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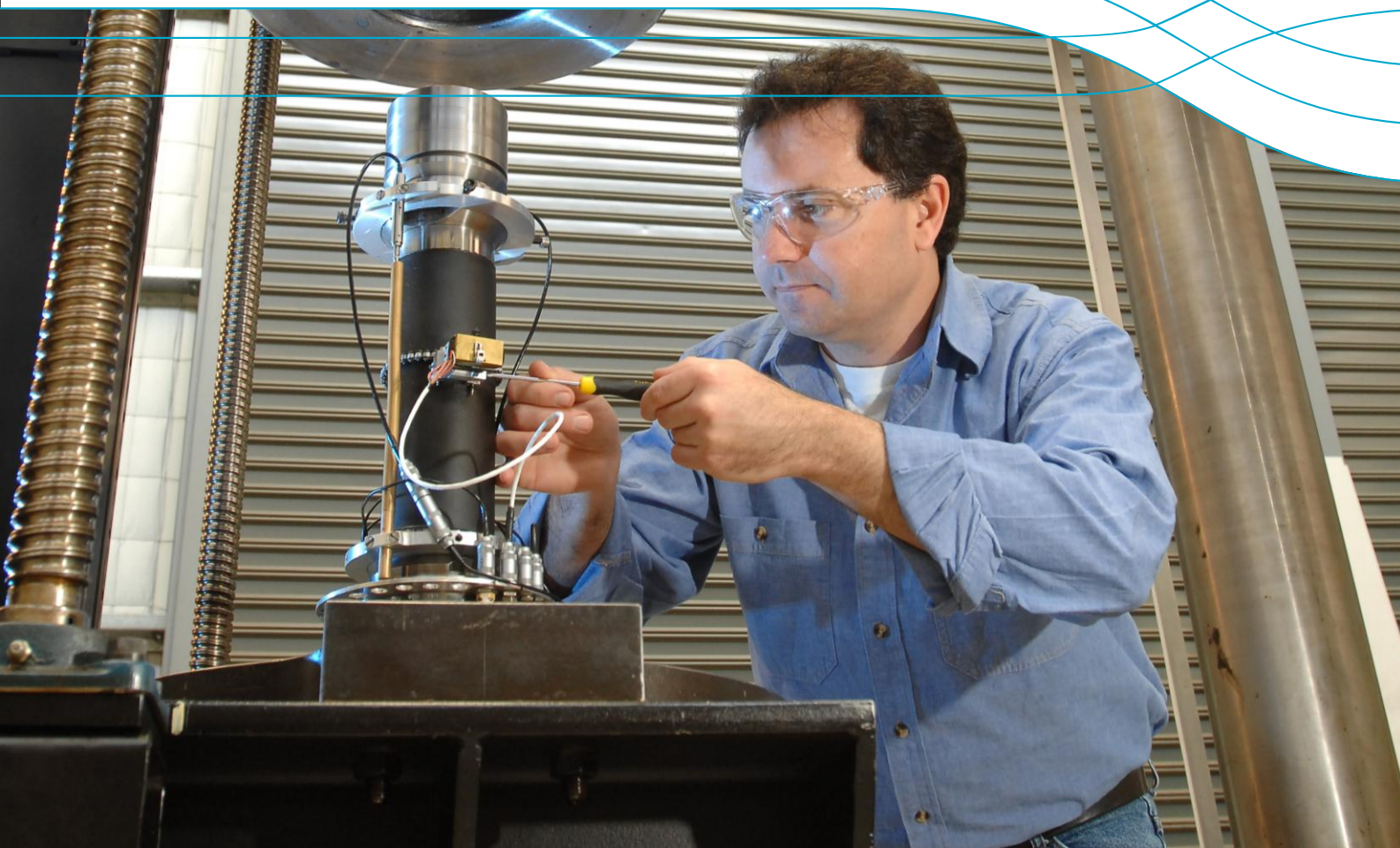
GEOMECHANICS & GEOPHYSICS LABORATORY

CSIRO Energy



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Important Disclaimer

1. COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

CSIRO, Australia's national science agency, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

CSIRO's rich history shapes our future direction. The Organisation's vision, mission and core beliefs have been built-up over the last 80 years and flow through everything we do.

At the same time, in response to some important challenges now facing Australia, we have embarked upon a new era at CSIRO.

Only our unrelenting focus on improving the quality of our science and the impact of our outputs will ensure our relevance for years to come. We are reinventing ourselves as a research enterprise with global reach. We demand of ourselves science excellence, business excellence and operational excellence.

CSIRO's strength lies in building multidisciplinary expert teams to tackle the big and complex problems and challenges facing humanity. We organise ourselves into five research groups, within which we operate 9 National Research Flagships, 12 research Divisions, five Transformational Capability Platforms and several national research facilities and collections.

CSIRO realises that the solutions to many challenges are increasingly being found across sectors and at the intersection of different scientific disciplines – and so, we are set up to support this. We have the breadth, skills, diversity, infrastructure, perspective and flexibility to work across boundaries, nationally and internationally, and deliver research outcomes of significance and impact.

Some facts:

- CSIRO ranks in the top one per cent of world scientific institutions in 14 of 22 research fields (based on the Institute for Scientific Information data on total citations of publications)
- CSIRO produced over 4,000 scientific publications in 2015, and also transfers know-how through over 8,000 client reports, and around 240 media releases annually, plus secondments, industry workshops, seminars and specialist publications
- CSIRO leads nine National Research Flagships that bring focus and scale to research addressing some of Australia's most important and complex challenges and opportunities
- CSIRO is the largest single participant in the Cooperative Research Centre (CRC) Program worldwide, CSIRO is involved in over 700 current or recently completed research activities, working with leading scientific organisations and firms in the United States, Japan and Europe, and with developing countries, especially in Asia
- CSIRO offers more than 50 specialised technical and analytical services. These include analyses for air pollutants and satellite imaging of natural resources through to fire testing of materials and diagnosis of exotic animal diseases
- CSIRO is Australia's leading patenting enterprise; holding over 3,900 granted or pending patents more than 90 spin-off companies are based on CSIRO generated intellectual property and expertise.
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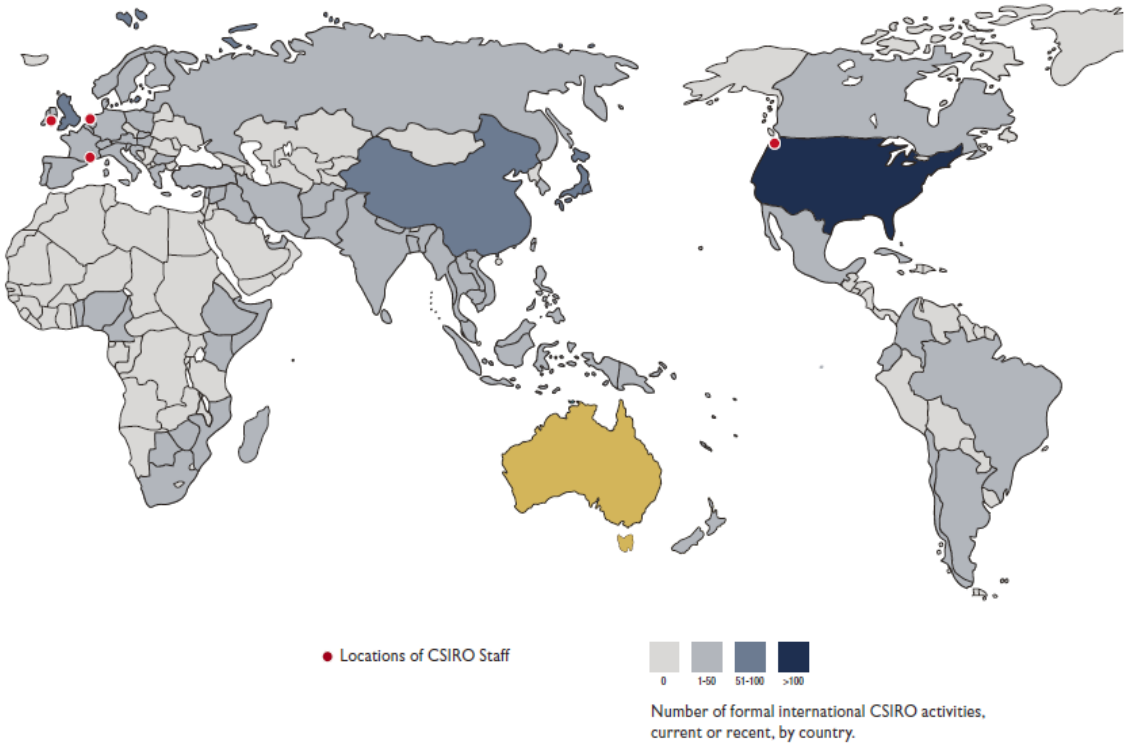
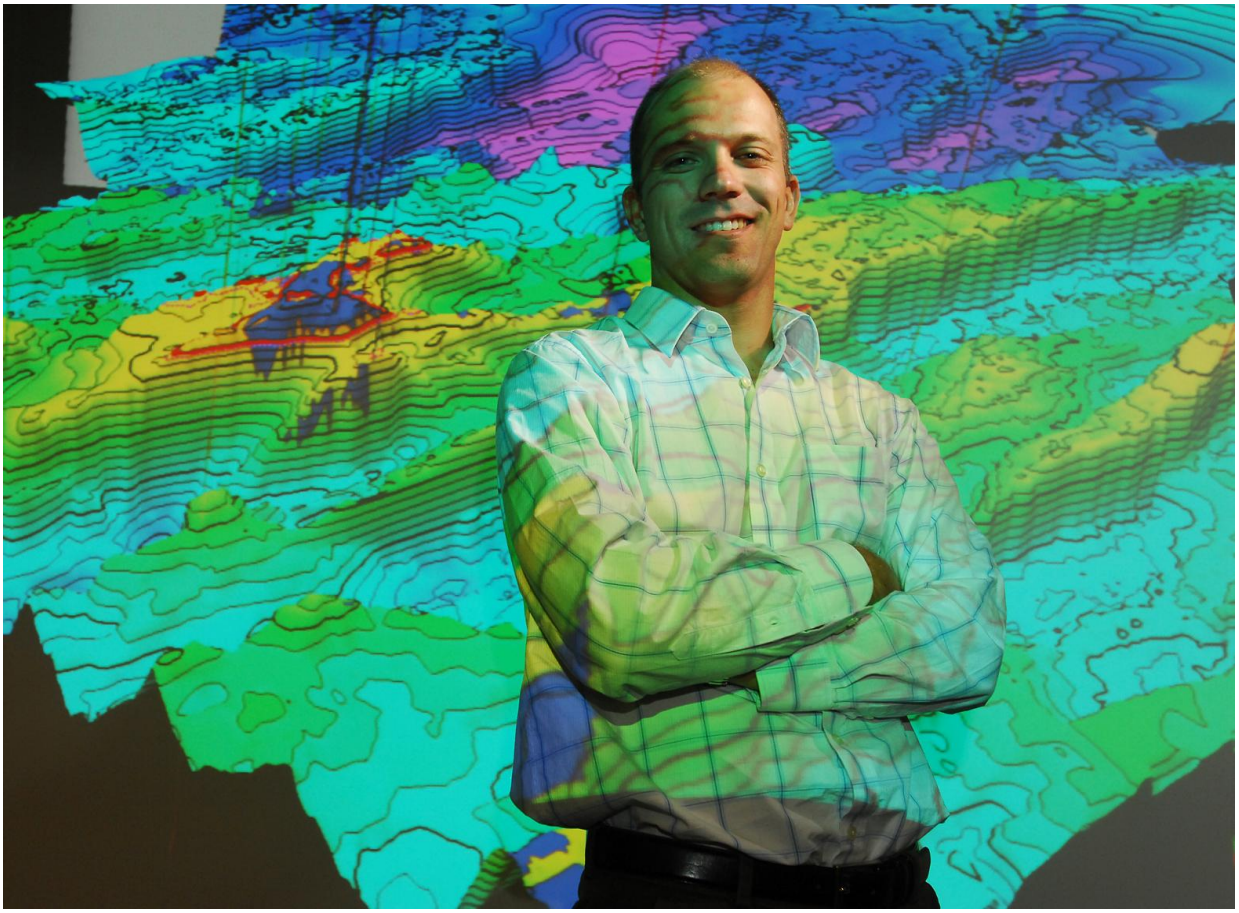
CSIRO's International Activities





2. CSIRO's PETROLEUM RESEARCH

CSIRO's research and development efforts in these areas contribute to the nation's priorities of securing access to cost competitive petroleum resources, accelerating large-scale cuts to greenhouse gas emissions and supporting a smooth transition to new energy futures.

With a critical mass of over 500 energy researchers and 300 geoscientists, CSIRO is providing solutions. The integration of complementary capabilities and technologies, large scale research focus and strong national and international partnerships with industry and government allow CSIRO to provide technology leadership to solve the nation's biggest challenges and develop new opportunities in the energy arena.

3. LABORATORY FACILITIES

CSIRO's Geomechanics and Geophysics laboratory, located at the Australian Resources Research Centre in Perth, is one of the leading rock mechanics and rock physics laboratories in the world.

Our specialised laboratory is equipped to measure the mechanical and ultrasonic properties of rocks under in-situ conditions of stress, pore pressure and temperature to provide essential data for modelling and prediction of mine safety, wellbore stability, trap integrity and sand production.

Laboratory testing is the only direct way to determine the mechanical properties of rocks. Accurate analysis of rock mechanical properties can improve exploration, drilling and reservoir management and assist the industry to maximise production and recovery. It may also help to optimise well siting, and minimise down-time and reservoir loss.

Our first mission is to provide key support to strategic research projects conduct by CSIRO and his partners though the development of leading edge experimental devices

Technical service projects are undertaken in collaboration with oil and gas companies for projects related to wellbore stability, reservoir compaction, 4D seismic interpretation, CO2 storage and hydraulic fracture stimulation.

Our laboratory shares the technical platform with the National Geosequestration Laboratory (NGL), a collaborative initiative funded by the state and federal governments and led by CSIRO, The University of Western Australia (UWA) and Curtin University. It has been established to conduct and deploy critical research and development to enable commercial-scale carbon storage options in Australia and overseas. For more information, please visit http://ngl.org.au/

4. EXPERTISE

The Rock Mechanics Testing team has extensive experience in experimental geomechanics and Rock physics. Further expertise includes geology, petrology, petrophysics, physics and materials science.

The projects carried out within the CSIRO's Rock Properties petrophysics laboratory is closely aligned with the multi-disciplinary team that is associated with the facility.

The experimental work is used as input into geomechanical, dynamic elastic and petrophysical modelling.

Our unique combination of capability allows us to conduct targeted experimental and theoretical research that directly addresses industry challenges.

The Sand Production Rig, one of our triaxial devices, allows to apply an axial load up to 400 kN under a maximum confining pressure of 70MPa

5. LABORATORY EQUIPMENT

The laboratory houses a number of instruments for static and dynamic rock mechanics testing:

Instrument	Confining pressure (MPa)	Pore pressure (MPa)	Axial load (kN)	Max. Temp. (°C)
Autonomous triaxial cells with axial ultrasonics	70	70	400	100
3 Autonomous triaxial cells with axial, radial and off axis ultrasonics	70	70	400	100
Autonomous triaxial cell with axial and radial brine permeability	70	70	400	100
High pressure cell	300	70	5 000	
Medium pressure cell	35	35	1 000	
Hoek cell	70	70	400	100
Terratek triaxial cell with axial, radial and off axis ultrasonics	70	70	400	
Sand production rig	70	70	400	
High pressure, high temperature cell with 20 channel active/passive transducer system	150	100	700	200
Velocity-resistivity rig	70	70		
Wykeham Farrance UCS & Brazil			50	

Six of these rigs have ultrasonic capability with both P- and S-wave transducers, of which three have the capability of simultaneous measurement in different orientations. Three ATCs and the HPHT rig have 16 and 20 channel active/passive acoustic emission systems.

We also develop leading edge new facilities to address specific research or industrial issues. We are currently developing a new installation to derive poro-elasticity parameters on low permeability seals or gas shale. Our scientists are also implementing low frequency measurements in existing ATCs to allow accurate measurement of elastic properties of rock in a broad frequency range (from seismic to ultrasonic frequencies) at reservoir conditions.

The laboratory is also equipped to prepare samples of specific size, shape and tolerances for mechanical testings as recommended by ISRM.

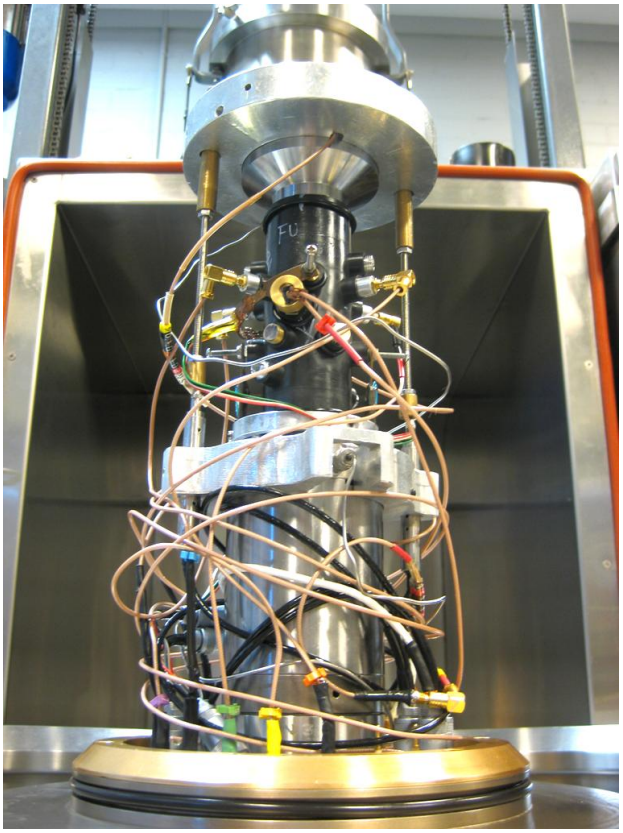
High pressure-high temperature rig coupled with High Frequency Ultrasonic Measurements:

The Acoustic Emissions Triaxial Cells at CSIRO are equipped with multiple single pin and up to 20 coaxial feedthroughs, allowing for the direct instrumentation of the rock specimen that is subjected to in situ conditions. The equipment loading capacity is as follows:

- cylindrical rock specimen: Ø = 38 millimetres (mm) and L = 80mm
- confining pressure: up to 150 MPa
- top pore pressure: up to 100 MPa
- bottom pore pressure: up to 100 MPa (independent from the top)
- axial Stress: up to 700 MPa (for Ø = 38 mm)
- temperature: up to 200 °C.

On a single rock specimen, this allows monitoring of:

- strains in axial, radial directions using dedicated sensors
- P- and S-wave velocities along many propagation paths to assess rock properties' (i) sensitivity to stresses and temperatures; and (ii) anisotropy (active seismic monitoring)
- micro-seismic activity (passive seismic monitoring) using the same set of ultrasonic transducers
- brine or gas permeability along the specimen's axis.
- geothermal production as well as for production in tight gas and shale gas environments.

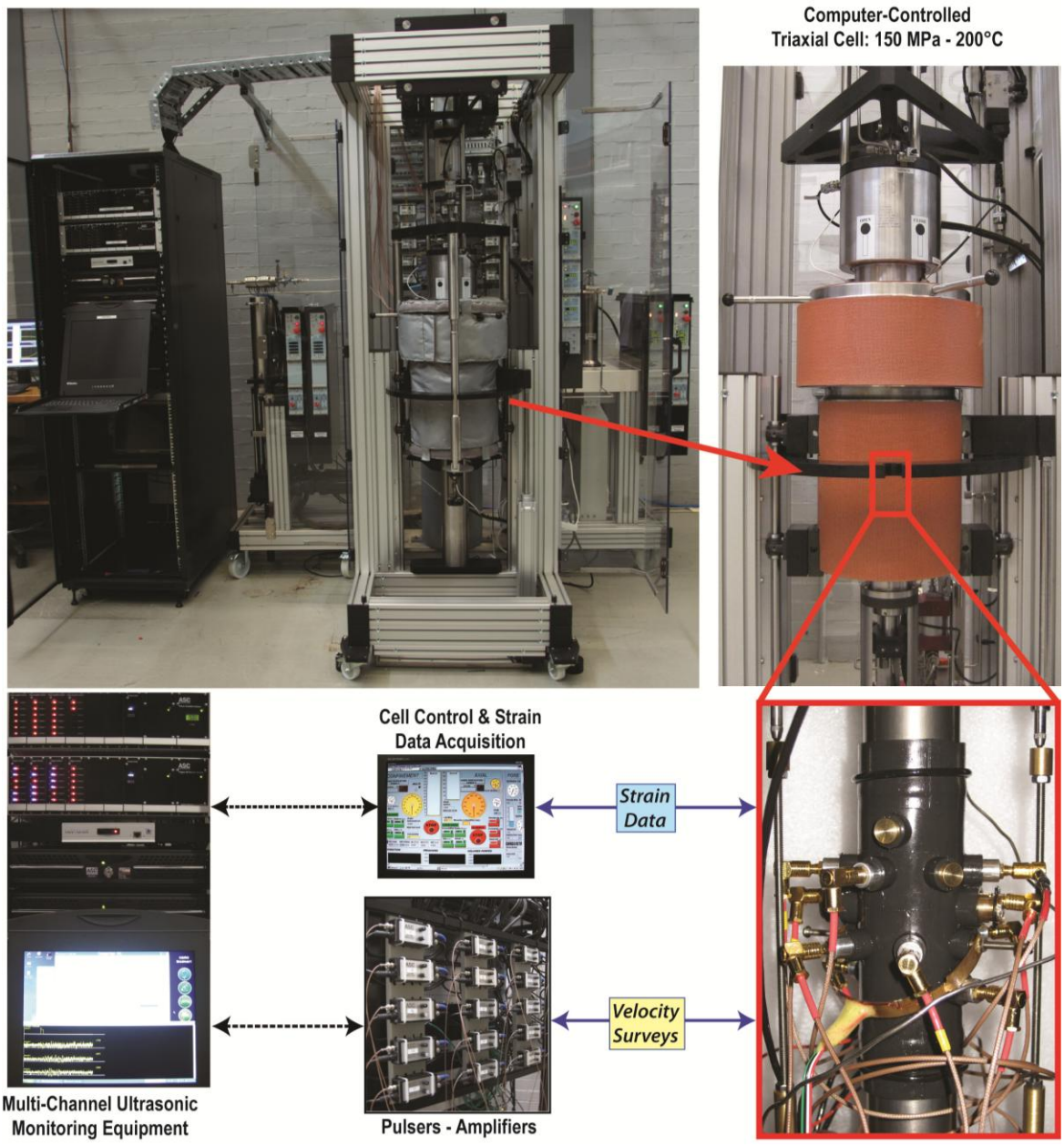


Specifically designed core sleeve equipped with P- and S-wave transducers for Multi-Axis velocity measurements and micro-seismic monitoring.

These laboratory measurements are of fundamental importance for the interpretation of field-scale geophysical data in exploration and production. They can be applied to:

- sub-surface seismic monitoring of oil and gas reservoirs or overburden
- geological storage of carbon dioxide or radioactive waste

The laboratory measurements are also used to inform and validate rock physics models developed by the CSIRO geophysics team.



CSIRO's HP-HT Triaxial Cell is equipped with 20 channels for active ultrasonic and passive micro-seismic monitoring, and can reach pressures up to 150MPa and temperature up to 200°C.

Autonomous Triaxial Cells:

The Autonomous Triaxial Cells (ATCs) at CSIRO are equipped with multiple single pin feed-throughs, allowing for the direct instrumentation of the rock specimen being subjected to in-situ conditions. The equipment loading capacity is as follows:

- cylindrical rock specimen: interchangeable sizes, normally Ø = 38 millimetres (mm) and L = 80mm or Ø = 25 millimetres (mm) and L = 50mm
- confining pressure: up to 70 mega pascals (MPa)
- pore pressure: up to 70 MPa
- axial Stress: up to 400 MPa (for Ø = 38 mm)
- temperature: up to 100 °C.

On a single rock specimen, this allows monitoring of compressive strength parameters such as peak and residual loads, Young's modulus and Poisson's ratio and failure envelopes. They may also provide Sample Compressibility Calculations and Peak Collapse Pressure data.

Some of our ATCs have the added capacity of ultrasonic signalling systems for the simultaneous measurement of both static and dynamic rock properties. We are also implementing a new system of directional permeability measurements, along and orthogonal to the sample axis, in one of our ATCs.

Autonomous Triaxial Cell is equipped with 16 channels for active and passive acoustic monitoring and can operate at pressure up to 70 MPa and Temperature up to 100°C.

The results of these tests provide industry with valuable information about the calibration and referencing of dynamic tools to more common static measurements and the determination of material anisotropy through off-axis ultrasonic measurement relative to axial measurement. CSIRO has also developed mechanisms whereby the ultrasonic sensors are in direct contact with the rock specimen face thereby eliminating offsets and signal dampening introduced with some other systems. We build ATC systems to custom specifications for various clients.

The laboratory measurements are also used to inform and validate rock physics models developed by the CSIRO geophysics team.

In addition to the geomechanics/geophysics capabilities, **CSIRO's Petrophysics laboratory** offers a range of dielectric measurement options in a broad frequency range for solid and drill cutting samples.

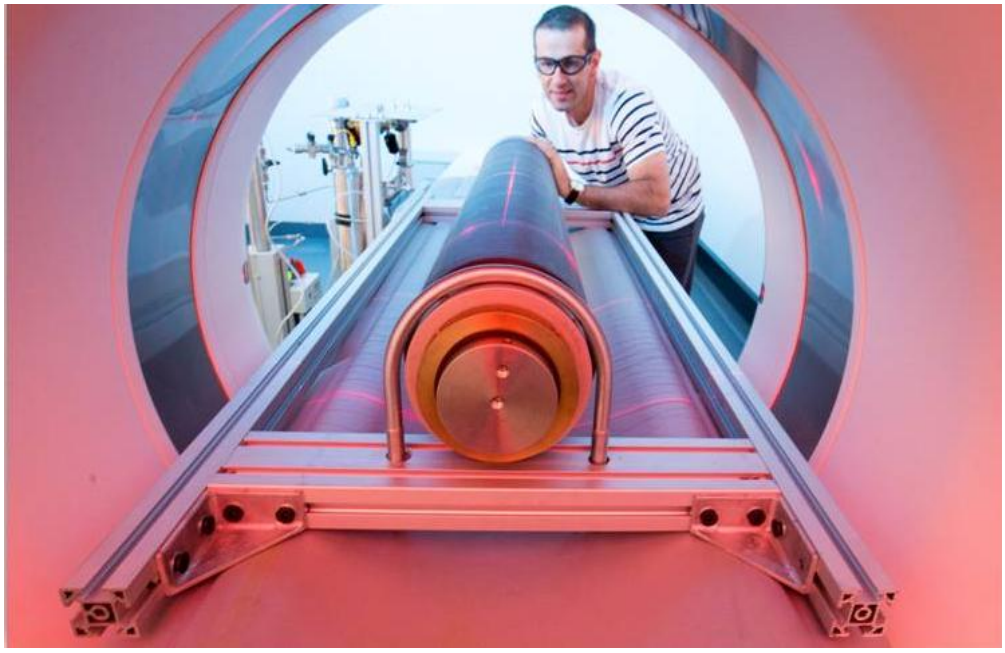
The Petrophysics laboratory has the following facilities:

- equipment for overburden pressure gas porosity and permeability
- dual energy medical-type X-ray Computed Tomography (CT) scanner with coreflood equipment
- high resolution micro X-ray Computed Tomography (CT) scanner
- X-ray transparent ultrasonic measurement cells for multi-phase flow under high pressure and CO_2 compatible
- combined resistivity/ultrasonic high pressure cell (CO_2 compatible)
- Nuclear Magnetic Resonance (NMR) spectrometers from 2 to 20MHz.
- triaxial/coreflood cell (30MPa) compatible with 2MHz NMR spectrometer.
- a wide range of broadband electrical and dielectric measurement systems in a dedicated laboratory suite (from 0.1 Hz to 6 GHz)

These facilities allow the Petrophysics laboratory to determine and interpret the physical properties of rocks to enable the characterisation of the production performance of petroleum reservoirs.

The Broadband Electrical Properties Lab conducts impedance analysis and dielectric spectrographic analysis of rock samples including core samples provided by industry and other research organisations, as well as powdered drill cutting samples.

Dielectric properties of rock are indicators of wettability, porosity, mineralogy, pore structure and pore geometry.



Medical CT-Scanner combining X-Ray transparent coreflood experiments

6. RESEARCH PROJECTS

The Geomechanics and Geophysics laboratory provides key support to strategic research projects on shale behaviour, top seal integrity and the geological storage of carbon dioxide. Our facilities are used extensively in the current research projects and have been extensively used in recently concluded and highly successful integrated projects.

Current research in experimental rock mechanics and rock physics at CSIRO follows a number of distinct paths:

CSIRO research investigates shale properties through two important projects:

The SHARC2 Consortium is investigating unconventional gas shale reservoirs using a micro-to-macro, lab-to-field, experiment-to-theoretical approach to examine links between rock physics, petrophysics and geomechanics.

This research consortium currently has three sponsors and run for three years to 2016.

The SHARPP Project aims to investigate the links between rock physics, petrophysics and micro-to-macro structure in conventional shales.

This research project is sponsored for three years to 2017 by an industrial partner

CSIRO also continuously consolidates and develops its expertise in Oil and Gas exploration/production related research, covering

The Fault Reactivation Project is a multi-disciplinary and multi-scale project aiming to quantify and model the mechanisms of fault generation and reactivation during hydrocarbon production operations in carbonate reservoir rocks.

This research project is sponsored for three years by an industrial partner and is almost finalized

Integrated rock physics, petrophysics and geomechanics are used to evaluate the impact of supercritical carbon dioxide injection on the elastic response of reservoir rocks and shales under in situ conditions.

Multi-physics rock characterisation takes a multidisciplinary approach to characterisation of rocks, including rock physics experiments and modelling, nuclear magnetic resonance for saturation plus coupled geomechanical modelling to evaluate four-dimensional (4D) seismic response.

Past research projects allowed CSIRO to build up a unique expertise and a proven track record in the assessment and characterization of conventional and unconventional hydrocarbon resources and reservoirs.

SHARC (Shale Research Centre) Consortium sponsored by Sinopec, Chevron, ConocoPhillips, Statoil, Total, ExxonMobil and BG-Group. The project aimed to provide a comprehensive set of experimental measurements and develop new models for shale behaviour. This study has

developed an extensive database of shale properties and has also successfully developed a new unique rock physics model for prediction of shale elastic properties.

IGEM-4D (Carbonate Multiphysics and Geomechanics for 4D Seismic Response) sponsored by Petrobras. This project aimed to upscale the hydraulic properties and geomechanical parameters of Carbonate reservoirs from the scale accessible in the laboratory to a reservoir-sized model.

APCRC Seals (Australian Petroleum CRC) focused on the characterization of Mechanical properties and microstructure of fault rocks and the regional properties of Muderong Shale.

TURI (Turbidite Research Initiative) led to the development of a unique workflow for the characterization of static and dynamic properties of turbidite reservoirs.

IPETS (Integrated Predictive Evaluation of Traps and Seals) delivered breakthrough prediction of Shale geomechanical properties, a unique description of shale rock physics response, anisotropy and fluid/rock interactions.

7. COLLABORATIONS

We work and had worked in collaboration with Oil/Gas and Mining companies for research projects related to wellbore stability, reservoir compaction, 4D seismic interpretation, CO2 storage and hydraulic fracture stimulation. We also provide technical services project for a wide range of worldwide Oil/Gas companies. Examples of past and current collaborations are Exxonmobil, Chevron, Sinopec, Petrobras, Petronas, Petrochina, Total, Conocophillips, Saudi Aramco, BP, BG-Group, Schlumberger, Woodside, Origin Energy, Santos, BHPBilliton.

CSIRO Geomechanics and Geophysics laboratory also develop and maintain constant interactions with State and Federal Government agencies, Cooperative Research Centres and international universities.

8.STAFF

<table>
<tr><th colspan="3">Rock Mechanics Testing and Maintenance</th></tr>
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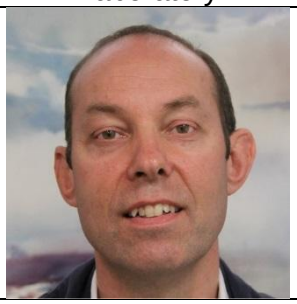
<tr><td>  </td><td>  </td><td></td></tr>
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Rock Properties Characterization	
	
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	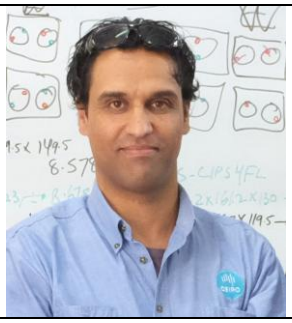
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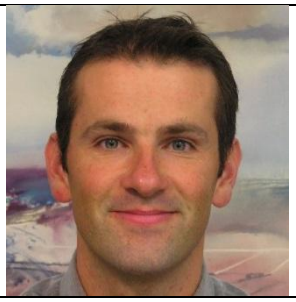
Petrophysical Characterization		
		
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