybrid system for capturing solar energy and generating liquid fuels is one-of-a-kind in the world."

Dr Woei Saw
School of Chemical Engineering

"Lowering the design wind speed of heliostats by nine metres per second led to an 18% reduction in the levelised cost of solar-thermal electricity."

Dr Maziar Arjomandi
School of Mechanical Engineering

Research Highlight **CET**

Reducing cost of solar technologies with better heliostat design

Reduced capital costs needed to increase economic viability of solar technologies

Heliostat design wind speed and heliostat field size can impact cost

Trade-off found between site-specific design and more robust and widely applicable design

Interest is growing in using solar technologies for commercial power generation, but capital costs need to be reduced. Dr Maziar Arjomandi and his team are investigating how the layout and heliostat field size affect the levelised cost of solar-thermal electricity.

Matthew Emes and Farzin Ghanadi.

Heliostats are a core structure within a concentrated solar power field. Heliostat design must take into account the static and dynamic forces within a turbulent flow field to ensure they perform efficiently and prevent structural damage during high wind situations. Design wind speed is a rating of the wind speed that can be tolerated by a particular heliostat design. The researchers have shown that lowering the design wind speed of heliostats by nine metres per second from the maximum 22 metres per second measured wind speed at Alice Springs can result in a 0.3% lower capacity factor and an 18% reduction in the levelised cost of solar-thermal electricity.

Heliostat design wind speed and size are inherently linked and so must be considered together. Optimal heliostat size decreases with increasing design wind speed, based on the assumption of quasi-static loads for the heliostat design. For example, the optimal heliostat size is 50 m^2 for a design wind speed of 10 metres per second, while it is only 25 m^2 for a design wind speed of 20 metres per second.

Heliostat costs can be minimised in regions where wind speeds are above 10 metres per second by manufacturing smaller heliostats than those commonly employed today. However, heliostat structure has to be optimised to account for wind speed. This would reduce the number of sites to which any given design applies and reduce the economies of scale. It is likely that there is a trade-off between site specific designs and a more robust design that is applicable at all sites, such as a heliostat with an increased mirror area at a low wind speed site.

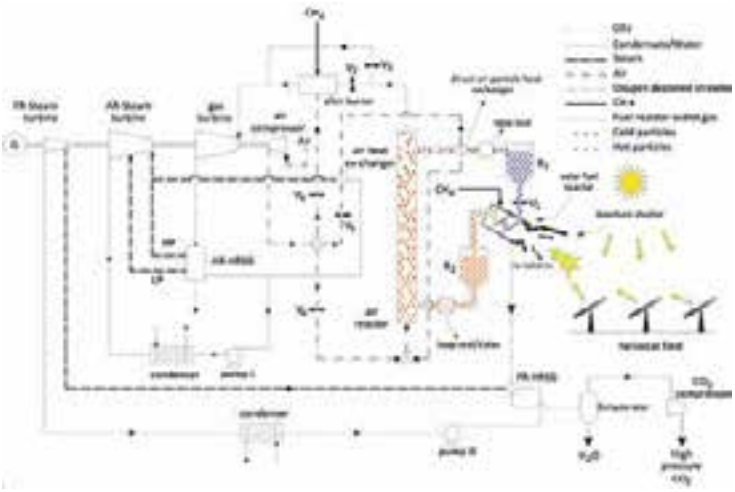
Reference
Emes M, Arjomandi M and Nathan G (2015) Effect of heliostat design wind speed on the levelised cost of electricity from concentrating solar thermal power tower plants, Solar Energy 115 (2015) 441–451.

A novel hybrid solar combined power cycle to decrease the cost of solar thermal power

Solar thermal power is low emission but is intermittent and high cost

World-first hybrid solar system has been developed aimed at reducing costs

System can provide base-load power generation with state-of-the-art thermodynamic performance



Dr Mehdi Jafarian is investigating whether the costs of solar technology can be reduced by combining it with chemical looping combustion (CLC) technology. Solar thermal power offers low net greenhouse emissions but the intermittent nature of solar radiation makes it a high cost technology. Fossil fuels offer continuous power and are more economical, but carbon dioxide (CO_2) emissions are high.

Chemical looping combustion technology was originally developed to provide industrially-pressurised CO_2 streams for sequestration or reuse. Using CLC process components CET researchers have designed a novel hybrid solar CLC (Hy-Sol-CLC) power plant (see figure) that can provide steady power generation despite variations in solar thermal energy input.

Mathematical models developed by the researchers compared the Hy-Sol-CLC system with other solar technologies. While current generation hybrids operate at around 3–10% solar share, the Hy-Sol-CLC power plant can achieve a solar share of 60% while maintaining base load power generation.

The thermodynamic performance of two configurations was also examined – with and without an after-burner. Without the after-burner the hybrid system achieved a first law efficiency of 44% with a solar share of 60% and produced pressurised and industrially-pure CO_2 ready for reuse or storage. With the after-burner the first law efficiency increased to 50% with a reduction in solar share. Sensitivity analyses indicated that further improvements to the performance of the cycle are possible.

The Hy-Sol-CLC system is a world-first with the potential to contribute to step change in integrating renewable energy technologies into conventional power generation systems. The ability to manage the inherent variability of solar power within the one system would significantly reduce costs. In addition to storing solar energy, the Hy-Sol-CLC system could also be run as a conventional CLC system during extended periods of low solar radiation.

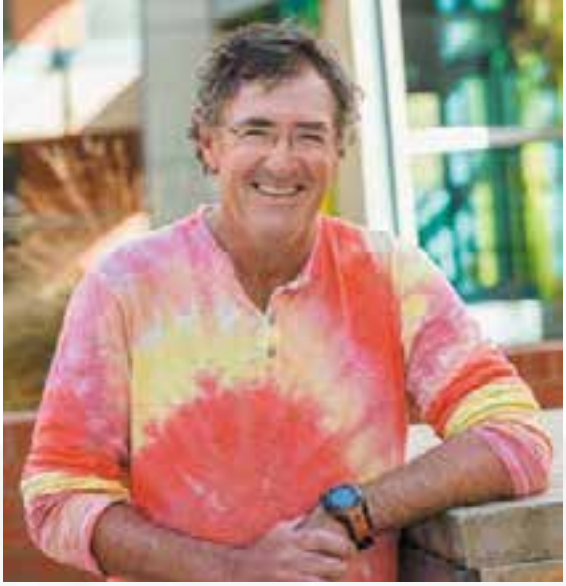
Reference
Jafarian M, Arjomandi M and Nathan GJ (2014). The energetic performance of a novel hybrid solar thermal & chemical looping combustion plant. Applied Energy 132, 74-85.

> "The hybrid solar CLC system has the ability to provide power production efficiency of around 50%. That is very close to state-of-the-art."

Dr Mehdi Jafarian
School of Mechanical Engineering

"With new high resolution heat flow data points we are increasing our understanding of the thermal state of the shallow crust in South Australia."

Professor Martin Hand
South Australian Centre for Geothermal Energy Research



Research Highlight **SACGER**

Revealing the resource potential of the South Australian shallow crust

Petrophysical and complementary wireline log data compiled from recently drilled wells

Insights into migration mechanisms of ore-bearing fluids plus thermal and physical processes in shale and coal seam gas resources

The mineral and energy resource potential of under-explored regions of the South Australian shallow crust is being revealed thanks to researchers from the South Australian Centre for Geothermal Energy Research (SACGER).

In 2014 the research team, led by Professor Martin Hand, gathered a comprehensive dataset of petrophysical and complementary wireline log data from wells across the northern and eastern Gawler Craton, Officer and Arckaringa Basins, Musgrave Province and Torrens Hinge Zone. Thirteen wells, drilled by seven different companies, were logged in areas of relative data paucity. The drilling of most wells was co-funded by the Department of State Development's Plan for Accelerating Exploration (PACE) program.

Supported by AuScope's Australian Geophysical Observing System (AGOS), data collected in this project is being used to materially constrain in situ stress; conduct geophysical inversions; construct geological and geothermal models; and undergo regional interpretation. Results 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.

In other research SACGER is conducting heat flow mapping in collaboration with the Department of State Development as part of the SA Therm project. This two-fold program is refining the heat flow database for South Australia by reviewing existing drill holes that have temperature data – either bottom hole temperature or continuous downhole wireline temperature logs. This thermal information is complemented with new petrophysical measurements on corresponding or analog core to derive robust heat flow estimates for each drill hole. Researchers are also acquiring new thermal data from recently drilled wells in under-explored areas of South Australia, mostly under the PACE Program, and its corresponding drill core. Heat flow studies are used to better understand regional geology and can lead to a better exploration tool for targeting resources.

"This research succeeded in locating additional permeable areas that can be targeted for Enhanced Geothermal Systems."

Dr Hani Abul Khair
SACGER

Research Highlight **SACGER**

Seismic surveys potential valuable tools for developing enhanced geothermal systems

Identifying and tapping into subterranean permeable reservoirs for Enhanced Geothermal Systems has been largely hit-or-miss

Seismic surveys highly effective in reservoir characterisation for geothermal exploration

Research conducted in SACGER could lead to significant cost and efficiency savings in Australia's geothermal industry. Dr Hani Abul Khair has shown that seismic data can provide accurate information for locating sweet spots within unconventional geothermal reservoirs, known as Enhanced Geothermal Systems (EGS).

Unlike conventional geothermal systems, unconventional systems depend on the presence of permeable locations within target reservoirs that allow water circulation between injecting and producing wells – either matrix or fracture permeability. By tapping into permeable areas of rock that surround geothermal energy resources, water can be circulated and steam collected to generate electricity.

Currently the geothermal industry does not have a reliable method for identifying well sites that tap into permeable reservoirs. Previously in Australia the focus has been on locating heat and then drilling with the expectation that the reservoirs will flow. This method has been very costly and not often successful. This study looked at correlating diagenetic history and seismic attributes to assess primary permeability in the Eromanga and Otway basins, two South Australian geothermal energy sites.

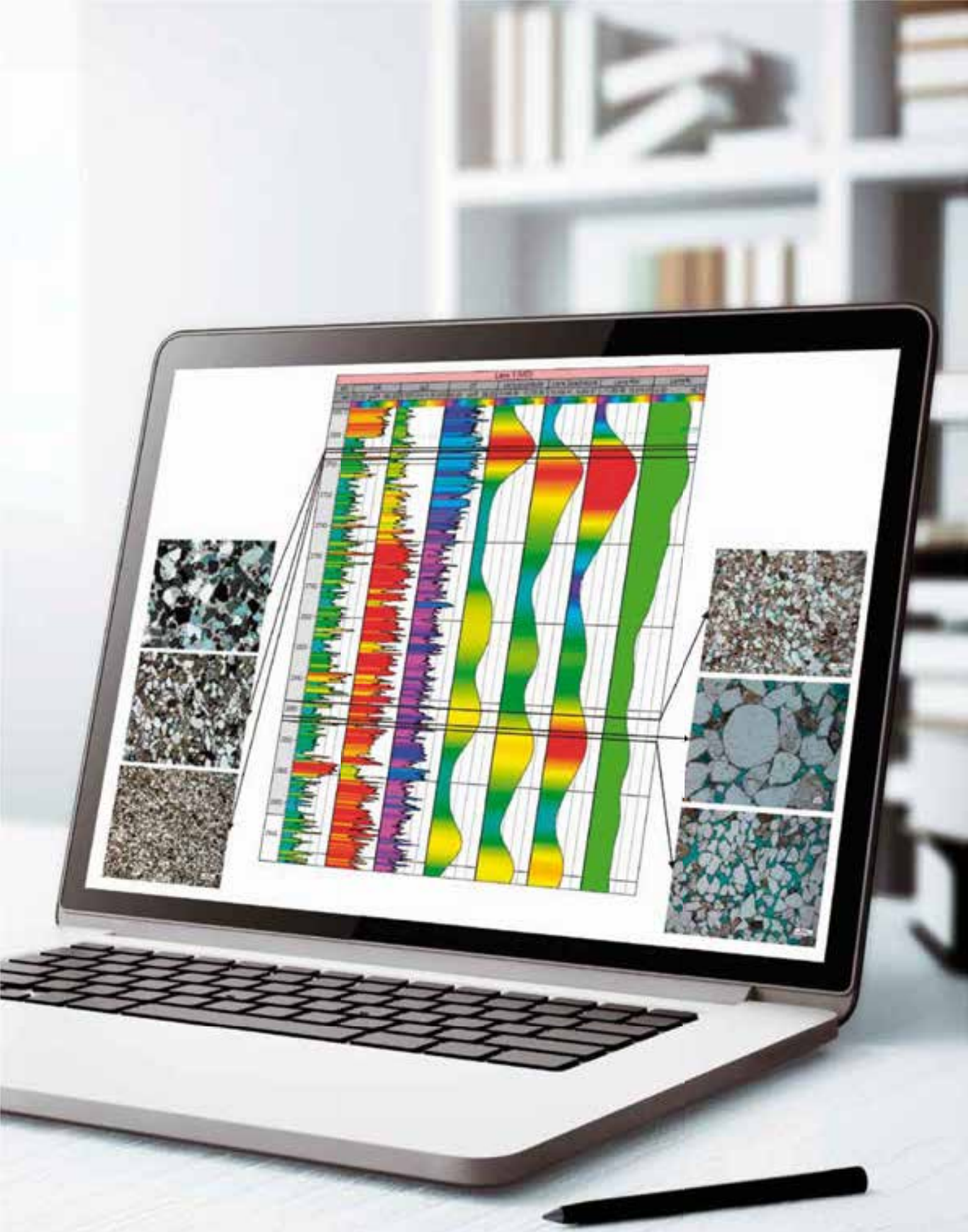
Understanding diagenetic processes – how rocks changed when deeply buried over time – can provide valuable information about permeability and porosity in reservoirs. Core samples were examined using normal scanning electron and cathodoluminescence microscopy.

Diagenetic processes that could reduce porosity and permeability were detected in both the Hutton Sandstone in the Eromanga Basin and the Pretty Hill Formation in the Otway Basin. Porosity and permeability were highly variable in both formations. Therefore a more robust methodology was needed to detect reservoir quality that could be correlated with the microscopic analysis.

Seismic surveys measure the reflection of sound waves to reveal characteristics of subterranean rocks and structures. Although they are routinely used for oil and gas exploration, they have not been applied in the geothermal industry in South Australia. Dr Abul Khair used seismic surveys to construct a structural framework model for the two geothermal plays, and the faults and target horizons were mapped. Seismic attributes that map the lateral reservoir variability were calculated for the target reservoirs and correlated with the microscopic results.

The study validates the capacity of seismic survey to accurately locate permeable reservoirs. Future development of this approach could provide a valuable new tool for identifying promising sites for unconventional geothermal systems.

This project started as part of an Australian Renewable Energy Agency project with additional funding provided by the Department of State Development.



Columnar section of Laira 1, GR: gamma ray, LLD: deep lateral log, DT: sonic velocity, note the higher amplitude and attribute values at 2686 m compared with 1864 m due to porosity variation.

Graded proppant injection to increase recovery of unconventional gas resources

Methane yield from coal bed and shale gas reservoirs is typically poor

Conventional proppant injection can improve recovery but optimising injection procedures in the field is costly and difficult

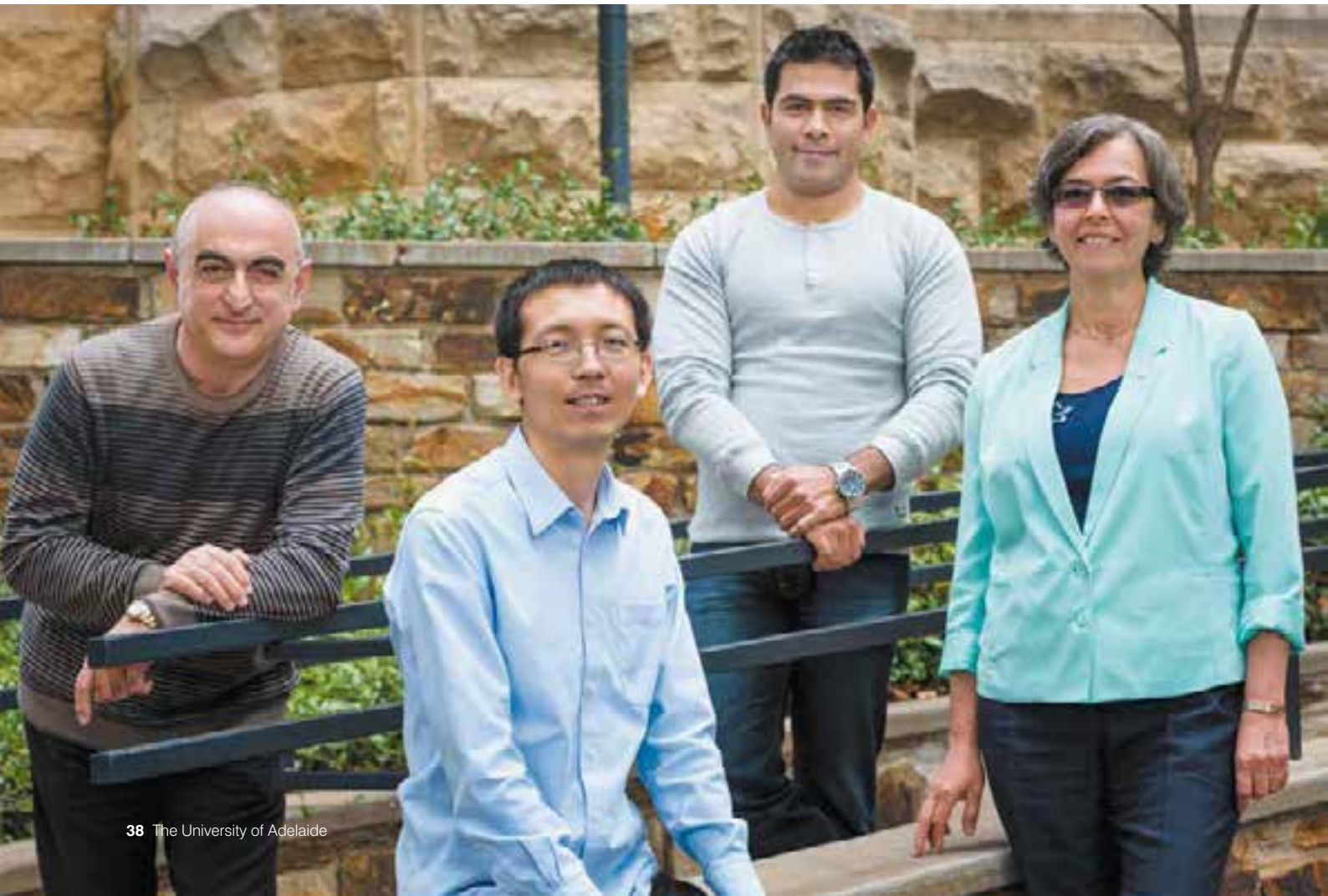
A technology for graded proppant injection for filling complex-shape cleats is developed

Laboratory model created to refine techniques in chemically-tailored carrier water

Extraction of methane from coal bed reservoirs is difficult and expensive due to the narrow apertures and low density of natural fractures (known as cleats).

Although hydraulic fracturing can be used to improve reservoir productivity, it is not always applicable due to environmental and stakeholder concerns. The Formation Damage & Enhanced Oil-Gas Recovery Research Group at the Australian School of Petroleum has designed an effective technology, based on laboratory procedures and mathematical models to improve methane extraction from coal bed reservoirs.

Pavel's team – Dr Alexander Badalyan, Dr Zhenjian You, Dr Abbas Zeinijahromi, Dr Themis Carageorgos.



“Graded proppant injection with chemically-tailored carrier water could improve well productivity up to six fold.”

Professor Pavel Bedrikovetsky
Australian School of Petroleum

Proppants are small sand-like particles that are injected into reservoirs to ‘prop’ open fractures so they will flow oil, gas or water better. Scientists are working on a model that can be used to investigate the effects of proppant size and fluid chemistry on the permeability of natural coal cleat and fracture systems.

To develop their model in the laboratory, researchers used core samples of coal from the Dawson Mine in Central Queensland as an experimental reservoir, and tiny glass spheres as proppants. Using state of the art laboratory apparatus, coal sample permeability before and after particle injection was monitored and recorded in real-time.

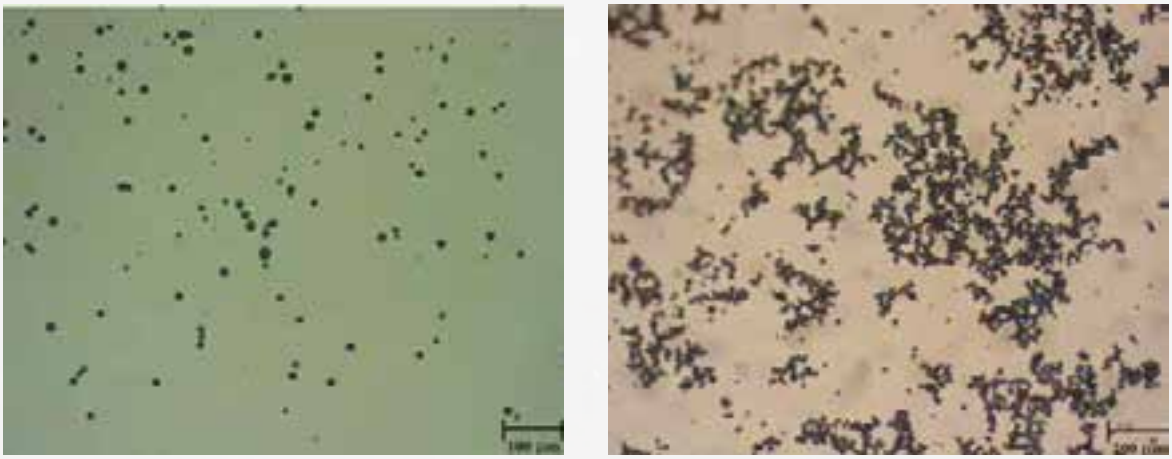
Results show that graded injection with chemically-tailored frac fluid that facilitates particle–particle and particle-rock repulsion can improve well productivity. Low salinity water was more effective in increasing permeability than water with high salinity. In the model, using different sized (graded) proppant particles in natural-fracture dominated coals at the highest pore pressure resulted in nearly a three-fold increase in coal permeability. Mathematical modelling and field case studies demonstrate that this permeability increase corresponds to a six-fold increase in the well productivity index in the field.

The results of this research could improve methods for coal seam gas extraction in the field. Future work will include refining various aspects of the techniques, including adjusting the salinity of the carrier water, to further optimise the system.

References

Keshavarz A, Yang Y, Badalyan A, Johnson Jr R, Bedrikovetsky P (2014) Laboratory-based mathematical modelling of graded proppant injection in CBM reservoirs, International Journal of Coal Geology. 136: 1–16.

Keshavarz A, Badalyan A, Carageorgos T, Bedrikovetsky P, Johnson Jr R (2015) Stimulation of coal seam permeability by micro-sized graded proppant placement using selective fluid properties. Fuel 144: 228-236.



Particles suspended in injected fluid. Left photo (100 µm scale) – low-salinity suspension. Right photo (200 µm scale) – high-salinity suspension.

"This new method was able to detect resistivity changes associated with frac fluids, and monitor with time how these fluids propagated through the shale formation."

Professor Graham Heinson
Leader, Electrical Earth Imaging Group

Research Highlight **Resource Engineering**

Monitoring hydraulic fracking with magnetotellurics

Current methods for monitoring hydraulic fracturing are complex and costly

New approach uses magnetotelluric resistivity models

Accurate models to monitor and guide hydraulic fracturing on horizon

In a world first, a team led by Professor Graham Heinson has used magnetotellurics (MT) to monitor fluid injection into a shale formation during hydraulic fracturing.

With further development, the approach has the potential to provide a direct and cost-effective method for monitoring fracking to improve the efficiency and environmental safety of shale gas production.

Hydraulic fracturing or fracking involves forcing liquid through shale to collect gas reserves. However, the low permeability of shale can lead to poor recovery, gas leakage and loss of injection fluids into aquifer systems. Fracking of shale causes environmental concerns related to the potential for gas leakage and contamination of aquifer systems.

The most commonly used method for monitoring the movement of liquid through shale is microseismic surveying, which maps fracture events rather than the passage of fluid deep underground. MT is a technique that images the conductive properties of Earth components and can accurately detect the presence and movement of subsurface liquid. MT monitoring of fluid injection during hydraulic fracturing offers an alternative that maps fluid movement rather than fracture development.

To conduct this study, a ten-stage horizontal-well hydraulic fracture in the Cooper Basin for a shale gas reservoir was monitored using MT. Four lines of instruments were placed radially in a cross-pattern from the central injecting well and monitored continuously for 65 days. This covered the 'frac and flowback' period of approximately one month.

To date, testing of this method in geothermal, coal seam and shale gas settings indicates that the method is feasible for monitoring deep injections of fluid. The sensitivity of the technique depends on the volume and the resistivity of the fluid injected and the connectivity, all of which can be fine-tuned for future applications. The capability for modeling of MT responses to produce time-lapse 1D, 2D, 3D and even 4D resistivity models is growing.

As with much of IMER's research, success to date has relied on an interdisciplinary approach with researchers working closely with the Australian School of Petroleum's Stress, Structure and Seismic group (S3). The study has demonstrated that MT has great potential for use in monitoring but improving outcomes from this relatively new technology will take time. Current research is aimed at improving this method for better applicability in hydraulic fracturing settings.

Reference

Carter, S., Heinson, G., Krieger, L., Rees, N., Conway, D., Putland, O., Rugari, J., Boren, G., Matthews, C., Monitoring of hydraulic fracturing in Moomba South Australia using magnetotellurics. APPEA Journal, volume 55 (2015), pages 149–162.

New method for rock burst based on micromechanical approach for safer deep mining

Deep mining operations prone to rock bursts due to high pressures and high temperatures

New model to improve mine design and mitigate the risk of rock-burst in existing deep mines

Bringing researchers and industry together to directly target the research needs of industry is at the core of IMER's success.

During discussions with OZ Minerals Dr Murat Karakus learnt of plans for a new mine at Carrapateena in South Australia. The deposit is approximately 470 metres below the surface, extending over 1000 m depth and with temperatures reaching around 60˚C, Dr Karakus realised the risk of rock burst would be a significant challenge for the company.

In deep mining projects, in situ stresses can have a major impact on mine layout and operation. The pressure in deep mines (>2000 metres) can already be up to 50-60 MPa and temperatures up to 60˚C. Methods used to make temperatures more favourable for workers can create temperature differentials that cause rock to store more strain energy. Drilling at this depth exerts even more stress that can lead to rock burst – an explosive failure that shatters rock, creating a dangerous situation for workers and reducing mine productivity.

Dr Karakus offered to identify and model the mechanism of rock burst using numerical analysis, with the aim of mitigating the risk of rock burst. Using samples from exploration drilling at OZ Minerals' Ankata underground copper mine at Prominent Hill, South Australia Dr Karakus is developing a new method for defining rock burst based on micro-mechanical methods. Core samples will be subjected to temperatures from 25–150˚C and pressures from 10–140 MPa. By looking at pre-failure and post-failure mechanisms, Dr Karakus and his team will develop a rock burst model – the first numerical model based on a micro-mechanical approach.

Dr Karakus will test his model at the proposed Carrapateena mine, on the eastern margin of the Gawler Craton. The model will have potential in existing mine settings to identify areas prone to rock burst and also in planning for new mines. Early project success has depended on connecting industry with researchers who have specialities in imaging and testing – a great example of how IMER's collaborative and interdisciplinary approach delivers real solutions for industry.

> "Rock bursts are actually initiated at the micro-level, so you have little fractures happening that get together to cause bursts."

Dr Murat Karakus
Resource Engineering

A team led by Professor Martin Hand, SACGER Director has recently returned from a world first expedition to assess the geology of northern Antarctica.

Key major projects active in 2014

IMER researchers gained support from prominent global companies, government and research partners in a large number of projects during 2014.

Here are details of key projects either initiated in 2014 or continuing as active projects through the year.

Centre for Tectonics, Resources and Exploration

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

Earth Sounding Network NCRIS2
Sponsor: Department of Industry
Chief Investigator: Professor Graham Heinson

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

Detachments in evaporites and shales: their controls on fold-thrust belt style and wedge geometry
Sponsor: Australian Research Council
Chief Investigators: Dr Rosalind King, Professor Alan Collins, Dr Mark Tingay, Dr Guillaume Backé
Collaborators: PTT Exploration and Production Public Company Ltd

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 Investigators: Associate Professor Jennifer Watling, Professor David Giles

Reservoir architecture and heterogeneity in marginal marine systems – *WAVE* Consortium Phase II
Sponsors: Apache, Badr Petroleum Co, BG, BHP Billiton, BP, Chevron, ConocoPhillips, Nexen, OMV, Shell, Statoil, Todd, Woodside
Chief Investigators: Dr Rachel Nanson, Dr Boyan Vakarelov, Professor Bruce Ainsworth (formerly lead CI, now with Chevron)

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: Professor Alan Collins

Calibrating electrical responses to natural fracture networks to support permeability mapping
Sponsor: Australian Geophysical Observing System
Chief Investigator: Professor Graham Heinson

Monitoring of Shale Gas Exploration and Exploitation
Sponsor: Australian Geophysical Observing System
Chief Investigator: Professor Graham Heinson

AusLAMP deep MT imaging of the South Australian crust
Sponsor: Department of State Development, Government of South Australia
Chief Investigator: Professor Graham Heinson

South Australian Centre for Geothermal Research

Further funding for South Australian Centre for Geothermal Energy Research
Sponsor: Department of State Development
Chief Investigator: Professor Martin Hand

High sensitivity and precision mass spectrometry for tracing Australia's ancient evolution and securing our future groundwater resources
Sponsor: Australian Research Council
Chief Investigators: Professor Martin Hand, Professor Bronwyn Gillanders, Professor John Foden, Professor Martin Kennedy
Collaborator: University of Tasmania

Reservoir quality in sedimentary geothermal resources
Sponsor: Australian Renewable Energy Agency
Chief Investigators: Professor Martin Hand, Professor Allan Pring, Professor Pavel Bedrikovetsky.

Chair of Geostatistics and Quantitative Geology
Sponsor: Department of State Development
Chief Investigator: Professor Peter Dowd

Centre for Energy Technology

Development of functional dendrimer-like inorganic nanomaterials with hierarchical pores for biological applications
Sponsor: Australian Research Council
Chief Investigator: Professor Shizhang Qiao

Green cool wine: Solar powered solid adsorption refrigeration system with ice storage to provide cooling capability for wine industry
Sponsors: Australian Research Council, Premium Wine Brands
Chief Investigators: Associate Professor Eric Jing Hu, Professor Mark Biggs, Dr Chen Lei

Mechanisms of sound absorption at the nanoscale
Sponsor: Australian Research Council
Chief Investigators: Associate Professor Anthony Zander, Dr Carl Howard, Associate Professor Ben Cazzolato
Collaborator: CSIRO

Nanostructured non-precious metal and metal-free catalysts for sustainable clean energy generation
Sponsor: Australian Research Council
Chief Investigator: Professor 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: Professor Gus Nathan

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

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

Oscillating water column efficiency improvement through impedance matching and active latching control techniques
Sponsor: Australian Research Council
Chief Investigators: Associate Professor Ben Cazzolato, Professor Gus Nathan, Dr Maziar Arjomandi

Quantifying the impact of wind farm noise on rural communities
Sponsor: Australian Research Council
Chief Investigator: Professor Emer 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 turbulent noise production
Sponsor: Australian Research Council
Chief Investigators: Dr Paul Medwell, Dr Cornelius Doolan, Dr Laura Brooks

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: Professor 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 Investigators: Associate Professor Christopher Sumby, Dr Christian Doonan
Collaborators: CSIRO, University of Sydney

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

Funding for unconventional energy research at the Australian School of Petroleum
Sponsor: Department of State Development
Chief Investigator: Professor Peter McCabe

Resource Engineering Program

Impact of rolling dynamic compaction
Sponsor: Australian Research Council
Chief Investigator: Professor Mark Jaksa
Collaborator: University of Sydney

Novel technology for enhanced coal seam gas production utilising mechanisms of stimulated cleat permeability through graded particle injection
Sponsor: Australian Research Council
Chief Investigator: Professor Pavel Bedrikovetsky, Professor Anthony Roberts, Dr Andrei Kotousov
Collaborator: University of New South Wales

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 reservoir rocks
Sponsor: Cooperative Research Centre for Greenhouse Gas Technologies
Chief Investigator: Dr Ulrike Schacht

Deep Exploration Technologies Cooperative Research Centre

Regional mineral system drilling for targeting and testing
Sponsor: Deep Exploration Technologies Cooperative Research Centre
Chief Investigator: Professor David Giles

Energy Pipeline Cooperative Research Centre

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

Dr Hani Abul Khair, Australian School of Petroleum, in the Visualisation suite.

IMER engagement

IMER continued to engage extensively and positively with other research organisations, industry and the community throughout 2014.

Local events were supported by international networking as IMER members contributed to a number of international conferences including the International Mineral Processing Congress (IMPC) and Unconventional Resources Technology Conferences.

Executive Director Stephen Grano participated in a study trip to Sweden and Finland with the Department of State Development, where important connections were established. IMER members also contributed to the Roundtable for Oil and Gas Projects in South Australia; ICT in Energy and Resources Roundtable; and the SA Government Clean Energy Summit.

A diverse program of public engagement ensures IMER remains connected, innovative and focused on industry and the community.

Industry Innovation Seminar Series kicks off with shale gas

IMER's new Industry Innovation Seminar Series is fostering links between industry and researchers. The series was launched in August with a seminar examining shale gas exploration and development delivered by Dr Bronwyn Camac, General Manager Unconventional Resources and Exploration for Santos Eastern Australia Business Unit and Mr Teof Rodrigues, Chief Reservoir Engineer of Santos Limited.

Australia – an energy technology leader or follower?

More than 150 people attended the inaugural Luxton Memorial Lecture held in November in honour of Professor Sam Luxton. Amory Lovins, Co-founder and Chief Scientist at the Rocky Mountain Institute delivered an introduction via video link from the Institute's passive solar banana farm in Snowmass, Colorado. CET Director Professor Gus Nathan presented an overview of Professor Luxton's legacy before Mr Tony Wood, Director of the Grattan Institute's Energy Program, presented the keynote address.

Professor Alan Collins ponders past planet in inaugural lecture

As part of the celebrations of the University of Adelaide's 140th anniversary, newly appointed Professor Alan Collins presented The Past Planet Puzzle. Prof Collins examined how we can reconstruct the past geography of the planet using the evidence in the roots of ancient mountain ranges and considered the impact of ongoing geological processes in our own time. The lecture was the third in the series of Inaugural Lectures by newly-appointed Professors, forming part of the celebration of the University of Adelaide's 140th anniversary.

CET research showcased at international forum

CET Director Professor Gus Nathan presented a lecture on recent developments in solar thermal hybrids with combustion technology at the Clean Energy Forum held at Tsinghua University, Beijing, China. Prof Nathan also presented a keynote lecture on direct hybrids between solar thermal combustion and gasification processes at the Australia-China Workshop on Novel Solar-Driven Carbon Dioxide Capture Technologies also held in Beijing.

SACGER research on show for Saudi Arabians

Dr Chris Matthews and Dr Alex Musson hosted a Saudi Arabian delegation at SACGER in May. The group presented their long term vision for renewable energy in Saudi Arabia and strategies for achieving their energy goals. The delegation were particularly interested in SACGER's research into electrical geophysics for mapping subsurface fluids; 3D seismic attribute analysis; management of reservoirs, porous media, water injection and seawater; fluid-rock interactions and regulation and legislation.

Halliburton takes IMER researchers on technical tour of the United States

Professor Stephen Grano, IMER Executive Director, and Dr Hani Abul Khair from ASP attended the 2014 Unconventional Resources Technology Conference (URTeC) in Denver, Colorado as part of a technical tour of the US hosted by Halliburton.

Roundtable on Enhanced Imaging of Australia's Mineral Resource Systems

In September IMER hosted a roundtable on the use of enhanced imaging in Australia's mineral resource systems. Professors Graham Heinson and Martin Hand led discussion on the potential of magnetotellurics to find new mineral systems, examine regional-scale prospectivity and investigate conductivity anomalies beneath world-class mineral systems. Participants also discussed establishing an ARC-funded Research Hub for Enhanced Imaging of Australia's Mineral Resource Systems – a large scale collaboration that would provide a critical mass to address key industry needs.

The event was attended by representatives from Lincoln Minerals Limited, BHP Billiton, Investigator Resources Limited, Adelaide Resources Limited, Sandfire Resources, Minotaur Exploration Limited and the Department of State Development.

Engineering Education Engagement Award for Honours program

The School of Mechanical Engineering's Honours program received an Award for Engineering Education Engagement (AAEE). This award-winning program is facilitated by Associate Professor Ben Cazzolato, Dorothy Missingham, Dr Will Robertson and Dr Zebb Prime.

CET Research Day and Annual Awards

CET held its annual Research and Awards Day in November to showcase research outcomes and highlights. Paul Heithersay, Deputy Chief Executive Department of State Development, presented a keynote address on the South Australia Government's vision for energy resources in this State. Awards were presented for Best Technology Development, Best contribution to Research Quality (PhD) and Best team player.

IMER researchers at International Sooting Flame Workshop

Professor Gus Nathan, Professor Bassam Dally, Associate Professor Zeyad Alwahabi, Dr Zhiwei Sun, Dahe Gu and Saleh Mahmoud attended the 2nd International Sooting Flame (ISF) Workshop in San Francisco in August.

Imperial Barrel Award puts IMER team amongst best in the world

An Australian School of Petroleum (ASP) team won the American Association of Petroleum Geologists (AAPG) Asia Pacific Region's Imperial Barrel Award (IBA) for 2014. The IBA is rigorous and highly-competitive and the ASP team, made up of David Kulikowski, Nachiketa (Sunny) Mishira, Stephanie Tyiasning, Alexander Robson and Kunakorn Pokalai, went on to receive an honourable mention at the finals held at the AAPG Annual Meeting in Houston.

For further enquiries

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