Deep Earth Imaging

Future Science Platform

Information for prospective early career researchers

Australia's future minerals, energy and water resources will come from far greater depths in the onshore regions and from deep offshore plays. Our ability to find, define and exploit these resources is limited by the deep and complex cover of sediments and weathered material that covers about 80% of Australia's land mass.

Deep Earth Imaging science will help us more precisely image and understand the significance of subsurface rock properties which in turn will unlock the resource potential of this vast and relatively under-explored continent, transforming it into a Glass Earth.

Future Science Platforms

The Concept

Beginning in 2016, six new CSIRO Future Science Platforms will underpin innovation in natural resources, health and biology, agriculture and manufacturing. Each will support the reinvention and creation of new industries, new wealth and new jobs for Australia.

Our Future Science Platforms fuel deeper collaboration across disciplines to tackle some of the things that haven't been done before, and will help Australia stay ahead of accelerating global disruption.

Some Platforms will draw on big data to make strides forward for health and environment, some will use CSIRO's precision science to transform biological systems, and others will focus on our deep knowledge of natural resources and manufacturing to create more sustainable industries to support the jobs of tomorrow.

Future Science Platforms are clearly a strategic investment in frontier research and delivery of solutions. But equally importantly, they are a targeted investment in the next generation of early career researchers who will work collaboratively on challenging science that will invent Australia's future.

The platforms empower CSIRO's strategy of solving Australia's toughest challenges, and getting science off the lab bench and into people's hands as quickly as possible to improve Australia's sustainability and prosperity.

Larry Marshall, CSIRO Chief Executive

The Big Six – CSIRO's future plans

CSIRO will make an initial $17 million investment in 2016–17 in six new areas of frontier science, and grow that investment to over $52 million per year by 2020, helping to turn Australia's challenges into opportunities and invent a better future. The platforms will facilitate an increase in the amount of staff working on frontier science as well as increased collaboration between universities and CSIRO.

The teams working on these platforms will have the chance to see their ideas fast tracked through technology pre-accelerators that will create connections between research, science and business,

enabling research teams to validate their research outcomes and translate them into real world applications.

The six new [Future Science Platforms](#) announced in September 2016 are :

Active Integrated Matter Reinventing fields as diverse as manufacturing, agriculture, emergency services, infrastructure and mining through combining advanced materials, robotics, sensing technologies, data processing and autonomous capabilities. New forms of autonomous robots will operate safely in dangerous environments while smart materials will enable new types of customised and personalised products and services.

Deep Earth Imaging Discovering the previously undiscovered minerals, energy and water resources that lie deep under the earth or sea. The science of Deep Earth Imaging will help us more precisely image subsurface geology to unlock the potential of this vast and relatively under-explored area.

Digiscape Helping agricultural industries to be more productive and providing more valuable knowledge to environmental policy makers through a new generation of decision tools. Using sensors, data visualisation, artificial intelligence and assisted decision making to generate timely and relevant advice and insights will allow better choices for more productive and sustainable outcomes.

Environomics Unlocking genetic and other knowledge from our vast species biodiversity so we can preserve and manage ecosystems under environmental change, better manage economically useful species, detect biosecurity threats and create new products based on previously unknown biological data.

Probing Biosystems A revolution in healthcare and agriculture through devices and systems to obtain real-time information from living organisms about their health and well-being. This will lead to the ability to provide health and medical interventions that are timely, customised and highly specific.

Synthetic Biology The design, fabrication, and construction of new biological parts, devices, systems, and machines, as well as the re-design of existing biological systems for useful purposes. Synthetic biology enables revolutionary advances in cellular factories, designer organisms and biological devices.

TEMPEST® AEM airborne electromagnetic acquisition system. Image credit: CGG Airborne.

Deep Earth Imaging

Platform Overview

In the future, Australia's minerals, energy and water resources will come from far greater depths in the onshore regions and from deep offshore plays. Our ability to find, define and exploit these resources is limited by the deep and complex cover of sediments and weathered material that covers about 80% of Australia's land mass.

Deep Earth Imaging science will help us more precisely image and understand the significance of subsurface rock properties which in turn will unlock the resource potential of this vast and relatively under-explored continent.

Platform Description

For over 120 years we have successfully mapped and analysed Australia's land surface, but our resources-rich continent has yielded most of its wealth from an area comprising only about 20% of the continent's exposed or shallow crust. Geologically, there is no reason to think that the relatively under-explored area is not at least as well-endowed in natural resources. The principal challenge is that this likely endowment is concealed by a complex cover of sediments and

weathered regolith. This vast area presents an enormous opportunity to discover buried natural resources – minerals, energy and water.

The recent decline in mineral exploration success across Australia is in large part due to the difficulty of exploring beneath and within the regolith and sedimentary basins that cover most of the continent. Future success requires diversification of the search and discovery space through this cover and to greater depths. Industry has identified and prioritised the development of a new suite of tools and workflows to explore through Australia's cover as articulated in the UNCOVER vision and the AMIRA Industry roadmap for UNCOVER.

UNCOVER Vision: ©Australian Academy of Sciences. Image: D. Müller.

Similarly, for energy resources, there is considerable potential for new oil provinces to be discovered and developed in frontier areas such as the Great Australian Bight. Onshore basins, particularly in the Northern Territory and central/western regions of Australia, have enormous unconventional natural gas potential. The recent COP21 meeting in Paris highlighted Australia's leading role in geosequestration to explore and develop new subsurface carbon storage reservoirs.

Building hydrogeological understanding from Deep Earth Imaging will also build public, government and investor confidence that resource development impacts on water resources will be minimised. Nationwide detailed water resource assessments are vital, and can be supported by innovation in deep aquifer imaging and characterisation, to help provide an integrated evaluation of the feasibility, economic viability and sustainability of Australia's water resource development opportunities and potential.

Deep Earth Imaging will use smart analytics and algorithms to simulate geological models and properties which enable subtle patterns to be identified and interpreted, thus, more precisely imaging subsurface rock properties.

We will build new analytical software tools founded in rock physics (digital-rock), drawing on predictive technology, machine learning, geological uncertainty analysis and geoscience modelling. These tools will manage real-time or near-real-time data streams and assemble multiple inputs from geology, (hydro)geochemistry and geophysics.

Our planned work will draw on expertise from several overlapping domains, including geophysical modelling and simulation, geological/geophysical/geochemical knowledge integration, and
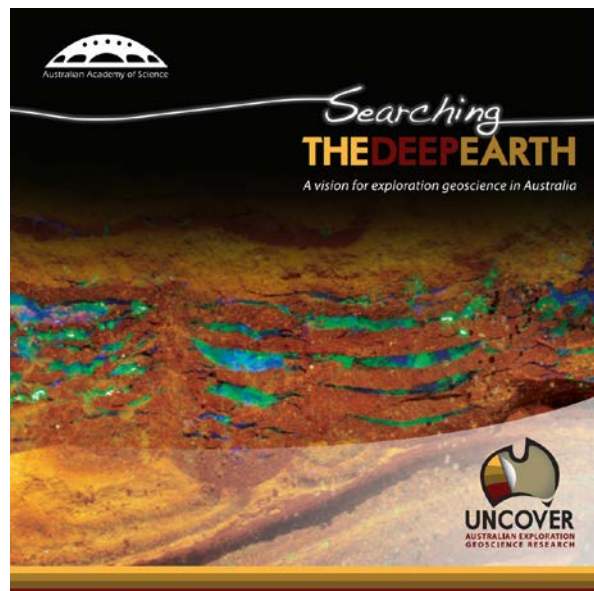
geological uncertainty reduction, with its impact delivered through a cloud-based platform to provide new tools as a service to industry and the nation.

Theme 1: Modelling and simulation

We will build a geophysical modelling software platform using forward simulations fused via Bayesian inversion, an approach that has the dual advantage of robustly computing uncertainty in the final output and allowing joint inversion of data from disparate sensor platforms. For example, magnetic and electromagnetic responses of contrasting rock units and effects such as remanence and superparamagnetism need careful consideration given our knowledge of geological relationships.

We will devise consistent methods for combining this information. Industry clients and researchers will use available data to build better models to quantify the risk associated with acting on predictions. Three critical avenues of research and development are required to make this toolbox a reality:

- A parameterised geological model to define possible inversion outputs;

- Estimates of process noise in each of the various forward models to properly weight its contribution to the final output; and

- Inversions compute economically via reduced-order modelling and empirical interpolation for smart sampling.

TOP-100 supercomputer Magnus, the most advanced in the Southern Hemisphere at the Pawsey Supercomputing Centre, part of the National Resource Sciences Precinct, where the Deep Earth Imaging platform is based.

Theme 2: Knowledge integration

We will pursue non-parametric approaches to directly infer cover characteristics and depth from an understanding of a geophysical, geochemical, surface geology and satellite data suite. Rather than employing geophysical and geological simulations to compute expected sensor measurements from candidate models, we will train probabilistic machine learning algorithms with example targets and features derived from available raw data sets. We will simulate geochemical processes and forward model geophysical responses. Coupled fluid-flow and chemical reaction (reactive transport) models can be employed to simulate ore formation and deposition processes, and produce a mineralogical model at various time steps showing how chemical alteration varies in space and time.

Theme 3: Uncertainty reduction

Blending probabilistic approaches with model reduction, data compression and empirical interpolation in forecasting will allow us to develop workflows and plan future observations to maximise expected information gain. Thus, rather than drilling or sensing in a grid, adaptive algorithms could optimally sample selective regions where the model is most uncertain, increasing the value of each measurement while reducing the overall cost of sample collection. This active sampling tool, in conjunction with parametric and non-parametric models, will determine the location and sensing modality of future measurements to maximise value. Greater recognition of all the contributing sources of uncertainty is required in future studies, whether hydrogeological or geological, particularly as we work across scales of measurement. Additional design constraints (*e.g.* distance from roads/infrastructure/water resources, or total cost per kilometre), will be added to the cost function. The key challenge in building an active sampling tool is to maintain computational tractability, especially when integrated with Bayesian inversions, justifying an emphasis on model reduction and data compression.

Theme 4: Large-scale computation

The tools we will build are computationally expensive to deploy. In an era of cloud computing, we do not expect our industrial customers to build and maintain new cyber-infrastructure. Rather, we will build a cloud-based platform to provide these decision-making tools to industry, seeking to lower the barrier to entry, thereby accelerating technology uptake.

Deep Earth Imaging Platform Outcomes

Our ultimate aim is for the overlying regolith to become 'transparent' by more precise imaging and profiling of subsurface rock properties, transforming the under-explored parts of Australia into a *Glass Earth*. Developing a toolkit to better navigate through the subsurface will add significant value to the wealth of geological and geophysical data that already exist. The full potential of these data remains untapped, mainly because there is a lack of appropriate interpretation technologies. By linking these methods to rock physics (digital-rock), and by discovering, understanding and modelling relationships between remotely-acquired geophysical observables and *in situ* rock properties, the uncertainty associated with exploration through this cover can be reduced. This means that further drilling and collection of geophysical data will be more efficient and achieved with lower risk. In addition, outputs from the development of the Platform will deliver generic software products that will boost Australia's world-leading expertise in this domain.

The Deep Earth Imaging Future Science Platform will:

* Create a research hub of expertise in deep earth imaging;

* Develop a product suite for data interpretation and decision making to solve deep cover challenges in resource exploration across water, minerals and energy;

* Deliver a range of commercialisation opportunities for SME partners to take up globally,

* Build a cloud-based platform to support rapid transfer and utilisation of the developed technology, and

* Establish a CSIRO-led geoscience network featuring a Deep Earth Imaging annual conference.

For the team, the Platform will be a nucleus for collaboration, the first ever exploration and environmental geoscience capability hub in Deep Earth Imaging that crosses the boundaries of minerals, energy, and water. Here, CSIRO will play a central role in serving as the innovation catalyst for the earth science community in Australia.

Continuous innovation and technological development are critical for improving the global competitiveness and productivity of the Australian resources sector, and as such are critical to the nation. Australia has a clear competitive advantage in its ability to conduct such research, with the mining sector accounting for 22 per cent of all business R&D investment. However, one of the major challenges is the commercialisation of these research outcomes. The Platform will connect

with the <u>METS Ignited</u> and <u>Oil, Gas and Energy Resources Growth Centre</u>, built to promote innovation through accelerating commercialisation and better collaboration between R&D and industry needs. Early collaboration will provide for rapid technology transfer mechanisms for our product suite into both sectors.

Likewise, the need for better understanding of deep aquifers in remote regions that could be vital for supporting natural environments and developing a sustainable agricultural and industrial base. Positioning to meet the demand for new water users and uses is an important driver for improved information and analysis of deep water resources that can be addressed through Deep Earth Imaging.

Prof Michael McWilliams
Platform Leader, *Deep Earth Imaging*
mike.mcwilliams@csiro.au

Dr Caroline Johnson
Platform Project Officer, *Deep Earth Imaging*
caroline.johnson@csiro.au

For further information please e-mail dei-fsp@csiro.au