FINDER
EXPLORATION

19 March 2018

Dr Tom Hatton
Panel Chair
Independent Scientific Panel
Locked Bag 33, Cloisters Square
Perth WA 6850

**Re: SCIENTIFIC INQUIRY INTO HYDRAULIC FRACTURE STIMULATION IN WESTERN AUSTRALIA**

Dear Dr Hatton

Finder Shale Pty Ltd (***Finder***) welcomes the opportunity to make a submission to the Panel in relation to the inquiries Terms of Reference (***ToR***). Specifically, the ToR have been developed to assess the risk of potential impacts associated with Hydraulic Facture Stimulation (**HFS**) on the following environmental aspects:

- Land: terrestrial environmental quality, biodiversity, beneficial use
- Air: greenhouse gas emissions and air pollution
- Water: quality, quantity and beneficial use
- Social surroundings: aboriginal heritage, amenity, public safety and seismicity

## INTRODUCTION

Finder is a privately owned Australian company which has successfully operated in Western Australia since 2004.

Finder operates an onshore petroleum exploration permit, EP 493 (***Permit***) granted under the provision of the Petroleum and Geothermal Energy Resources (***PGER***) Act 1967 in the Great Sandy Desert within the onshore central Canning Basin. The Permit is located within unallocated Crown land with no national parks or reserves, conservation significant eco-systems or wetlands and rivers in the Permit area.

Deep shale reservoirs (+1,300m vertical depth) are known to contain oil and gas resources within the Permit. The target shale of oil and gas exploration focus for Finder is separated from the shallow groundwater aquifers by thick impermeable rock formations.

Through this submission, Finder will provide scientific information and discuss outcomes of various data analysis specific to the Finder Great Sandy Desert project and relevant to the ToR. This document should be read in conjunction with Finders Great Sandy Desert project presentation (Attachment 1) which is referenced throughout this submission.

Finder has an abundance of geoscience data and analysis available in regard to the onshore Canning Basin, Western Australia. If the Panel feel it will be helpful in their enquiry, Finder is happy to disclose and/or present this data and analysis to the Panel.

**REGULATORY FRAMEWORK**

The petroleum resource industry in WA has a mature and robust regulatory regime in place. Comprehensive risk based assessments and regulatory approvals are required for each petroleum activity.

The Department of Mines, Industry Regulation and Safety (***DMIRS***) has a high level of technical expertise reflected in their track record of regulating a large-scale petroleum industry in the state over a long period of time.

Over the last 7-8 years, further reforms to the regulatory regime have been implemented to further strengthen the regulatory framework for petroleum activities, specifically in relation to hydraulic fracturing.

Regarding the Background and Issues Paper that the Panel provided to the public, Finder would like to note that Section 11: Current Best Practices, omits the legislative changes that were introduced as a result of the previous WA Parliamentary Inquiry in 2015-2016, summarised as follows:

The Memorandum of Understanding between DMIRS and the Environmental Protection Authority[1] was amended in February 2016 to include a trigger that requires DMIRS to refer all hydraulic fracturing proposals and all applications for production licences that are determined to be significant proposals to OEPA for assessment.

The Administrative Agreement between DMIRS and the Department of Water, which is now merged and known as the Department of Water and Environmental Regulation (***DWER***) was amended in February 2016 to include a trigger that requires DMIRS to undertake pre-approval consultation with DWER on all exploration activities proposed under the PGER Act 1967.

DMIRS is also continuing to develop a comprehensive reform package to strengthen the regulatory framework for onshore petroleum activities:

- to ensure well integrity and control – petroleum operators are required to prepare a Well Management Plan in accordance with new *Petroleum and Geothermal Energy (Resource Management and Administration) Regulations* introduced in July 2015. The Well Management Plan details the planning, design, construction and actual operational steps occurring on each petroleum well.
- to ensure protection of groundwater resources – petroleum operators are required to conduct groundwater baseline assessments and carry out routine groundwater monitoring in accordance with DMIRS's *Guideline for Groundwater Monitoring in the Onshore Petroleum and Geothermal Industry*, August 2016.
- to ensure proper response to a spill incident – petroleum operators are required to prepare Oil Spill Contingency Plans in accordance with DMIRS's *Guideline for the Development of an Onshore Oil Spill Contingency Plan* introduced in July 2016. The Guideline prescribes requirements for preparedness, emergency response, and recovery arrangements that cover all potential spill scenarios.

The timeline of these reforms is outlined in Figure 1.

[1] http://www.dmp.wa.gov.au/Documents/Environment/ENV-MEB-016.pdf

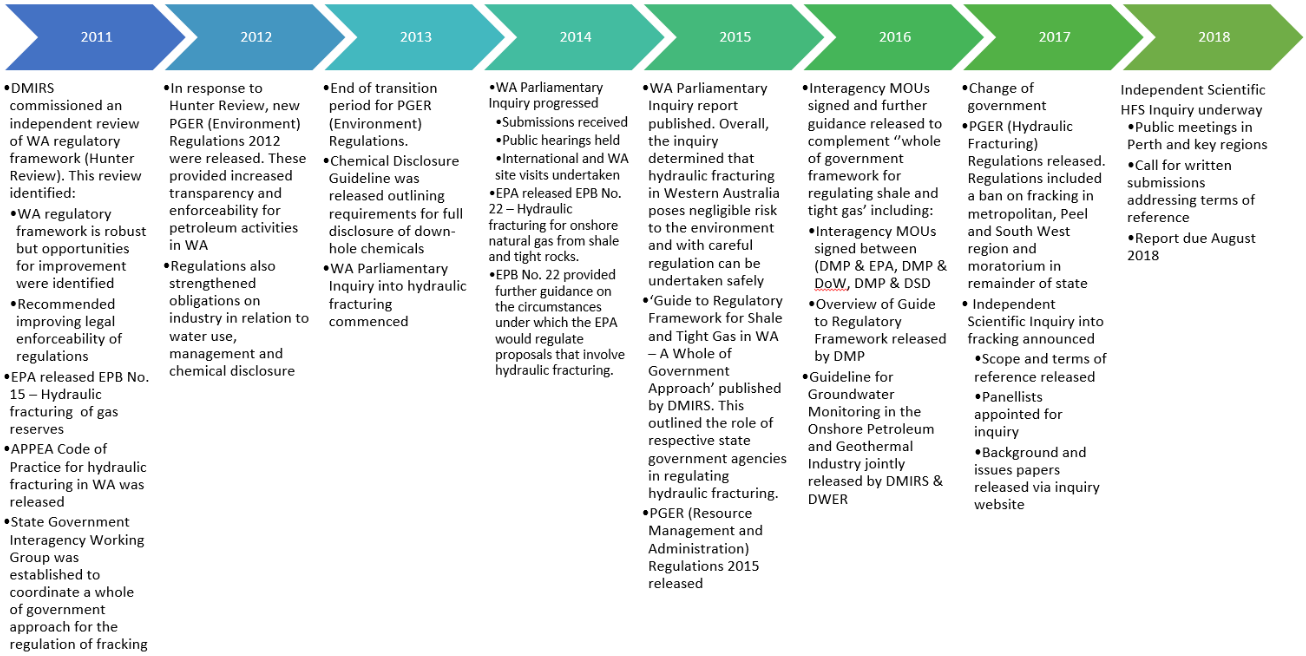


***Figure 1: Reforms timeline***

Key aspects of the current WA regulatory framework include:

- The PGER process includes transparency of information such as disclosure of an Environment Plan (***EP***) summary document when lodging the EP and full disclosure of downhole chemicals. DMIRS is the lead agency for regulation of petroleum activities and implements the PGER Act and associated regulations.
- DWER are responsible for regulating emissions and discharges and the management of water resources. DWER regulates the management of surface and groundwater resources including proposed water bores, the extraction of water and protecting public drinking water source areas.
- WA Environmental Protection Authority performs environmental impact assessments for proposals that are likely to have significant environmental impacts.
- Land access for petroleum activities in Western Australia are regulated by the PGER Act 1967. This requires negotiations with identified Native Title bodies, notification of landowners and lessees of proposed activities and, in relation to privately owned land, consent in writing and a compensation package.

## OPPORTUNITIES FOR REGULATORY REFORM

Finder supports the application of an objective, risk-based regulatory approach for petroleum activities as per the PGER Act 1967, Environmental Protection Act 1986 and associated regulations.

Finder would support further refinement of the regulatory framework that categorises petroleum operations into low, medium and high risk activities based on the level of operational and environmental risk. Such an approach has been adopted in Queensland[2] and South Australia[3.] for petroleum activities.

[2] https://www.ehp.qld.gov.au/licences-permits/compliance-codes/ and https://www.ehp.qld.gov.au/management/non-mining/environmental-authority.html

[3] http://petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0007/256327/Exploration_and_Production_Flowchart_Ver_8_September_2015.pdf

Under this approach, eligibility criteria and standard conditions apply for low-risk petroleum exploration, petroleum survey, and petroleum pipeline activities. Eligibility criteria include specified restrictions which ensure environmental risks associated with the operation of an environmentally relevant activity are able to be managed by the standard conditions. Standard conditions are a set of operating conditions which must be complied with when undertaking the activity.

For example, a standard approval applies for low-risk activities (such as airborne surveys, 2D and 3D seismic surveys without clearing of native vegetation, groundwater baseline assessment and groundwater monitoring etc.). The standard approval is based on environmental and operational standards, a code of practice and model conditions developed for low risk activities where the applicant meets eligibility criteria and commits to comply with standard conditions. A site or activities specific assessment process applies to activities where variations to the standards or model conditions are required, e.g. exploration drilling, production test, pipeline. High risk activities (such as a field development or coordinated project) are assessed under an environmental impact assessment regime.

The same standard approach has been adopted by NOPSEMA[4] through the development of reference cases for petroleum activities that are undertaken using industry standards and code of practices with known risks. For example, reference cases would be developed for 'low risk' activities such as airborne surveys, seismic surveys or for an operational aspect such as waste management, weed and pest control, air pollution control etc. Reference cases would be publicly available providing increased transparency regarding environmental risks and mitigation measures.

## ONSHORE CANNING BASIN GREAT SANDY DESERT PROJECT OVERVIEW

Finder operates our onshore petroleum exploration Permit in the Great Sandy Desert and has identified a major oil and gas shale resource within the Goldwyer III Unit tight shale formation (***Shale***). The Shale reservoir is buried under more than 1,300m of rock, half of which forms a natural impermeable barrier that separates the target shale from the main near surface aquifer.

Finder assess the resource is of a nationally significant scale, development of which will lead to a 20+ year Western Australian mega project. Current estimates indicate a resource of 35 billion barrels of oil and 24 trillion cubic feet of gas within the Permit (***Project***). Development of the Project could create more than 4,000 direct and indirect local jobs and pay royalties in excess of AU$29 billion.

Finder has currently invested AU$17million studying the onshore Canning basin regional geology utilising all available geoscience data and integrated and updated its regional evaluation with recently recovered geological data through the drilling of exploration well Theia-1 in 2015. Theia-1 recovered an extensive suite of geological data including 778 metres of continuous core and petroleum logs through the Shale and bounding stratigraphy.

The data and core recovered was extensively analysed and evaluated utilising third party multinational service companies such as Schlumberger and Weatherford. Detailed laboratory analysis included geochemical and geomechanical evaluation of the core. The results of this analysis were integrated with other well data in a petrophysical log analysis, geomechanical rock property analysis and hydraulic fracture design and modelling. A key part of this evaluation included assessment of natural rock and formation barriers that separate the Shale from shallow aquifers.

The established and proven well completion method essential to the commercialisation of hydrocarbons from shale reservoirs around the world is Hydraulic Fracture Stimulating (***HFS***). The next critical phase in

[4] https://referencecases.nopsema.gov.au/

Finder's exploration program is to prove commerciality through additional drilling operations and subsequent completion of a horizontal well with HFS to achieve a hydrocarbon flow test.

**LAND IMPACTS**

| | |
|---|---|
| **Environmental Factor:** | Terrestrial Environmental Quality |
| **Operational aspect:** | Spillage of chemicals used during HFS; or<br>the spillage of flowback water |
| **Potential Risk:** | Direct impact on soil quality;<br>Indirect impact on the health of people, plants and animals |

Discussion:

All chemicals and other substances used on-site and introduced to a well or a formation require DMIRS approval in accordance with the PGER (Environment) Regulations 2012. Petroleum operators are required to prepare the chemicals and other substances disclosure statement in accordance with the Chemical Disclosure Guideline 2013 using DMIRS's chemical disclosure report template[5]. All information is publicly available on the DMIRS website[6].

HFS fluid mixtures are typically comprised of 98-99% water, sand or proppant by volume with the remaining 2% made up of salt and fluid additives. In addition, BTEX chemicals are prohibited to be used in Western Australia in HFS operations.

All chemicals are stored on-site in designated lined and bunded storage areas and handled in accordance with Australian Standards AS:1940:2004 Storage and Handling of Flammable and Combustive Liquids and AS:3780:2008 Storage and Handling of Corrosive Substances that apply in every other industry.

Chemicals that Finder used during previous drilling activities have been managed in accordance with DMIRS approved EP (e.g. Theia-1 Exploration Well STP-EPA-0055, Rev.4) which is publicly available on the DMIRS website[7] and Safety Management Systems approved by DMIRS[8].

Residual drilling mud and flowback water is classified as "wastewater" and has been managed in accordance with DMIRS approved EP.

Finder (along with all oil and gas companies) is required to disclose the final composition of fluids and additives as part of the EP Chemical Disclosure Statement. The chemical disclosure submission will include details on chemical mass-balance, eco-toxicity data and relevant material safety data sheet information.

To prevent direct impact on soil quality, Finder applies the following management control to its operations in accordance with regulatory requirements:

- Establishing a designated chemical storage area and using HDPE liners and bunds for chemicals storage areas in accordance with recommendations of DWER's WQPN 65: Toxic and Hazardous Substances.
- All chemicals are transported to site in accordance with the Dangerous Goods Safety (Road and Rail Transport of Non-Explosives) Regulations 2007.

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[5] http://www.dmp.wa.gov.au/Environment/Forms-19751.aspx
[6] https://ace.dmp.wa.gov.au/ACE/Public/PetroleumProposals
[7] https://ace.dmp.wa.gov.au/ACE/Public/PetroleumProposals
[8] http://www.dmp.wa.gov.au/Safety-Regulation-System-SRS-1486.aspx

- Water storage facilities are designed to accommodate the maximum amount of wastewater produced onsite and handle stormwater resulting from a 1:100-year rainfall event.
- Water storage facilities are lined with 0.75 mm HDPE plastic liners to prevent soil contamination from wastewater. This meets requirements of DWER's WQPN No. 26: Liners for containing pollutants, using synthetic membranes and Water Quality Protection Guidelines No.3 – Liners for water containment.
- Water storage facilities have an earth bund at least 0.5m in height to prevent overflow and have an overflow line to divert excess water.
- Most if not all wastewater is subject to evaporation. Wastewater is also tested at a NATA certified lab to determine toxicity.
- Solid phase is tested to determine landfill class and disposal options in accordance with the *Landfill Waste Classifications and Waste Definitions Guideline, 2013*.

**Slide 21** of Attachment 1 illustrates Finder's Theia-1 well site and shows examples of key environmental protection measures.

In the unlikely event of chemical spillage on-site, all spill material is limited to the volume of the storage container and is easily contained within the site. Any wastewater is usually pumped directly to the water holding facilities. Finder has a DMIRS approved project specific Oil Spill Contingency Plan (EP493-ENV-OSCP-1001-1) in place with field personnel being inducted and trained prior to the project activity on how to halt the spill and remediate an affected area.

The following regulatory mechanisms are in place to mitigate or minimise risks to an acceptable level:

- PGER Act 1967 and Environmental Regulations 2012
- EP prepared in accordance with DMIRS's *Guideline for The Development of Petroleum and Geothermal Environment Plans In WA, Nov 2016*
- Safety Management Systems prepared in accordance with the PGER (Management of Safety) Regulations 2012
- Chemicals and Other Substances public disclosure statement prepared in accordance with DMIRS's *Guideline Environmental Risk Assessment of Chemicals Used in WA Petroleum Activities 2013* and publicly available on DMIRS's website
- Oil Spill Contingency Plan prepared in accordance with DMIRS's *Guideline for the Development of an Onshore Oil Spill Contingency Plan, August 2016*.

| **Environmental Factor:** | Biodiversity |
|---|---|
| **Operational aspect:** | Clearing for drill pads, roads and pipelines;<br>Noise and light from operations |
| **Potential Risk:** | Habitat loss or fragmentation;<br>Increased noise and light from operations;<br>Spread of weeds and pests |

Discussion:

Any ground disturbance/clearing proposal in WA, regardless of the type of activity (whether it is petroleum, agriculture, infrastructure development, mining or urban development) requires a clearing permit under the Environmental Protection Act 1986 (***EP Act***). There is a requirement under Part 5, Division 2 51E of the EP Act that independent on-ground ecological assessments/surveys (flora,

vegetation, fauna and fauna habitat) should be undertaken[9]. This allows for the quantification of environmental sensitivities and the establishment of baseline conditions of vegetation, flora, fauna and its habitat.

As an example, prior to proposed ground disturbance and clearing of native vegetation between 2014 and 2016, Finder engaged with various independent environmental consultants to conduct desktop assessments[10] and carry out on-ground ecological surveys[11] (vegetation/flora and fauna/habitat), in parallel, indigenous land owners with anthropologists carried out Cultural Heritage surveys, refer **Slide 13**.

The results of the surveys show that native vegetation within the project is described as Pindan vegetation. The vegetation is uniform consisting of three main units *Acacia/Grevillea Tall Scrub, Acacia monticola Tall Scrub* and *Acacia Low Heath*.

The environmental surveys indicated no threatened or priority ecological communities declared under the State Wildlife Conservation Act 1950 or Commonwealth EPBC Act 1999, no Ramsar listed wetlands, no flora species of conservation significance or its habitat, no fauna species of conservation significance, or significant habitat were recorded and no weed species. The nearest wetland of national significance is the Dragon Tree Soak Nature Reserve approximately 80km to the south. The nearest zone of ecological significance is Munro Springs approximately 90km to the south-west.

Since 2014, in collaboration with the Native Title Group (Karajarri People) several fauna surveys have been carried out by Bamford Consulting Ecologists, RPC and Ecologia to better understand the fauna population numbers and their distribution. The bilby (*Macrotis lagotis*) is known to inhabit the Great Sandy Desert. The surveys identified that bilbies are present within the Permit, however no signs of bilbies were recorded during the fauna surveys.

To protect fauna, Finder developed a Fauna Management Plan in consultation with an independent consultant (RPS) and the Department of Parks and Wildlife. The Fauna Management Plan includes preventive measures such as fencing with small animal mesh attached to the base of the fence to prevent fauna ingress into any open pits[12]. During Finder's project activities which started in 2014, there is no evidence of impact on marsupial populations or habitat.

To prevent spread of weeds and pests, Finder has in place a Weed Management Plan that includes vehicle brush down procedures. Post operations periodic site monitoring which incorporates inspections for any weeds is included in the site rehabilitation management plan.

The clearing footprint for one well site is usually limited to 2ha. It is common industry practice to use horizontal drilling and multi-well pad design to develop shale resources. This significantly reduces the surface clearing footprint, a single 8 horizontal well surface pad (~2ha area) replaces what would have been ~36 vertical well sites in the days before horizontal drilling and multiple pad drilling. Multi-well pad drilling developments also reduce the surface impacts associated with auxiliary infrastructure such as access roads, flowlines, and water storage facilities. Due to the reduced disturbance footprint, the rehabilitation outcomes are significantly better compared with a single-well site design (**Slide 41**, Attachment 1).

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9 https://www.der.wa.gov.au/images/documents/your-environment/native-vegetation/Guidelines/Guide2_assessment_native_veg.pdf or http://www.dmp.wa.gov.au/Environment/Information-required-to-assess-4944.aspx

10 Desktop Flora and Vegetation Assessment Report, RPS 2014
Desktop Flora and Vegetation Assessment Report, RPS 2015

11 Level 1 Flora and Vegetation Assessment Report, RPS 2014
Fauna Assessment Report, M.J. & A.R. Bamford Consulting Ecologists, 2014
Ecological Surveys (flora/fauna) Report, Ecologia 2017

12 Theia-1 Exploration Well, STP-EPA-0055 and Helios-1/1H EP493-ENV-PLN-1001-1A

At the end of project life, disturbed areas are restored and rehabilitated to their original state in accordance with DMIRS approved Rehabilitation Management Plan. **Slide 39**, Attachment 1 illustrates the Theia-1 site restoration after drilling activities were completed and a photo comparison showing vegetation regrowth (before rehabilitation) after one year.

The following regulatory mechanisms are in place to mitigate or minimise risks to an acceptable level:

- Clearing of native vegetation for the petroleum activities is regulated in accordance with Part V of the EP Act (Clearing permit)
- On-ground (flora/fauna) ecological surveys in accordance with EPA's Guidance 51: Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in WA (2004), EPA's Guidance 56: Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (2002), EPA/Department of Parks and Wildlife Technical Guide Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment 2010, DPAW's Guideline: Priority Ecological Communities for Western Australia 2015 and DEE's Survey guidelines for Australia's Threatened Mammals 2011.

Under the EP, Finder's environmental management (biodiversity) includes:

- Soil and Erosion Management Plan
- Native Vegetation and Flora Management Plan
- Fauna Management Plan
- Weed and Pest Management Plan
- Decommissioning and Maintenance Plan
- Rehabilitation Management Plan

| **Environmental Factor:** | Beneficial land use |
|---|---|
| **Operational aspect:** | Hydraulic fracturing and its associated activities |
| **Potential Risk:** | Impact on beneficial use of land by degrading or restricting access to land that would have been used for other productive purposes including agriculture. |

Finder's Project is located in the central Canning Basin, in the Great Sandy Desert, **Slide 16,** Attachment 1.

- Land use is unallocated Crown land, no existing pastoral leases or farming/agricultural proposals were identified.
- The nearest pastoral lease is the Dampier Downs station, which lies 70km to the north-east.
- No State or Commonwealth declared conservation significant land or environmentally sensitive areas (ESA) such as wetlands, national parks or reserves are located in the vicinity of the Project area. The nearest wetland of national significance is the Dragon Tree Soak Nature Reserve approximately 80km to the south and the nearest zone of ecological significance is Munro Springs approximately 90km to the south-west[13].
- The closest major population centre is the town of Broome, which is approximately 155km north-west.
- No permanent waterways are located within or in proximity to the Project area, the nearest landscape feature that contains ephemeral water courses and a chain of waterholes is the Edgar Ranges located > 6km to the north-east.

[13] Wetlands of the north-western Great Sandy Desert in the LaGrange hydrogeological sub-basin, Water and River Commission, 1999 http://www.water.wa.gov.au/__data/assets/pdf_file/0018/5283/11727.pdf

- No groundwater dependant systems are present within the Project area. The shallowest groundwater aquifer within the Project area is the Wallal Sandstones which is 160m deep.
- No public drinking water source areas or Aboriginal community drinking water bores are present in the Project area. The nearest public drinking water reserve is near the town of Broome, approximately 150km to the north-west.
- No social values such as recreational areas, tourist attractions or caravan parks are present.
- Limited groundwater values and therefore limited beneficial use as the project is located in a remote area on unallocated Crown land.
- No populated areas and no identified groundwater users are located in the vicinity of the Project area.

The Great Sandy Desert is an arid region and has little agricultural potential. Despite climate conditions, the area is nominated as an "irrigation investigation area" under the Shire of Broome Planning Strategy 2014.

In 2014 Finder conducted a groundwater baseline assessment in the vicinity of the Theia-1 exploration well. The nearest aquifer is the Wallal Sandstones, 160m deep. Water samples were collected in accordance with AS/NZS 5667.1:1998 Water Quality Sampling – Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples, Groundwater Sampling and Analysis—A Field Guide (Geoscience Australia, 2009) and assessed by NATA[14] accredited laboratory MPL Lab. The results of the baseline assessment were compared with the Australian Drinking Water Guideline 6, 2016. The water quality is not suitable for human consumption having TDS between 1500-1600mg/l, turbidity between 29-53 NTU and the iron level exceeds the Standards 2016 taste threshold, however it is suitable for stock watering or agricultural activities, refer **Slide 18**, Attachment 1.

The Finder Project can significantly contribute to sustainable land development and use in the Great Sandy Desert. For example, the requirement to establish groundwater baseline conditions and long-term monitoring necessitate drilling of water bores at various locations. The monitoring water bores can be used beneficially as water supply bores and used to construct infrastructure, such as roads, providing secure access to these remote areas for potential agricultural development. A petroleum development utilising multi-horizontal wells per pad can easily co-exist with other land users such as pastoralists and agriculture due to the minimalistic surface footprint. **Slide 42** to **Slide 44** illustrate the surface footprint for a conceptual shale oil and gas development.

The following regulatory framework is in place to ensure land access and sustainable land use:

- Land access for petroleum activities in Western Australia are governed by the PGER Act 1967. This requires for negotiations with identified Native Title bodies, notification to landowners and lessees of proposed activities, and, in relation to privately owned land, consent in writing and a compensation package. For example, Finder has in place Heritage Protection Agreements (***HPA***) with the traditional land owners within our Permit.
- Consultation with relevant stakeholders prior, during and post activities in accordance with PGER (Environment) Regulations 2012 and DMIRS's *Guideline for the Development of Petroleum and Geothermal Environment Plans In WA, Nov 2016*.

A supplementary land access model agreement has been developed by the Australian Petroleum Production & Exploration Association (***APPEA***), WA Farmers, Pastoralists and Graziers Association of WA, and Vegetables WA to ensure that farmers' and explorers' respective rights and priorities are accommodated in the potential expansion of the onshore gas industry in the Mid-West.AIR IMPACTS

[14] National Association of Testing Authorities, Australia

| Environmental Factor: | Greenhouse Gas Emissions and Air Pollutants |
|---|---|
| **Operational aspect:** | Well failure leading to release of greenhouse gases into the atmosphere during hydraulic fracturing and associated activities.<br>Fumes from drilling equipment and road traffic. |
| **Potential Impact:** | Health of people, plants and animals |

The Project is located in a remote area approximately 150km from the nearest town of Broome. The ambient air quality in the region is influenced by seasonal factors. During winter, dust storms from the Great Sandy Desert are common. Bush fires are also common during the dry season. Bush fires contribute naturally significant amounts of $CO^2$ and GHG emissions. Other than that, there are no other activities identified as sources of air pollution.

Potential fugitive emissions, as a result of migration along the well bore is mitigated through existing well construction standards consisting of multiple layers of cemented steel casing strings combined with standard well integrity testing such as logging runs to access cement, pressure tests and monitoring the well using gas detectors.

The Shale and overlying geology is not highly overpressured (assessed from the Theia-1 well and other onshore Canning Basin well drilling data) and as such, the risk of uncontrolled gas release events are very low compared to conventional overpressured reservoirs. Other sources of GHG emissions are limited to vehicle and equipment operations. Further development of the project would necessitate the construction of a pipeline instead of trucking hydrocarbons which would reduce Project GHG emissions.

The following regulatory mechanisms are in place to prevent, reduce and report air pollution:

- The National Greenhouse and Energy Report Act 2007 (***NGER Act***) and the National Greenhouse and Energy Reporting (Measurement) Determination 2008 and Technical Guidelines require petroleum operators to report emissions from all stages of petroleum production, supply and use, including fugitive emissions to the Department of the Environment and Energy.
- The Well Management Plan (or Field Development Plan) under the PGER (Resource Management and Administration) Regulations 2015[15].
- Monitoring and reporting to DMIRS on emissions and discharges under the PGER Act and Environmental Regulations 2012[16] require operators to report emissions from all petroleum activities to DMIRS.

**WATER IMPACTS**

| **Environmental Factor:** | Groundwater aquifers quality<br>Surface Water quality |
|---|---|
| **Operational aspect:** | Leakage of wells due to a failure in well integrity, or degradation over the life of the well;<br>Spillage of chemicals, flowback water or brines produced from water treatment;<br>On-site spills resulting from the overtopping of water storage tanks due to extreme weather events;<br>Spills from the transportation of chemicals;<br>Induced connectivity between hydraulically fractured shale and aquifers;<br>Reinjection of treated water. |

[15] http://www.dmp.wa.gov.au/Documents/Petroleum/PD-SBD-ADM-180D.pdf
[16] http://www.dmp.wa.gov.au/Environment/Environment-reports-and-6133.aspx

| Potential Impact: | Groundwater and surface water contamination;<br>Health of people, plants and animals |
| --- | --- |

Discussion:

**Regional hydrogeological model**

**Slide 16** and **Slide 17**, Attachment 1

Since 2013, Finder has carried out hydrogeological investigations over the Permit to understand the geological and hydrogeological setting of the region. Finder has consulted with the Department of Agriculture, DWER and relevant stakeholders to prepare a hydrogeological investigation report. The report was reviewed by the DWER and approved by the DMIRS[17].

Generally, the Canning Basin contains two main aquifer systems hosted in the largely unconfined Broome Sandstone and the confined Wallal Sandstone. The Cuncudgerie Sandstone is considered the deepest recognised aquifer in the region and has low usage potential due to the likelihood of water quality being saline to hyper-saline. The deeper Cuncudgerie Sandstone is impractical to access due to depth and high salinity and is not considered by the DWER for water allocation purposes in the central Canning Basin (La Grange Allocation Plan, DWER 2010).

The hydrogeological investigations demonstrate that:

- The Shale is approximately 600m below the nearest aquifer (Cuncudgerie Sandstone), and approximately 1200m below the Wallal aquifer.
- Within the Project Area the Wallal aquifer water quality is brackish with salinity levels exceeding threshold standards for drinking water quality (NATA[18] accredited laboratory MPL Lab), according to the *Australian Drinking Water Guidelines 6, 2016***, Slide 18**, Attachment 1.
- The Shale and nearest aquifer are separated by regionally wide spread thick impermeable formations consisting mostly of shales and carbonates, **Slides 31** and **32**, Attachment 1.
- At the Theia-1 location the depth of the Shale is 1,472m below ground with a thickness of 120.6m.

**Slide 17**, Attachment 1 illustrates the conceptual hydrogeological profile of the central onshore Canning Basin. **Slide 31**, Attachment 1 illustrates multiple barriers separating the aquifers from the target formation.

**Well design and integrity**

In Western Australia, well design and construction is regulated under the PGER (Resource Management and Administration) Regulations 2015 and requires an operator to prepare a Well Management Plan and submit it to the DMIRS for approval. The Well Management Plan includes a specific section on risk assessment of well integrity. The well is designed by qualified drilling engineers to meet or exceed industry standards such as those specified by the American Petroleum Institute (***API***) notably the *Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines* (API, 2009) and the APPEA Code of Practice for Hydraulic Fracturing.

Well casing is designed in accordance with API standards, notably Specification 5CT/ISO 11960, for Casing and Tubing and tested prior to drilling to ensure integrity, performance, quality and consistency. The casing is designed to withstand the anticipated fracture stimulation pressure, hydrocarbon

[17] Groundwater Baseline Monitoring Report and Groundwater Monitoring Program EP493-ENV-PLN-1001-1-GWMR, March 2017

[18] National Association of Testing Authorities, Australia

production pressures and corrosive conditions. At each casing point the well is pressure tested prior to commencing the next stage of operations (drilling or fracture stimulation) to confirm the integrity of the casing and cement. In addition, drilling mud and stimulation fluids are designed to neutralise aggressive properties of the receiving environment and prevent material damage of the well casing. This is achieved by adding corrosion inhibitors and pH stabilisers into drilling and fracture stimulation fluids.

**Slide 23**, Attachment 1 illustrates a conceptual design of the well, **Slide 24**, Attachment 1 describes the typical horizontal shale well design that Finder will use for the project.

Continuous improvements in technology, well construction and engineering practices over the past 75 years in the oil and gas industry along with current regulations and standards in place in Western Australia mean today's wells are of the highest standards and ensure well integrity and the required isolation are maintained.

To ensure well integrity, the following standards and guidelines apply to the well design:

- API 5B Specification for Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads
- API 5CT/ISO 11960 Specification for Casing and Tubing
- API 10A/ISO 10426-1, Specification for Cements and Materials for Well Cementing
- API 10B-2/ISO 10426-2, Recommended Practice for Testing Well Cements
- API 10D-2/ISO 10427-2, Recommended Practice for Centralizer Placement and Stop Collar Testing
- API 10TR1, Technical Report Cement Sheath Evaluation
- API 10TR4, Technical Report on Considerations Regarding Selection of Centralizers for Primary Cementing Operations
- API 65-2, Recommended Practice Isolating Potential Flow Zones During Well Construction
- API Guidance Document – HF1 Hydraulic Fracturing Operations – Well construction and Integrity
- API Guidance Document – HF2 Water Management Associated with HFS
- API Guidance Document – HF3 Practices for Mitigation Surface Impacts Associated with HFS
- API Recommended Practice 65-2, Isolating Potential Flow Zones During Well Construction
- APPEA Code of Practice for Hydraulic Fracturing (2011) Guideline 5

**Natural geological fracture barriers**

The geological setting of the onshore Canning basin has been studied by Finder in detail. Extensive analysis of all available onshore Canning Basin data (wells, seismic, gravity, magnetic) plus Finder commissioned studies was carried out prior to drilling Theia-1 in order to produce a pre-drill regional geological Shale model. The Theia-1 exploration well recovered data and core which was used to carry out extensive studies and analysis to assess and update Finders geological model. Details of the data acquired and analysis on the Theia-1 well are available through the well completion report and interpretive well completion report available online through the DMIRS WAPIMS Petroleum & Geothermal Information Management System.

The Shale formation and bounding lithology were studied by Finder in conjunction with several independent expert companies and consultants; Weatherford, Schlumberger, Task Frontera, 3D Geo, Source Geoscience, CoreLab, Chemostrat, Good Earth Consulting, Dr Ray Johnson (Consultant HFS modelling and design specialist) and Steve Broome (Consultant Reservoir Engineer). The unconventional petrophysical and geomechanical evaluation was undertaken by Schlumberger. The Schlumberger geomechanical analysis of the Shale and the bounding geological formations is provided as Attachment 2, Theia-1 Geomechanics report. The results show that the carbonate rocks above and

below the Shale form natural fracture barriers. The Shale thickness is ~120m, in the unlikely event an induced vertical fracture reaches the Shale boundary, it will encounter a carbonate (~100m thick, Goldwyer II Unit) which will tend to fracture horizontally (not vertically) as the horizontal stresses (Shmin & SHmax) exceed the vertical stress (Sv). The stress data plot is provided under **Slides 33 & 34,** Attachment 1.

Additional impermeable shale and carbonate stratigraphic barriers overlie the Goldwyer II Unit carbonate. An isochron thickness map of the Top Nita carbonate to the Top Goldwyer III Shale produced from regional 2D seismic lines and well data is provided on **Slide 32**, Attachment 1. In addition, the top Nita carbonate is overlain by the Carribudy shale which is 137m thick at the Theia-1 well location. These tight low permeability geological barriers overlying the Shale varies in thickness from ~400m to 650m across the Project area. An example seismic line is shown on **Slide 35**, Attachment 1 highlighting in red the carbonate and shale impermeable barriers.

### Fracture modelling

HFS modelling was performed using Schlumberger's Unconventional Fracture Model (***UFM***) software. The UFM was selected as the best tool to capture real-world complexity.

The modelling incorporated Theia-1 well data, petrophysical analysis and geomechanical rock properties. The modelling then simulated different horizontal landing points, fluid types, cluster spacing, stress interference and total stages/clusters per stage. UFM ran more than 13 models to evaluate area/height/length of stimulated zone. The models show that the induced fractures are contained within the Shale.

The modelling predicted a maximum vertical fracture height of approximately 85m above the stimulation initiation point and 40m below the stimulation initiation point (totalling a vertical fracture height of 125m). While this is the maximum height predicted, the likely fracture height is expected to be 60m, confined to the Shale, **Slide 36**, Attachment 1 illustrates the stimulation fracture distribution.

### Groundwater Baseline Assessment and Monitoring

Groundwater baseline assessment is regulated under the *Guideline for Groundwater Monitoring in the Onshore Petroleum Industry Guideline*, DMIRS, August 2016. A groundwater baseline assessment establishes groundwater conditions before petroleum activities commence and gathers sufficient baseline data such as field parameters, the groundwater level, chemical analysis of water quality and the construction details of the water bore.

Finder commenced the groundwater baseline assessment in 2015, prior to drilling the first exploration well (Theia-1). The baseline assessment water bore was drilled to 166m depth and completed in the Wallal aquifer by Kimberley Water Pty Ltd in accordance with Finder's Licence to Construct Well granted under Section 26D of the Rights in Water and Irrigation Act 1914 and the Minimum Construction Requirements for Water Bores in Australia (NUDLC, 2012).

The results of the baseline assessment were compared with the *Australian Drinking Water Guideline 6, 2016*. The water is slightly saline and not suitable for human consumption (electrical conductivity 2,700µS/cm, TDS 1600mg/L, turbidity between 18-53NTU). **Slide 18**, Attachment 1 illustrates the baseline assessment summary of the Wallal aquifer. The concentration values exceeding the *Australian Drinking Water Guideline 6, 2016* are indicated in red.

Based on hydrogeological investigations and groundwater baseline assessment results, Finder developed a groundwater monitoring program for subsequent activities to ensure that sufficient data is gathered and any potential impacts from the petroleum activities are measurable against the baseline data. The monitoring program establishes surveillance monitoring through the life of the project, beyond site decommissioning and rehabilitation and demonstrates that groundwater resources are monitored and provides evidence whether groundwater has or has not been affected by petroleum activities.

Legislative context:

The following regulatory mechanisms are in place to ensure protection and monitoring of groundwater resources:

- Requirement to undertake hydrogeological investigation is regulated under the PGER (Environment) Regulations 2012 and the Environmental Factor Guideline: Hydrological Processes, EPA, 2016
- Groundwater Baseline Assessment regulated under the *Guideline for Groundwater Monitoring in the Onshore Petroleum Industry Guideline*, DMIRS, August 2016.
- Groundwater Monitoring Program regulated by DMIRS *Guideline for Groundwater Monitoring in the Onshore Petroleum and Geothermal Industry*, August 2016.

| **Environmental Factor:** | Water Quantity |
|---|---|
| **Operational aspect:** | Hydraulic fracturing and its associated activities might impact water quantity due to the amount of water required for the hydraulic fracturing processes. |
| **Potential Impact:** | Decrease in groundwater and surface water availability;<br>Plant and animal habitats degradation through a decrease in water availability |

Surface and groundwater is regulated under the Rights in Water and Irrigation Act 1914. The DWER manages water extraction though licences. A licence allows a licensee to take a specified volume of water each year. The DWER decides a licence after assessing whether the proposed extraction of water is sustainable and will not impact water dependent values and other licenced water users. Licence conditions set out annual monitoring requirements and reporting arrangements. This process applies to all water users.

The volume of water available for abstraction in the Canning – La Grange area without impacting on the aquifer and before ecological and cultural considerations was estimated by the DWER at 105,000 ML/year (the La Grange allocation plan 2010). The DWER has accounted for the water's ecological and cultural values by allowing approximately 50% of the 105,000ML/year to remain in the aquifer to support those values. This results in an allocation limit of 50,000 ML/year in the Broome Sandstone aquifer in the La Grange subareas.

Current water use in the La Grange subarea is about 6,700 ML per annum. Existing licenced water abstraction of approx. 3,700 ML/year is used for agricultural purposes, domestic consumption and tourism. Approximately 3,000 ML/year is being used for unlicensed or exempt purposes such as water for stock, domestic purposes and firefighting.

Currently Finder has a 5C licence (No GWL179507) to extract water from the Wallal Aquifer with an annual allocation of 60 ML for exploration activities. In the central Canning Basin, licenced groundwater use is limited to a total annual allocation of approximately 175 ML (including Finder's water allocation of 60 ML). The licence holders are predominantly petroleum exploration companies.

Based on the Schlumberger hydraulic fracturing design, the water requirement is approximately 1.2 ML-1.4 ML per stage or approximately 12 ML-14 ML per horizontal well with a 10 stage stimulation treatment.

Assuming a conceptual small-scale project of 3 wells (3 pads) are to be drilled annually, this will require 36 ML - 42 ML of water annually for stimulation activities.

Assuming a conceptual full-scale multi-well pad production project of 24 wells (3 pads with 8 horizontal wells on each pad) to be drilled annually over a 20 year period, the water requirement for this concept will be limited to 288 ML – 336 ML per year or 4,460 ML-6,720 ML over a 20 year period.

In comparison, a 1200ha horticultural farm uses approximately 20,000 ML for irrigation per year.

| | |
|---|---|
| **Environmental Factor:** | Beneficial use of water |
| **Operational aspect:** | Hydraulic fracturing and its associated activities |
| **Potential Impact:** | Impact other beneficial uses of water due to competition for water; or loss of utility due to contamination |

The central Canning Basin is an extensive and largely undeveloped resource that could provide fit-for-purpose water for a variety of important uses. These include pastoral and diversified agricultural activities, mining and petroleum development. The Wallal aquifer, as it is substantially larger than the Broome Sandstone aquifer, has greater potential as a water resource.

In the central Canning Basin, the Wallal aquifer is 160m deep at the Theia-1 well location. Finder's groundwater baseline assessment suggests the water quality is slightly saline and is not suitable for human consumption. The Cuncudgerie Sandstone is the deepest recognised aquifer on the area and the likelihood of water quality being saline to hyper-saline. Access to the deeper Cuncudgerie is impractical due to depth and high salinity and is not considered by the DWER for allocation purposes in the central Canning Basin (La Grange Allocation Plan, DWER 2010).

High water use or consumption for HFS alone does not necessarily result in impact to the beneficial use of water. Rather, impacts result from the combination of water use or consumption and water availability at local scales. Additionally, water availability is rarely impacted by just one use or factor alone (USEPA, 2015). The potential for impacts to water resources from water withdrawals is lowest in areas with a relatively low scale of activities associated with the groundwater consumption and long-term water availability. A misconception is that hydraulic stimulation requires the use of fresh water, this is not the case as even brackish and saline waters are considered to be alternatives to fresh water for drilling and stimulation activities.

The Finder Project is located on unallocated Crown land with little potential for agricultural activities. The Wallal and Cuncudgerie aquifers have limited groundwater values with water allocation being available for various activities. There are no pastoral leases, no groundwater users, no public drinking water source areas for potable water supplies within the Project Area. The nearest public drinking water reserve is near the town of Broome, approximately 150 km to the north-west, sourcing water from the Broome aquifer. There are also no sensitive environmental receptors that could potentially be impacted by water extraction, therefore no uncertainties associated with cumulative impacts of groundwater extraction exist. HFS does not require a high quality of water, the Wallal aquifer could be utilised for Project activities without any impact to other groundwater users.

Contamination of the Wallal aquifer from HFS activities is highly improbable due to the physical vertical separation between the Shale and the Wallal aquifer and the natural geological barriers present.

Contamination of the Wallal aquifer from a surface spill, leak of hydrocarbons or chemicals is unrealistic as the separation distance from the surface is 165 m of interbedded siltstone, claystone and sandstone with a vertical hydraulic conductivity of only 0.0001m/d.

## SOCIAL SURROUNDS IMPACTS

| **Environmental Factor:** | Aboriginal heritage |
|---|---|
| **Operational aspect:** | Hydraulic fracturing and its associated activities could impact Aboriginal heritage through the alteration or degradation of the environment |
| **Potential Impact:** | Damage to sites of cultural significance; or<br>Loss of bush tucker or bush medicine. |

Finder consults regularly with relevant Traditional Owner groups and has a HPA in place.

Any activities on traditional owners' land are carried out in accordance with the HPA. To protect cultural values and ensure no impact to cultural heritage sites or other cultural sensitivities occur, cultural inductions and cultural awareness are provided to the Project personnel and cultural heritage surveys are carried out prior to any ground disturbing activities. Any identified cultural heritage sites or sensitive areas are avoided.

| **Environmental Factor:** | Amenity and Aesthetic Enjoyment and Public safety |
|---|---|
| **Operational aspect:** | Hydraulic fracturing and its associated activities could impact the amenity of the local area;<br>Hydraulic fracturing and its associated activities could impact public safety through transport accidents and accidents on site |
| **Potential Impact:** | Increased noise and dust from construction, operation and transport;<br>Increased light from construction and operation;<br>Loss of visual amenity arising from infrastructure;<br>Damage to recreational sites; or<br>Public safety |

In Australia, there is no established technical procedure for measuring the significance of changes to the landscape and visual impacts. Companies consider visual amenity in detailed planning processes by considering the sensitivity of the landscape or scenery and the magnitude of change expected as a result of the development.

Visual amenities will be limited to a drilling rig on a drilling pad, auxiliary infrastructure and access roads and associated cleared land.

The Canning Basin is a low density populated area with the central part of the Basin being unallocated Crown land with no population and no private properties or registered pastoral leases. The nearest major population centre is approximately 150 km and the nearest pastoral lease is approximately 75 km. Transport access is available via the Great Northern Highway.

There are no social values such as recreational areas and tourist attractions associated with this area. Public access to the Great Sandy Desert is restricted due to lack of roads and infrastructure to support recreational activities. Sensitive receptors in the Great Sandy Desert are limited to reptiles and mammal species.

Commercialisation of the Shale resource necessitates the utilisation of horizontal drilling and multi wells per surface pad development methods, such as 8 or more horizontal wells on a single 2ha well site which substitutes 36 or more vertical wells. This also advantageously reduces the visual amenity impact. The surface environmental disturbance footprint (well pads, access roads, pipelines, facilities) is minimised and better rehabilitation outcomes are achievable due to reduced disturbance. **Slide 41** to **Slide 44**, Attachment 1 illustrate the likely surface impact for an onshore Canning Shale development.

It is proven that oil and gas projects can co-exist in populated areas with other land users and industries. In this case a valuable Shale oil and gas resource happens to be located in a completely undeveloped, remote and arid region of the state.

The following safety legislative requirements are in place to ensure public safety:

- Petroleum and Geothermal Energy Resources (Occupational Safety and Health) Regulations 2010
- Petroleum and Geothermal Energy Resources (Management of Safety) Regulations 2010
- Dangerous Goods Act and regulations may also apply to petroleum operations.

The above legislation provides for the requirement of a Safety Management System to be developed for all project activities, approved by the regulator (DMIRS), implemented and maintained on-site during the project life.

| | |
|---|---|
| **Environmental Factor:** | Seismicity |
| **Operational aspect:** | Hydraulic fracturing and its associated activities could induce seismic events that impact local infrastructure and safety. |
| **Potential Impact:** | Local infrastructure and public safety |

The Canning Basin is an old geological platform with no presence of human impacting seismic activity. It is unrealistic that HFS carried out in tight rocks at a depth of more than 1200m would induce seismicity which is naturally detectable by humans (2 or greater on the Richter Scale).

During HFS operations, micro-seismic monitoring with seismic sensors can be used to detect and record seismicity data. This data can then be analysed and processed to produce 3D HFS fracture images, see **Slide 37**, Attachment 1. Analysis of micro-seismic data and images can then be utilised to compare and update geomechanical earth and fracture stimulation models, for the planning and optimisation of future HFS. Finder will utilise this micro-seismic monitoring technology in addition to the continuous real-time monitoring of pressure, rate and volume data during HFS operations.

Micro-seismic monitoring has been used successfully by third party exploration companies in the onshore Canning basin (Buru) and North Perth basin (AWE).

## CONCLUDING REMARK

Development of the Shale oil and gas resource would necessitate the long term employment of personnel to fulfil a wide range of roles and responsibilities, refer **Slide 49**, Attachment 1. The Project would generate substantial employment opportunities for Traditional Owners to work on their land and also for local people within the wider community. Training programs and other education initiatives would be reviewed and implemented by Finder should the Shale project proceed to development.

Finder thanks the Panel for the opportunity to make its submission to the scientific inquiry into hydraulic fracture stimulation in Western Australia. Due to the extensive amount of work which has been carried out by Finder in the onshore Canning Basin, much of the technical detail and reports have not been included in this submission. Should the Panel require access to additional supporting documents for their review, please feel free to contact Finder.

Yours faithfully

Ryan Taylor-Walshe
Manager- Onshore
Finder Shale Pty Ltd

Attachment #1 – Great Sandy Desert Project (EP 493) –Shale oil and gas (Presentation)

# Great Sandy Desert Project (EP 493)

## Onshore shale oil and gas, Western Australia

*Petroleum Exploration Permit EP 493*

# Great Sandy Desert Project (EP 493) – Shale oil and gas

FINDER EXPLORATION

1. Background, location & shale play model
2. Well planning and WA state regulatory approvals
3. Groundwater usage and waste management
4. Well construction, well integrity
5. Below ground geological setting and HFS risk assessment
6. Well site remediation and site rehabilitation
7. Project development utilising current horizontal multi well pad drilling methods
8. Community and Social Impact
9. Finder Concerns

# WA's next mega project (100% Australian owned)

FINDER EXPLORATION


## Petroleum Exploration Permit EP 493

- Population, Zero
- Pastoral Leases, Zero
- Traditional Land Owner Groups, Three
- 100% unallocated crown land

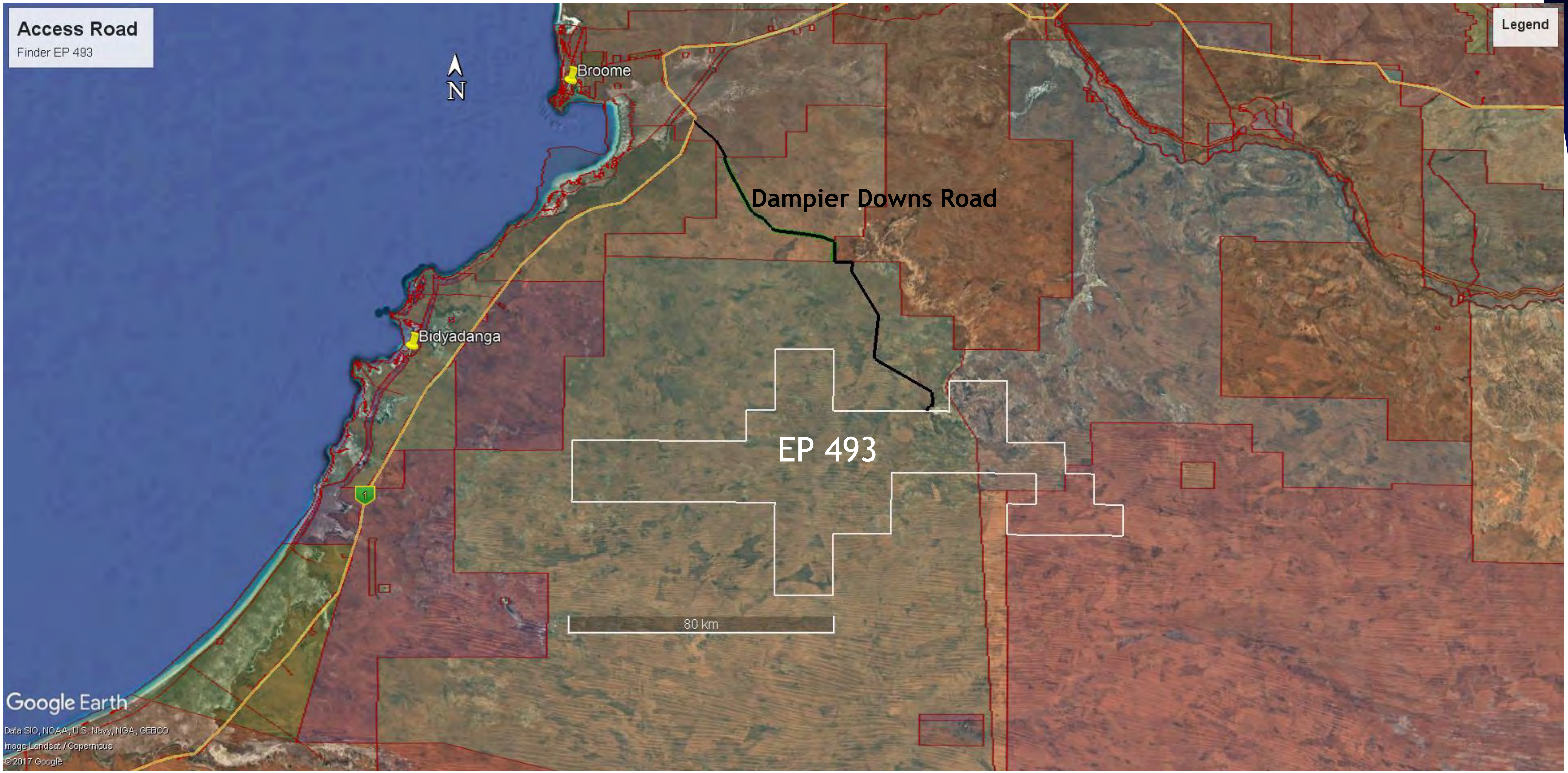
## Great Sandy Desert Shale Oil and Gas Project

- Finder have $17 million invested in the project and the next phase, +$35 million, is fully funded
- Potential of supplying a quarter of Australia's oil & half WA's domestic gas needs for decades to come
- Potential to double Australia's daily oil production providing domestic energy supply security
- Economic stimulus for the region and state (over 20 to 30 years),
  - State royalties ~$29.5 billion
  - Crude oil excise tax ~$132 billion
  - Project related costs ~$156 billion majority spend in Western Australia
  - Over 5000 direct and indirect long term Australian jobs
  - Job opportunities for local indigenous people on their land

*PHOTO - EP 493 – Great Sandy Desert, WA – September 2015*

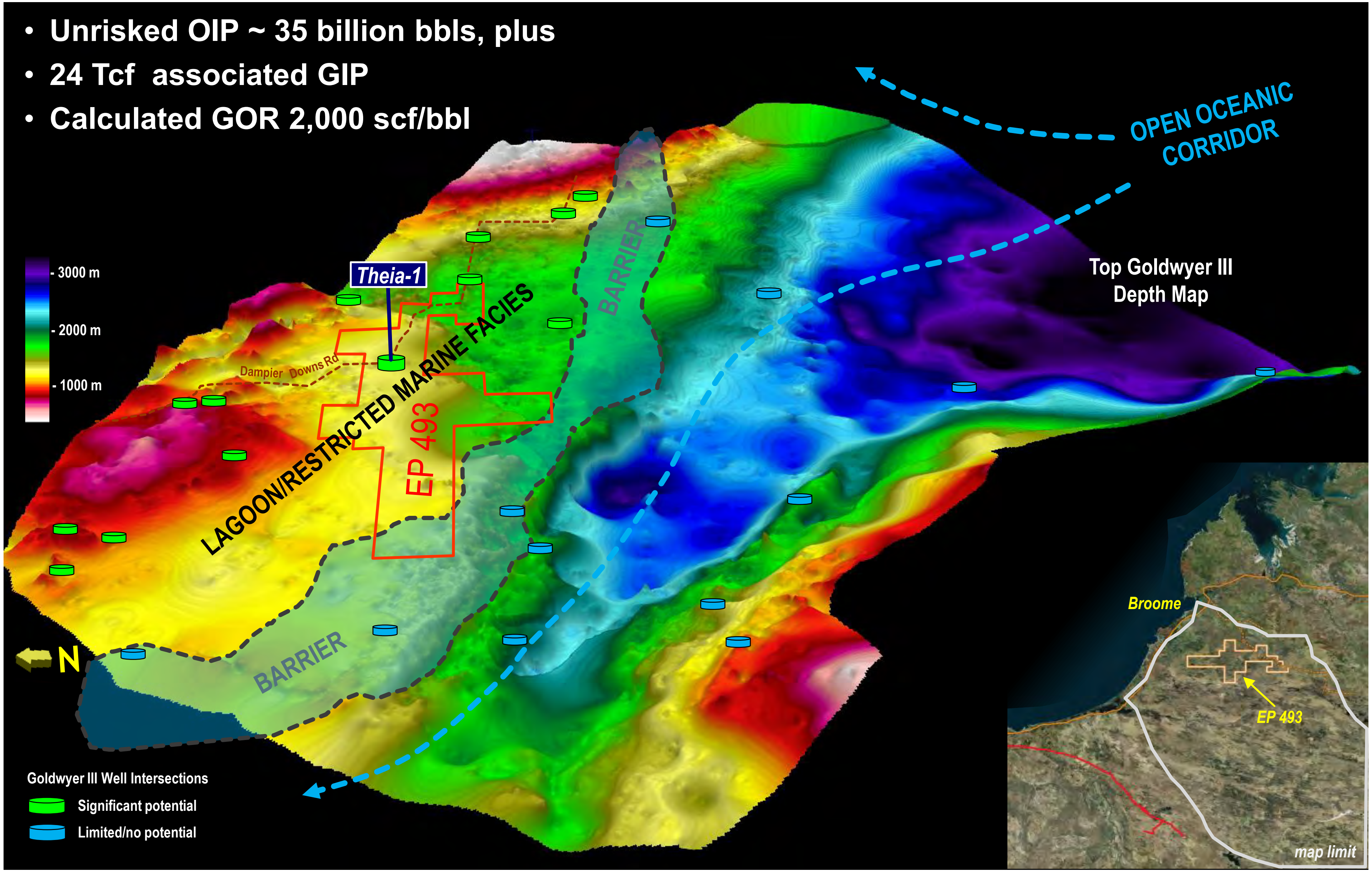
# Petroleum Exploration Permit EP 493, Location Map

FINDER EXPLORATION



# Finder geological model (onshore Canning basin)

- **Unrisked OIP ~ 35 billion bbls, plus**
- **24 Tcf associated GIP**
- **Calculated GOR 2,000 scf/bbl**




**Data driven analysis**

Twenty five wells intersecting the Goldwyer III shale analysed

Numerous studies commissioned incorporating all available well data (core, cuttings, logs, drilling information)

Regional seismic data reprocessed and detailed geological interpretation carried out and integrated with gravity and magnetic data

*OIP – Oil in Place, GIP – Gas In Place, GOR – Gas Oil Ratio*

# Robust Goldwyer III regional geological model

FINDER EXPLORATION

- The regional Goldwyer III geological model has **successfully predicted the results of four wells**:
  - ✓ Nicolay-1 (high oxygen depositional environment with low Total Organic Carbon (TOC);
  - ✓ Cyrene-1 (high toc, shallow, lower reservoir temperature and overpressure, lower gas oil ratio);
  - ✓ Commodore-1 (shallow barrier, high energy, oxygenated environment, low TOC); and
  - ✓ Theia-1 (Lagoonal anoxic depositional environment, high TOC).
- The **proven predictive accuracy of the model** provides increasing confidence in the models robustness and indicates that the Goldwyer III shale properties are highly predictable
- Theia-1 was drilled by Finder in September 2015 and fulfilled its objective of collecting the maximum amount of geological information to access the Goldwyer III shale oil with associated gas resource potential. Theia-1 succeeded in confirming Finders pre-drill geological model
- Due to the success of Theia-1 a **follow-up horizontal well (Helios-1) is planned to drill and complete using HFS** in order to test production flow rates to access commerciality. The surface location of Helios-1 is within the existing Theia-1 well pad

# 2015 Theia-1 petroleum exploration well

# EP 493 Goldwyer Resource Technical Summary

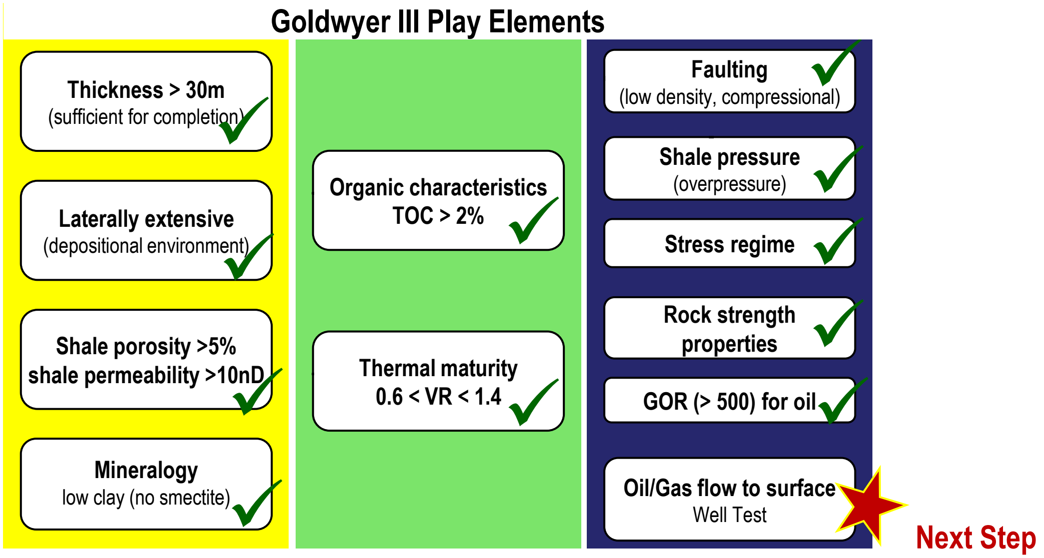
FINDER EXPLORATION

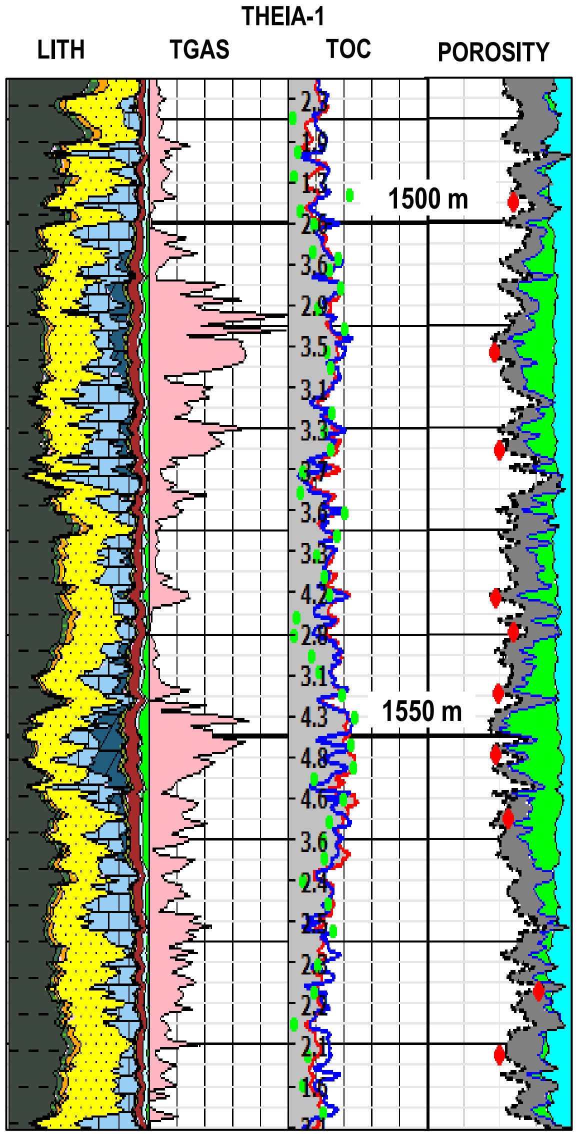
### Theia-1 highlights during drilling

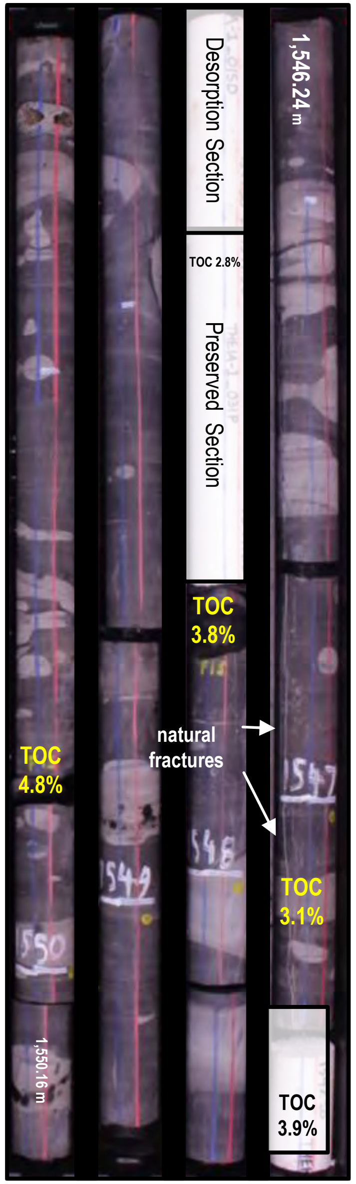
- high wet mud gas readings
- a visible gas haze escaping from the cores at surface
- Fluorescence (direct oil indicator) with strong hydrocarbon odour

### Post well analysis (performed by Weatherford & Schlumberger)

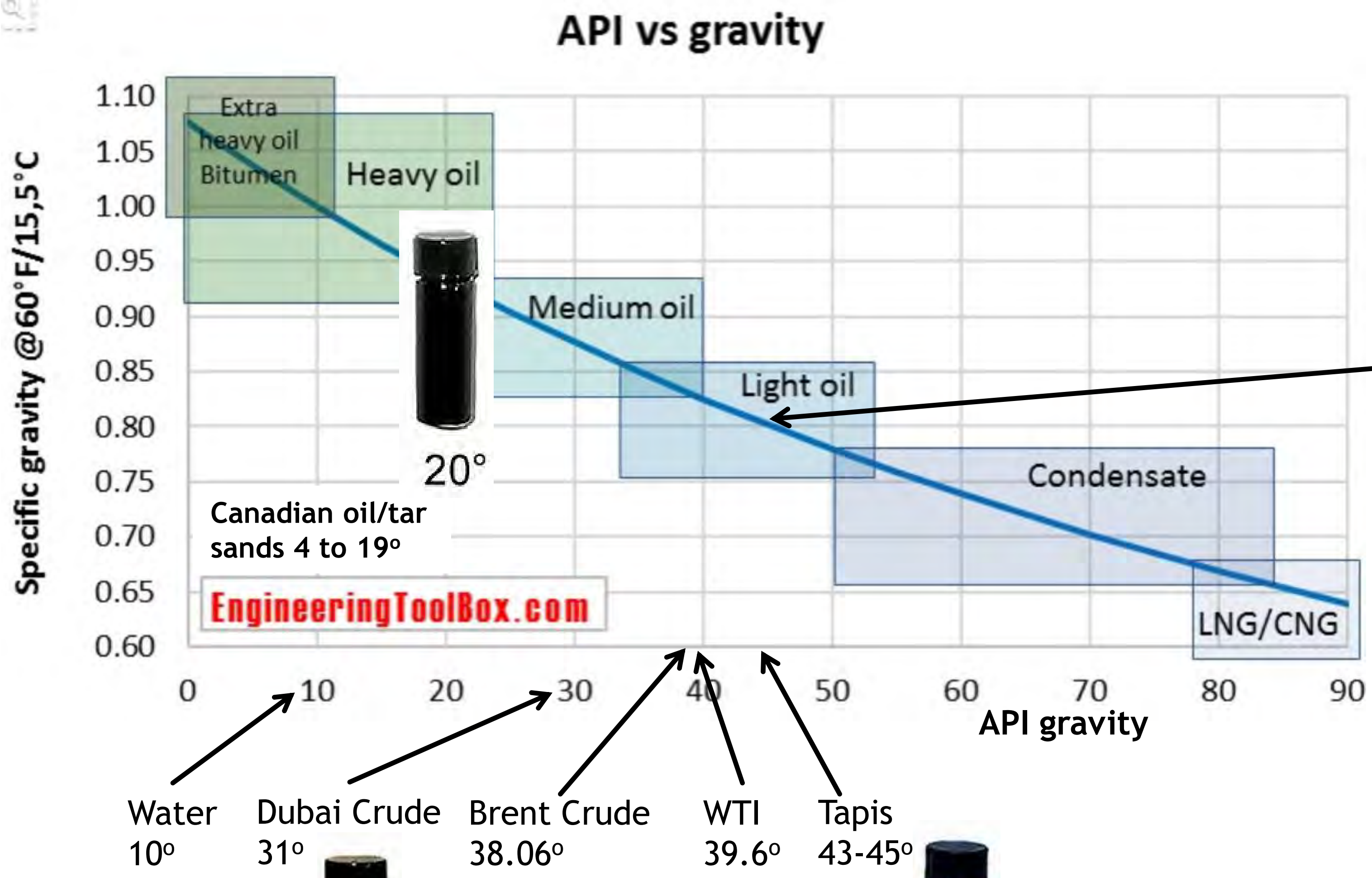
- high TOC (geochemistry)
- light oil (~45º API) with low wax content (geochemistry)
- high porosity (10%) from core
- geothermal gradient and kerogen maturity indicating peak oil window at uniquely shallow depth of 1,500m
- over-pressured, 1.22 sg (10.15 ppg)
- rocks prone to vertical fracture propagation (geomechanics)



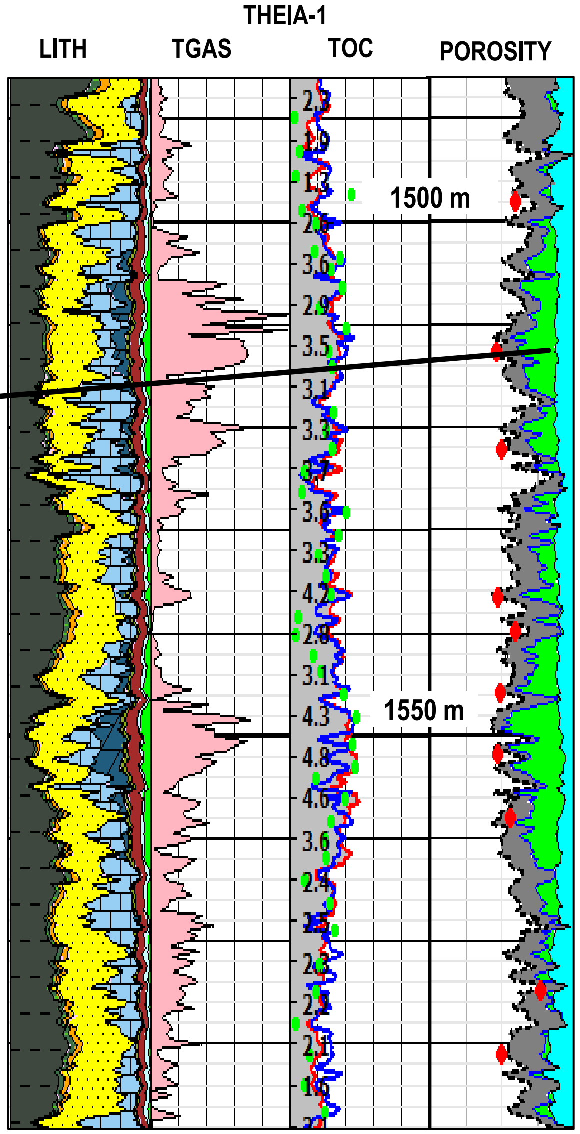



# EP 493 Goldwyer shale oil 45° API, no sulfur, no $CO^2$




30°




45° API gravity of Diesel Fuel (40° to 45°)

# Great Sandy Desert Project (EP 493) – Shale oil and gas

FINDER EXPLORATION

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# Planning to drill and complete a well – existing WA regulatory approvals

FINDER EXPLORATION

**Summary of regulatory requirements for exploration activities:**

1. **Well Management Plan (DMIRS assessment and approval)**
   - describes detailed well engineering design, risk assessment of the well integrity and HFS activities and provides well-specific management control
2. **Safety Management System (DMIRS assessment and approval)**
   - details the health and safety management requirements for project personnel, contractors and sub-contractors, how hazards are managed on-site and defines project-specific roles and responsibilities and how incidents are reported
3. **Environmental Management Plan (DMIRS and OEPA assessment and approval)**
   - describes environmental aspects, risk assessment, mitigation strategies, management control and reporting arrangements
4. **Chemical and Other Substances Disclosure Statement (DMIRS assessment and approval)**
   - provides details of all substances that will be used on-site and publicly available on DMIRS website
5. **Oil spill contingency plan (DMIRS assessment and approval)**
   - outlines how project personnel will respond to a spill incident, describes preventive measures and management controls
6. **Groundwater Baseline Assessment and Groundwater Monitoring Plan (DMIRS and the Department of Water assessment and approval)**
   - operator required to gather baseline groundwater data/samples and to undertake groundwater monitoring pre, during and post operations (including HFS) which are evaluated and compared against the baseline and monitoring data
7. **Rehabilitation Plan (DMIRS assessment and approval)**
   - describes rehabilitation scope of work and incorporates a site rehabilitation monitoring program to verify rehabilitation completion criteria are achieved
8. **26D and 5C licences to construct a water bore and extract groundwater (approval from the DoW)**
   - the assessment process takes a risk-based approach and considers the quantity of water available, whether the action would prejudice other current and future needs for water, and the potential risk of surface or groundwater contamination

# Health, Safety and Environmental Management

**Environmental Management includes:**

1. Cultural Heritage survey with indigenous owners and an anthropologist. Carried out prior to clearing any native vegetation
2. On-ground ecological (vegetation/flora and fauna) survey and report in accordance with the EP Act guidelines
3. Consultation with relevant stakeholders prior, during and post on-ground activities
4. Environmental risk assessment - identification of potential impacts and associated risks that may affect the environment
5. Development of mitigation measures and management controls that include:
   - Cultural Heritage Management Plan
   - Soil and Erosion Management Plan
   - Native Vegetation and Flora Management Plan
   - Fauna Management Plan
   - Weed and Pest Management Plan
   - Surface and Groundwater Management Plan
   - Groundwater Baseline Assessment and Groundwater Monitoring Plan
   - Air Pollution Control
   - Waste Management Plan
   - Fire Response Plan
   - Contamination and Spill Management Plan and Oil Spill Contingency Plan
   - Decommissioning and Maintenance Plan
   - Rehabilitation Plan
6. Environmental compliance and reporting criteria

**Safety Management includes:**

1. Well engineering and design
2. Well Management Plan
3. Training and competencies of personnel are verified
4. All personnel undergo site inductions
5. Toolbox meetings are held to discuss environmental issues
6. Weekly HSE meetings and daily workplace inspections are conducted by the site manager and HSE coordinator
7. Emergency Response and Incident Management Plans with daily emergency drills conducted
8. Regular internal audits and reporting are carried out and logged

# Cultural heritage survey 2016

# Ecological survey 2016




# Environmental compliance and reporting criteria

FINDER EXPLORATION

- API and ISO International best-practice and operational standards for petroleum activities are required to be met or exceeded in WA
- Comprehensive, effective, transparent and accountable legislative framework in place to regulate petroleum activities in WA
- Decision making authorities adopt risk and outcome-based approach to assess projects
- Transparency with approval processes, Environmental Plans are publicly available on DMIRS website, referral and assessment process under the EPBC Act and EP Act are made available for public consultation
- External environmental & safety audits and inspections by regulatory authorities and independent authorities
- Operating Management System & HSE Management System is a mandatory requirement for petroleum operators
- Regular review of Operating Management Systems and continual improvements
- Training, drills and exercises
- Internal compliance audit and inspections
- Mandatory monthly and annual reporting to the regulatory authority:
  - any recordable or reportable incidents including all facts, actions taken and preventative actions implemented
  - GHG emissions
  - Waste generation and disposal
  - Results of groundwater baseline assessment and groundwater monitoring
  - Water consumption
  - Annual environmental report
  - Rehabilitation progress and close-out report

# Great Sandy Desert Project (EP 493) – Shale oil and gas

FINDER EXPLORATION

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# Hydrology - Surface water

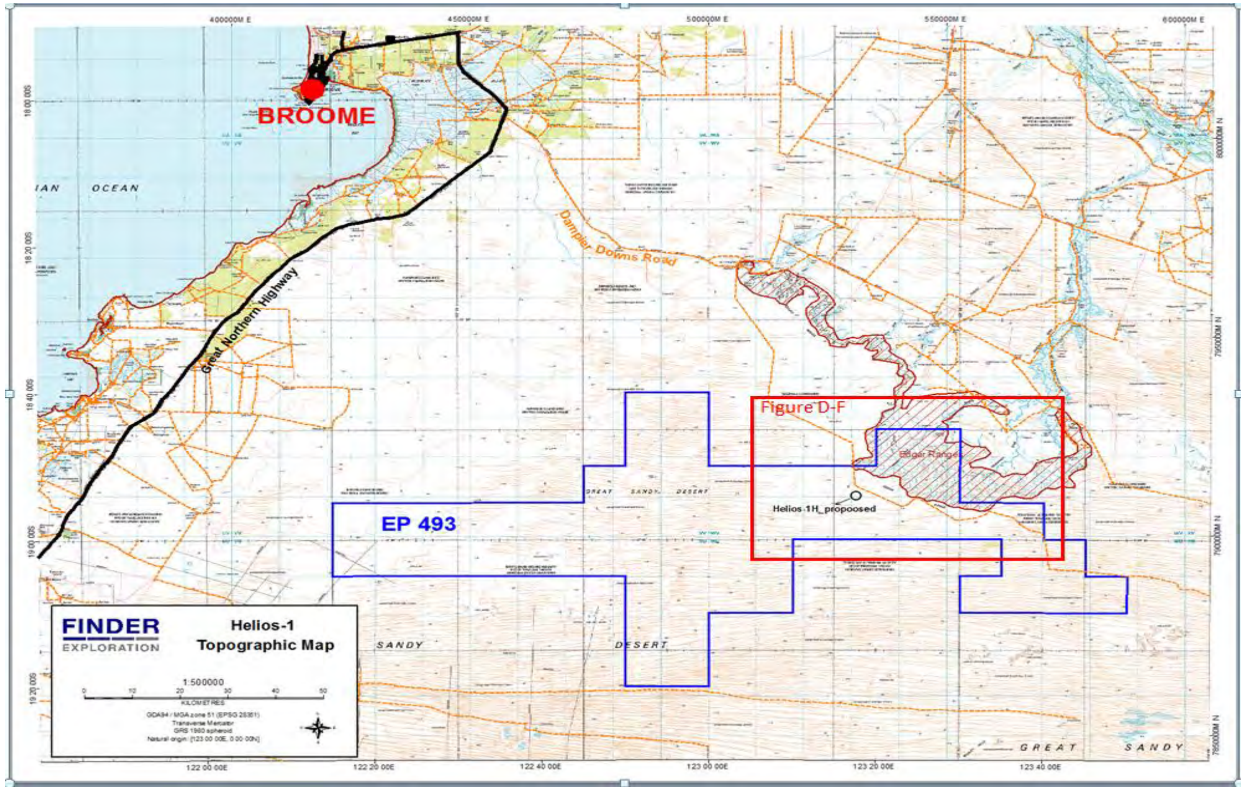
Within the project area no permanent surface water features or systems other than ephemeral are present.

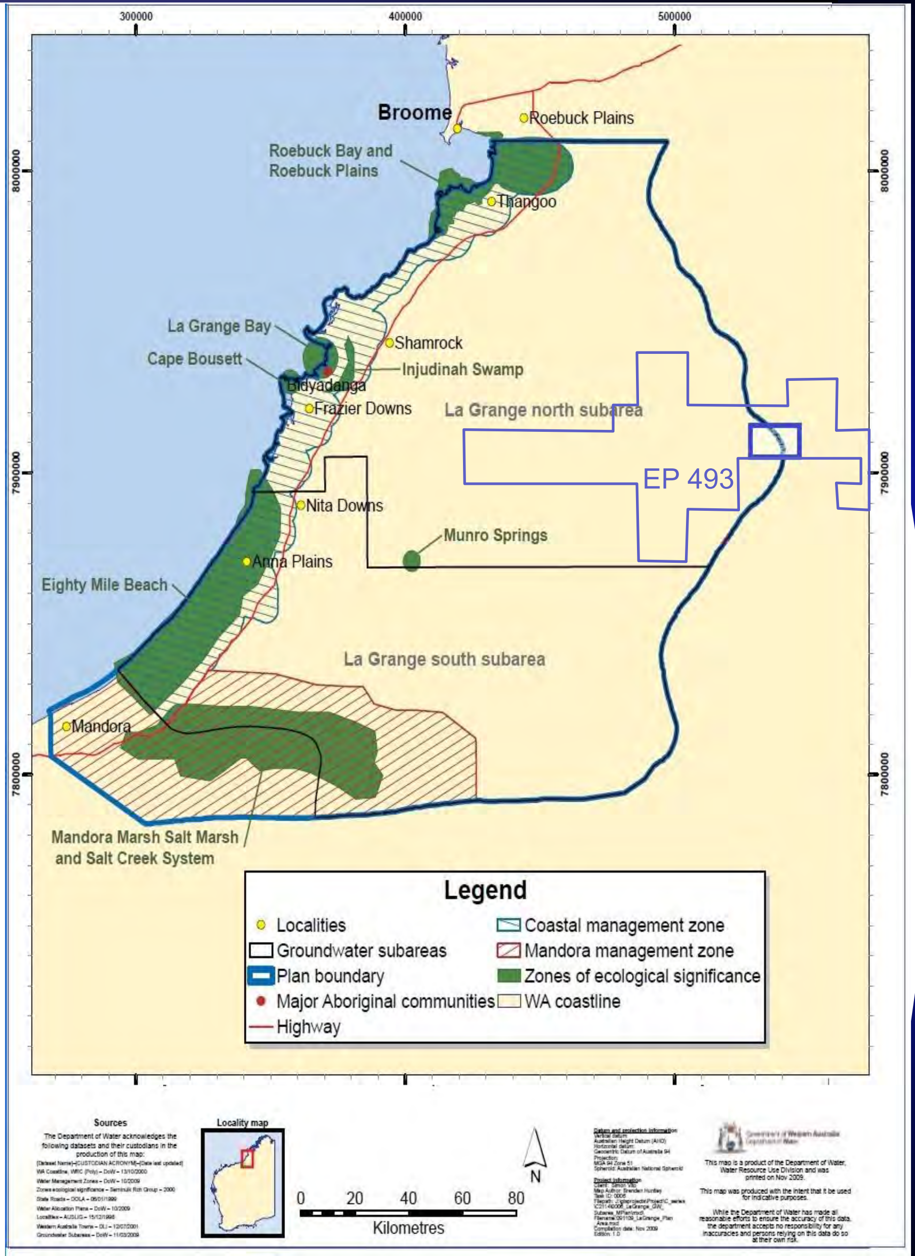
The nearest landscape feature that contains ephemeral watercourses and a chain of waterholes is the Edgar Ranges, NE corner of permit EP 493.

The Geegully Creek, Woolonwarra Creek and its major and minor tributaries (including ephemeral systems) and waterholes are wholly contained within the Edgar Ranges.

No wetlands which are Ramsar listed, Conservation Category, or listed in the Directory of Important Wetlands are present within EP 493.

No groundwater dependent systems.




Map is a product of the Department of Water, Nov 2009

# Hydrogeology - Groundwater

FINDER EXPLORATION

## Hydrogeological investigations:

- understand geological and hydrogeological settings of the existing environment
- regulated under the PGER (Environment) Regulations 2012 and s.38 of the EP Act

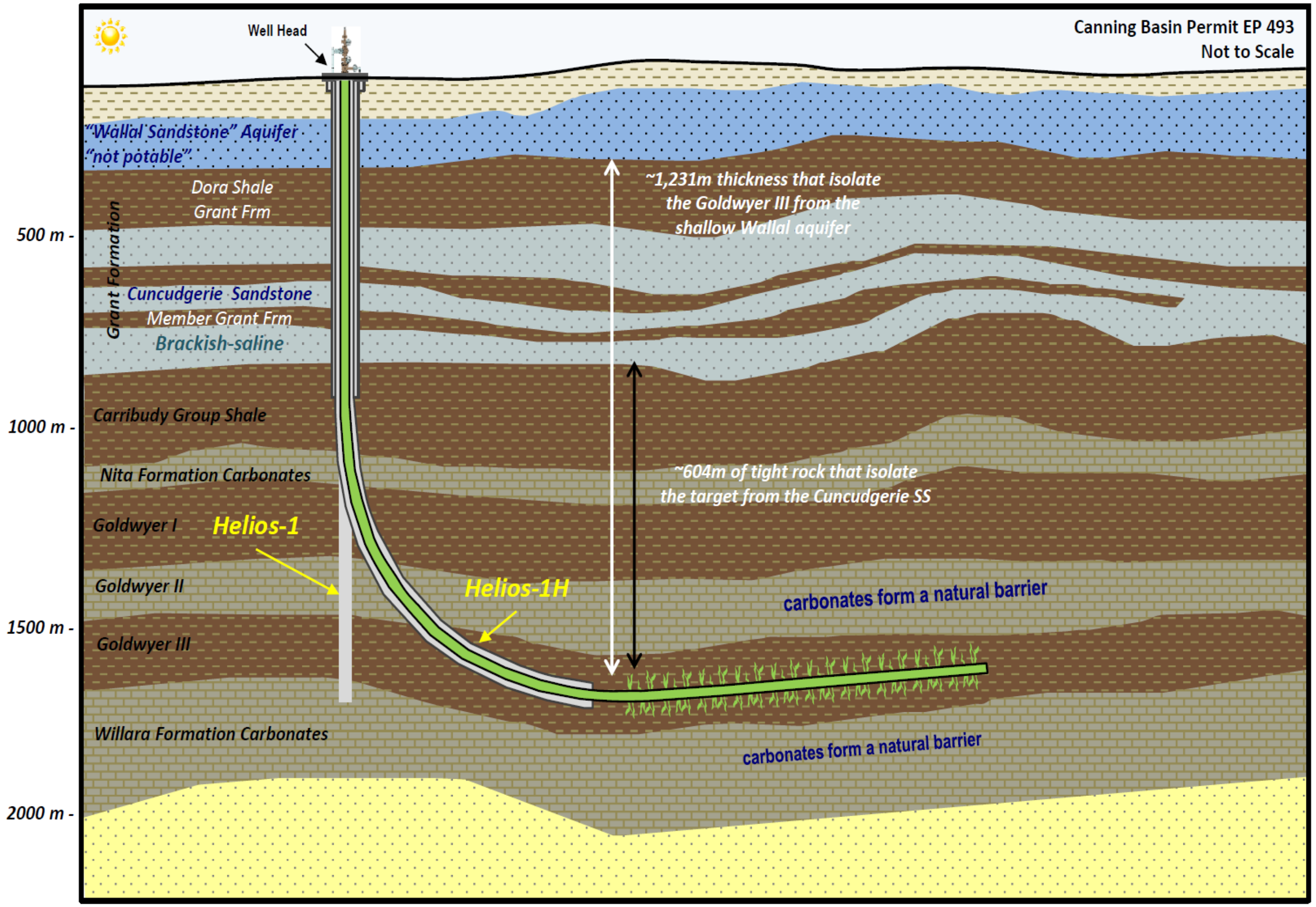
## Groundwater Baseline Assessment:

- regulated under Section 4.5 – Provision of Information, Guideline for Groundwater Monitoring in the Onshore Petroleum Industry Guideline, DMIRS, August 2016
- establishes groundwater conditions before petroleum activities commence
- gathers sufficient baseline data – field parameters, the groundwater level, chemical analysis of water quality and the construction details of water bore

## Groundwater Monitoring Program:

- requirement of the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012
- regulated by DMIRS's Guideline for Groundwater Monitoring in the Onshore Petroleum and Geothermal Industry, August 2016
- establishes surveillance monitoring through the life of the project and beyond site decommissioning and rehabilitation
- demonstrates that groundwater resources are monitored and provides evidence whether groundwater has or has not been affected by petroleum activities

***Conceptual hydrogeological profile of the Canning Basin***




*The geology of the Canning Basin is well understood at a regional scale through petroleum and mineral exploration wells and various hydrogeological investigations.*

# Water bore at Theia-1 well location

## example of groundwater baseline sampling and assessment



GTP002: Theia-1 Exploration - Water Bore Test Results (2015)

| | | | | | | Australian Drinking Water Standards | PAGE 203 - 216 OF 'AUSTRALIAN DRINKING WATER STANDARDS 6' |
|---|---|---|---|---|---|---|---|
| **Reference** | | 168790 | 16889 | 170333 | 170333 | | |
| **Description** | | Water Analysis | Water Analysis | Water Analysis | Water Analysis | | |
| **Sample** | | Bore 2 [Drill Pad] | Bore 2 [Drill Pad] | Bore 2 [Drill Pad] | Bore 2 [Drill Pad] | | |
| **Sample** | | 1 | 1 | 1 | 1 | | |
| **Date Sampled** | | 20/07/2015 | 23/07/2015 | 27/08/2015 | 27/08/2015 | | |
| **Potable water source** | | | | | | | |
| **Drilling water source** | | x | x | x | x | | |
| **Type of sample** | **Units** | **Water** | **Water** | **Water** | **Water** | **ADWS mg/l** | **Comments** |
| pH in water | pH Units | 6.3 | 6.1 | 6.7 | 6.7 | 6.5-8.5 | <6.5 may be corrosive. No health guideline value |
| Electrical Conductivity water | µS/cm | 2700 | 2500 | 2700 | 2700 | | No health guidline |
| Total Dissolved Solids (grav) | mg/L | 1600 | 1500 | 1600 | 1600 | 600 | **For good potability, not a health requirement** |
| Total Suspended Solids | mg/L | 68 | 34 | 9 | | | No health guidline |
| Turbidity | NTU | 53 | 18 | 29 | | 5 | **Based on aesthetic considerations turbidity should not exceed 5NTU** |
| Colour (True) | HZU | <3 | <3 | 22 | | | No health guidline |
| Aluminium-Total | mg/L | 0.16 | 0.04 | 0.02 | 0.02 | 0.2 | No health based guideline currently; <0.1mg/l desirable |
| Cadmium-Total | mg/L | <0.0001 | 0.0001 | <0.0001 | <0.0001 | 0.002 | |
| Copper-Total | mg/L | 0.036 | 0.003 | 0.007 | 0.006 | 2 | |
| Iron-Total | mg/L | 2.3 | 1.4 | 6.5 | 6.1 | **0.3** | **Taste threshold; insufficient data to set a health guideline value** |
| Lead-Total | mg/L | 0.002 | <0.001 | 0.002 | 0.001 | 0.01 | |
| Nickel-Total | mg/L | 0.024 | 0.002 | 0.02 | 0.02 | 0.02 | |
| Zinc-Total | mg/L | 0.066 | 0.055 | 0.066 | 0.062 | 3 | Taste threshold; insufficient data to set a helath guideline value |
| Calcium - Dissolved | mg/L | 58 | 57 | 58 | 59 | | Not included in ADWG document as not neccessary. |
| Potassium - Dissolved | mg/L | 52 | 49 | 50 | 51 | | Not included in ADWG document as not neccessary. |
| Magnesium - Dissolved | mg/L | 40 | 39 | 38 | 39 | | Not included in ADWG document as not neccessary. |
| Sodium - Dissolved | mg/L | 400 | 390 | 400 | 400 | **180** | **Taste threshold** |
| Bicarbonate $HCO_3$ as $CaCO_3$ | mg/L | 53 | 53 | 58 | 57 | | No guideline |
| Carbonate $CO_3^{2-}$ as $CaCO_3$ | mg/L | <5 | <5 | <5 | <5 | 200 | |
| Hydroxide $OH^-$ as $CaCO_3$ | mg/L | <5 | <5 | <5 | <5 | | No guideline |
| Total Alkalinity | mg/L | 53 | 53 | 58 | 57 | | No guideline |
| Chloride in water | mg/L | 700 | 700 | 700 | 710 | **250** | **Aesthetic guideline** |
| Sulphate in water | mg/L | 240 | 240 | 230 | 230 | 500 | |
| Nitrate as $NO_3$ | mg/L | <0.5 | 0.8 | <0.5 | | 100 | 50 for infants under 3 months |
| Nitrite as $NO_2$ | mg/L | <0.5 | <0.5 | <0.5 | | 3 | |
| Hardness as $CaCO_3$ | mg/L | 310 | 300 | 300 | 310 | **60-200** | **Good quality 60 - 200 mg/l** |
| Ionic Balance | % | -2.2 | -2.8 | -2.5 | -2 | 10% | <10% considered acceptable for a good test |
| Ammonia as N | mg/L | 0.005 | 0.027 | 0.009 | | 0.5 | Aesthetic; insufficient data to set a health guideline value |
| Total Cyanide | mg/L | <0.004 | <0.004 | <0.004 | | 0.08 | |
| Fluoride in water | mg/L | 0.2 | 0.4 | 0.2 | | 1.5 | |
| Sulphide in water | mg/L | <0.01 | <0.01 | <0.01 | | | |
| Antimony-Total | mg/L | <0.001 | <0.001 | <0.001 | | 0.003 | |
| Arsenic-Total | mg/L | 0.002 | 0.001 | <0.001 | <0.001 | 0.01 | |
| Barium-Total | mg/L | 0.075 | 0.055 | 0.053 | 0.05 | 2 | |
| Boron-Total | mg/L | 0.3 | 0.27 | 0.24 | 0.22 | 4 | |
| Chromium-Total | mg/L | 0.024 | 0.01 | 0.003 | 0.002 | 0.05 | |
| Manganese-Total | mg/L | 0.064 | 0.043 | 0.089 | 0.089 | 0.5 | >0.1 mg/l causes taste and staining |
| Molybdenum-Total | mg/L | 0.001 | <0.001 | 0.001 | 0.001 | 0.05 | |
| Selenium-Total | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 | |
| Silver-Total | mg/L | <0.001 | <0.001 | 0.001 | <0.001 | 0.1 | |
| Tin-Total | mg/L | <0.001 | <0.001 | <0.001 | | | Not neccessary, conc in water very low |
| Uranium-Total | mg/L | <0.0005 | <0.0005 | <0.0005 | | 0.017 | |

## Exploration program 2015 (Theia-1)

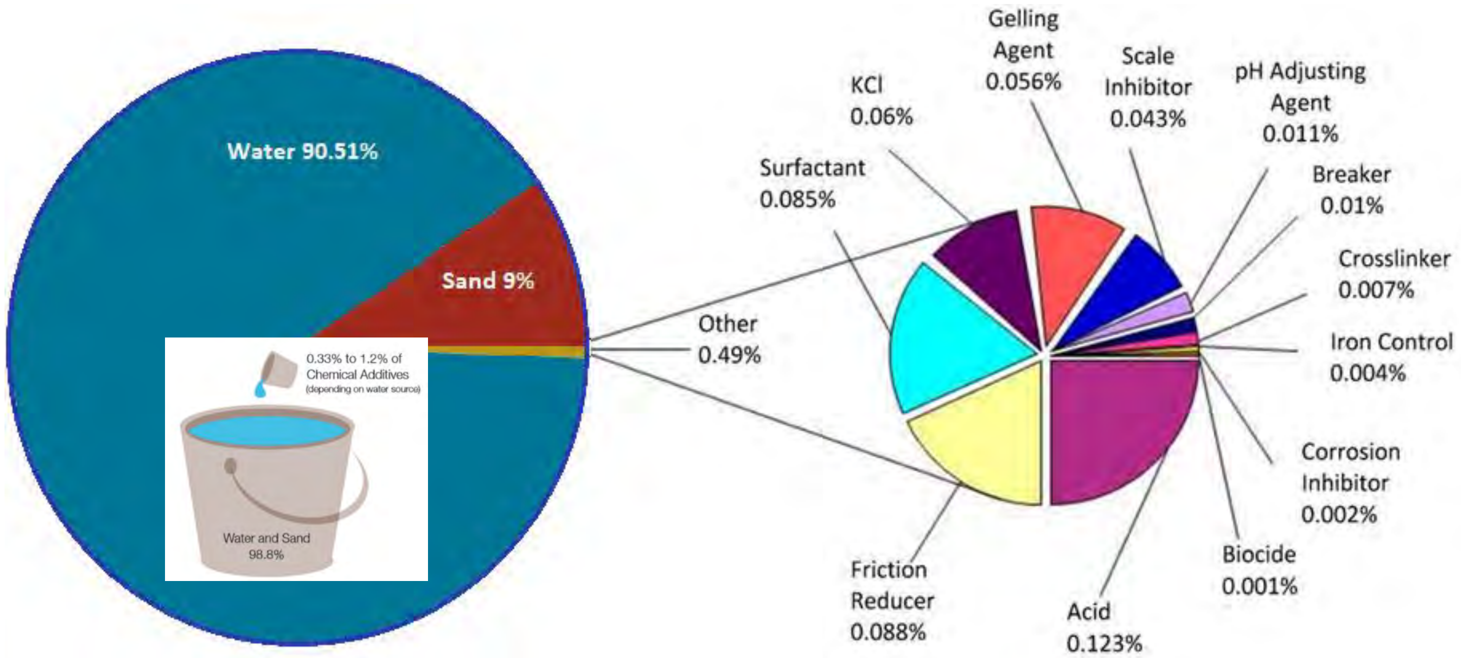
## Baseline assessment summary of the Wallal Aquifer, central Canning Basin:

- water bore depth 160m
- samples were taken before and after drilling
- water is not suitable for human consumption
- no impact to/changes in groundwater quality due to petroleum activities

**RED indicated values outside Australian Drinking Water Standards**

**WATER IS NOT SUITABLE FOR HUMAN CONSUMPTION**

# Hydraulic Fracturing Fluid Composition




*Reference: http://www.aplng.com.au/pdf/factsheets/Factsheet_Fraccing-APLNG.pdf*


HFS fluid injected into the formation ~1.5km underground is ~30 times less toxic than swimming pool water (Ecotox Services Australasia, test protocol ESA SOP 117 (ESA 2013)[1]).

All chemicals and other substances introduced to a well or formation require DMIRS approval. All information is publicly disclosed and available on DMIRS website.

| Chemical type | Use | Common application |
|---|---|---|
| **Friction reducer** | Reduces the friction forces of fluids being pumped to increase flow rates | Food and pharmaceutical industry, mineral turpentine, clothing manufacturing, cooling systems |
| **Biocides** | Control growth of bacteria and control well corrosion | Common use disinfectant, bleaching agent, cleaners, water treatment, cosmetics, dishwashing liquids |
| **Corrosion inhibitors** | Removes oxygen and control well corrosion | Shampoos, cosmetics, perfume production, plastics, dyes, food preservatives |
| **Iron control/ scale inhibitors/ acids** | Limits the build-up of iron and mineral scale and control well corrosion | Anticorrosion products, detergents, cleaning products, pharmaceutical applications |
| **Cross linkers/ Gelling agent** | Increases the thickness of fluids which allows more proppant to be carried into rock fractures | Cement, adhesives, ceramics, detergents, cosmetics, food additive and thickener |
| **Breakers** | Breaks down the gelling agents and releases the proppant into rock fractures | Food industry, washing powder, cements, antacid medicine |
| **pH control** | Adjusts the chemical and physical properties of the fluid | Household cleaning, food additive, swimming pools, drinking water |
| **KCL** | Increase viscosity of the fluid | Table salt |
| **Surfactants** | Reduces the stickiness of fluids to improve flow rates | Cleaning agents, Laundry detergent |

[1] ESA (2012) SOP 117: Freshwater and Marine Fish Imbalance Test. Issue No 9. Ecotox Services Australasia, Sydney, NSW

# Water requirements and Wastewater Management

FINDER EXPLORATION

**Baseline conditions**:

- No public drinking water source areas or potable water supplies
- Limited beneficial use of groundwater - Unallocated Crown Land and not suitable for human consumption
- Water allocation in the West Canning Basin ~41,000ML annually is available for various activities
- Current cumulative consumption of groundwater in central Canning Basin – 175ML

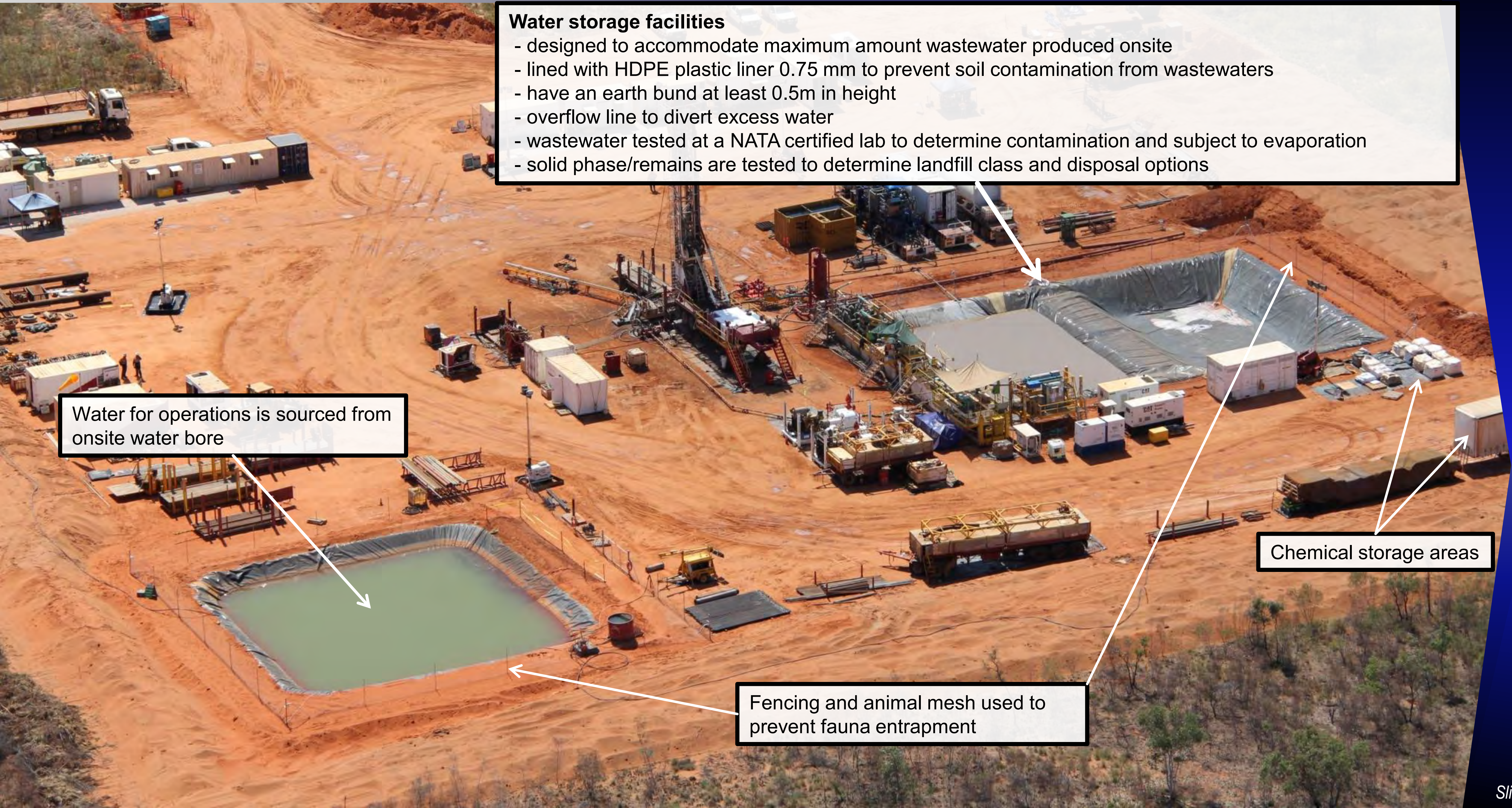
**Water requirements once per well (Helios horizontal well HFS fluid design):**

- 1,200kL-1,400kL per HFS stage (~2.5 times average household annual consumption)
- 12,000-14,000kL for the Helios-1 horizontal well (a 1200 hectare horticultural farm uses ~20,000,000kL for irrigation per year)

**Wastewater management**

- 40-60% of hydraulic fracturing fluid (flowback) returned to the surface. The flowback is treated as "wastewater" in accordance with waste management hierarchy – re-use, recycle, treat and dispose:
- Re-used during further hydraulic fracture stimulation (reducing water requirements)
- Stored in lined and bunded water storage facilities for further reduction via evaporation
- Solid phase is tested for contaminants to determine disposal options in accordance with the ***Landfill Waste Classifications and Waste Definitions 2010*** and the ***Environmental Protection (Controlled Waste) Regulations 2004***
- DMIRS conducts regular site audits of hydraulic fracture activities to ensure operators are complying with approved plans for chemical use, storage and disposal

# Examples of key environmental protection measures



# Great Sandy Desert Project (EP 493) – Shale oil and gas

FINDER EXPLORATION

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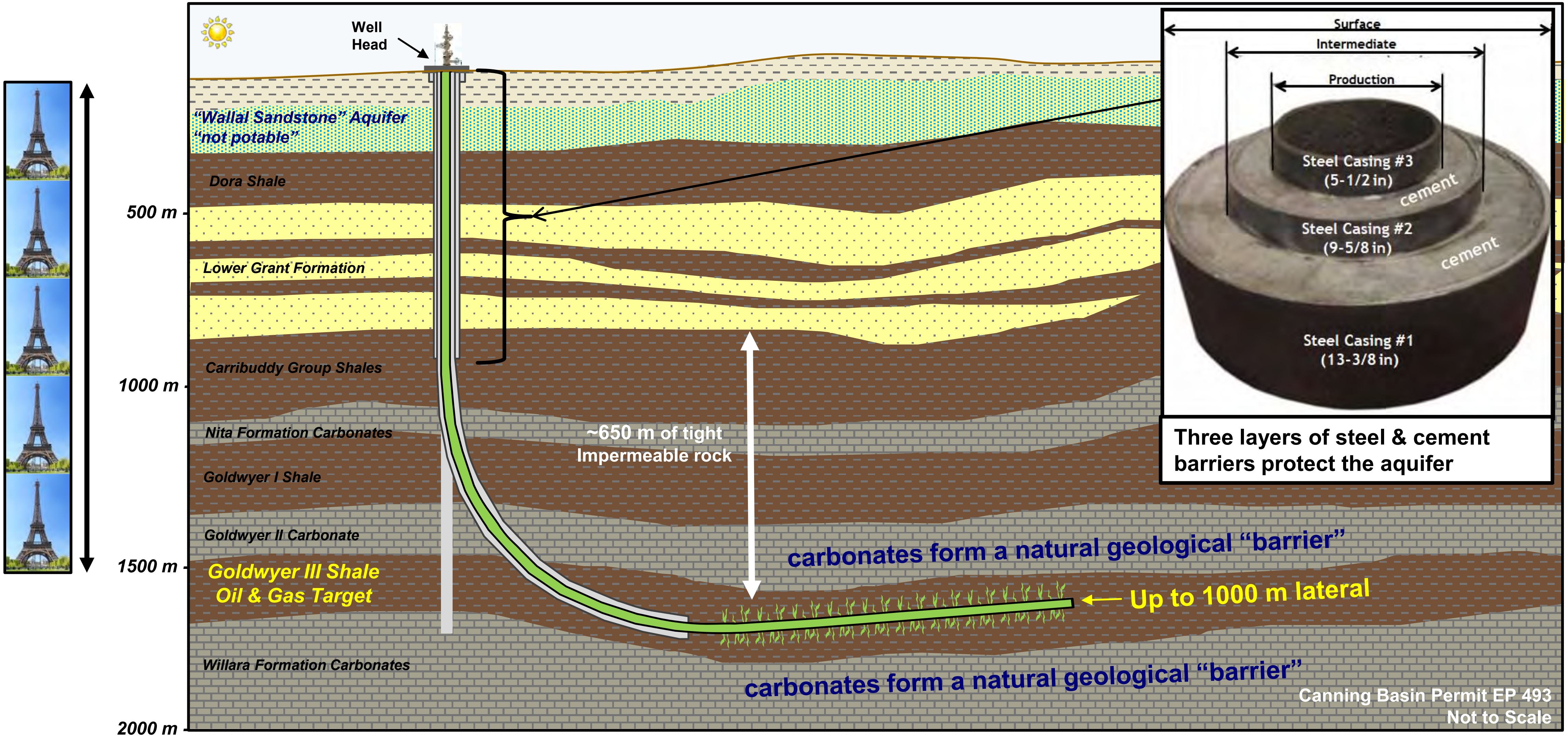
# Onshore Canning basin HFS & production test (horizontal well)

FINDER EXPLORATION




Wells are designed and constructed to ensure well integrity under all operating conditions over their life cycle which includes drilling, fracture stimulation, and subsequent production operations.

# Typical Goldwyer III horizontal shale well construction

FINDER EXPLORATION

**20” conductor pipe**

- installed at the surface and set at approximately 30m where it is cemented back to surface. This provides the initial stable structural foundation for the well

**13-3/8” surface casing string**

- which extends from the surface to approximately 870m where it is set in a laterally continuous shale in the Carribudy and cemented back to surface. This isolates the near-surface groundwater in the saline Grant sandstone aquifers and brackish Wallal sandstone acquifer, neither of which is being used for agricultural or other non drilling purposes at present

**9-5/8” intermediate casing string**

- set inside the surface casing and extends from the surface to approximately 1500m vertical depth cemented back to 1150m (50m above sealing shale formation). It is not cemented back into the surface casing annulus so that pressure monitoring of that annulus is possible during fracture stimulation and so it is possible to confirm that fracture stimulation pressures or fluids are constrained in the deep reservoir and are not transmitted up the well into the near surface formations

**Production casing string (typically 5-1/2” casing with high strength and high pressure rating)**

- run and cement inside the intermediate casing from the surface to the end of the lateral (reservoir vertical depth of 1550m and lateral distance of 600m or greater). This is cemented back 150m into the intermediate casing to ensure isolation of pressures seen deep underground in the reservoir from higher up the well

**Well Management Plan**
Includes a specific section on risk assessment of well integrity – is developed and submitted for approval by the Regulator (DMIRS). At each casing point the well is pressure tested prior to commencing the next stage of operations (drilling or fracture stimulation) to confirm the integrity of the casing and cement

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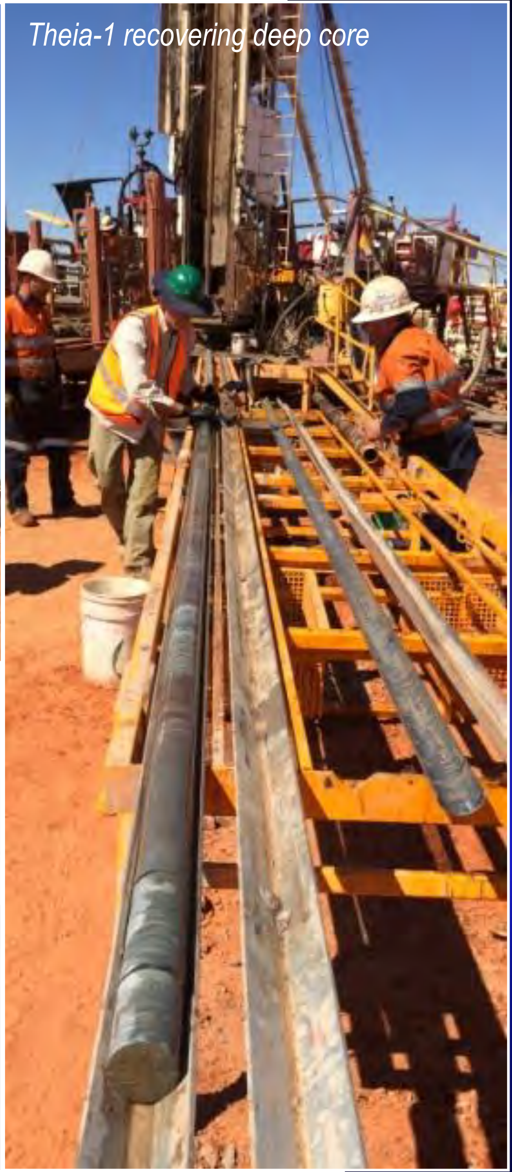
# Theia-1 (2015) Positive Geological Assessment

Theia-1 September 2015
Petroleum Exploration Well, Great Sandy Desert, WA

Theia-1 recovering deep core



Theia-1 Geo Shack

Theia-1 intersected ~70m oil and gas column within a shale reservoir at 1,550m depth and confined within thick (650m) impermeable geological rock barriers

# Theia-1 – lots and lots of core (continuous rock samples)


**lots and lots of real rocks! (778 metres of core = 6.5 tonnes)**

# Theia-1 data acquisition and post well analysis

FINDER EXPLORATION

## Wireline Data acquisition

Gamma Ray & spectral gamma logs, Cross Dipole Sonic, Resistivity, Neutron, Density Log, Image Log
Checkshot/Vertical Seismic Profile

## Integrated post well analysis of core, data and drilling information

| Analysis | Description | Interval | Data | Appendix | |
|---|---|---|---|---|---|
| Shale Analysis (Weatherford Laboratory) | Desorption Analysis<br>Crushed Gas Analysis<br>Gas Composition Analysis<br>Gas Isotope Analysis<br>Spectral Core Gamma<br>Crushed Density Analysis<br>Geochemistry – TOC, Rock-Eval, HC<br>Extract – GCMS (whole, aromatic, saturate)<br>Organic Petrography<br>Thin Section Petrography<br>Field Emission SEM<br>XRD<br>Rock Mechanics<br>Shale Rock Properties (bulk density - porosity-perm-saturation) | 1,450 – 1,608 | Basic report and Data | Appendix N | Core sample analysis |
| Cross-Dipole Sonic Anisotropy Processing (Weatherford) | Shear Anisotropy<br>Fast Shear Azimuth direction | 870 - TD | Report, LAS, PDF logs | Appendix O | Petrophysical analysis |
| Tight Rock Analysis (Schlumberger Terratek) | Retort Porosity, Saturations and Permeability<br>Liquid extraction porosity and saturations<br>Pulse Decay permeability | 1,511 – 1,556 | Data | Appendix P | Core sample analysis |
| GeoMin (FTiR) (Ana-min) | Wellsite FTiR | Entire Well | Report, Data Tables | Appendix Q | Core sample analysis |

**WADMP GSWA** geologists have also conducted a suite of analysis on the Theia-1 core (not included) to better their knowledge on the regional understandings of the Ordovician rock sequence in the onshore Canning Basin. Their studies cover the entire well and include a detailed sedimentological core log, HyLogger, palynology, conodonts, geochronology, geochemistry, routine core analysis and petrography. The data from these studies will be submitted in accordance with the government sampling guidelines.

# Theia-1 Post-well analysis – assessing well results

FINDER EXPLORATION

- Detailed analysis on core and cuttings samples, wireline, gas samples…….
- Schlumberger SIS team provided analysis and interpretation of the data
  - Petrophysics
  - Geomechanics modelling
  - HFS modelling

Weatherford LABORATORIES | TASK Fronterra Geoscience | 3D GEO | SOURCE GEOSCIENCE

Good Earth Consulting | Core Lab RESERVOIR OPTIMIZATION | Schlumberger | CHEMOSTRAT

| Sample | Top Depth (m) | Bottom Depth (m) | Desorption Analysis (Q1, Q2) | Crushed Gas Analysis (Q3) | Gas Composition Analysis | Isotopic Analysis | Core Handling/Slabbing | Core Gamma | Detailed Core Photography | Crushed Density Analysis | TOC Determination | Programmed Pyrolysis | HRGC & GCMS | Organic Petrography | Thin Section & FEESEM | X-Ray Diffraction | CT Scanning | Rock Mechanics | Shale Rock Properties |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | | | 25 | 25 | 10 | 10 | 36 | 50 | 31 | 25 | 99 | 38 | 8 | 11 | 15 | 11 | 10 | 5 | 11 |

**Chemostratigraphy**
**Fluid Inclusion Technology**
**Image log interpretation**
**Core interpretation**

**Petrophysics**
**Geomechanics and MEM**
**Fracture modelling**
**Production forecasting**

Palynology
Geochron - Zircon SHRIMP
Conodonts
Petrography, SEM, XRD
SCAL
Geochemistry

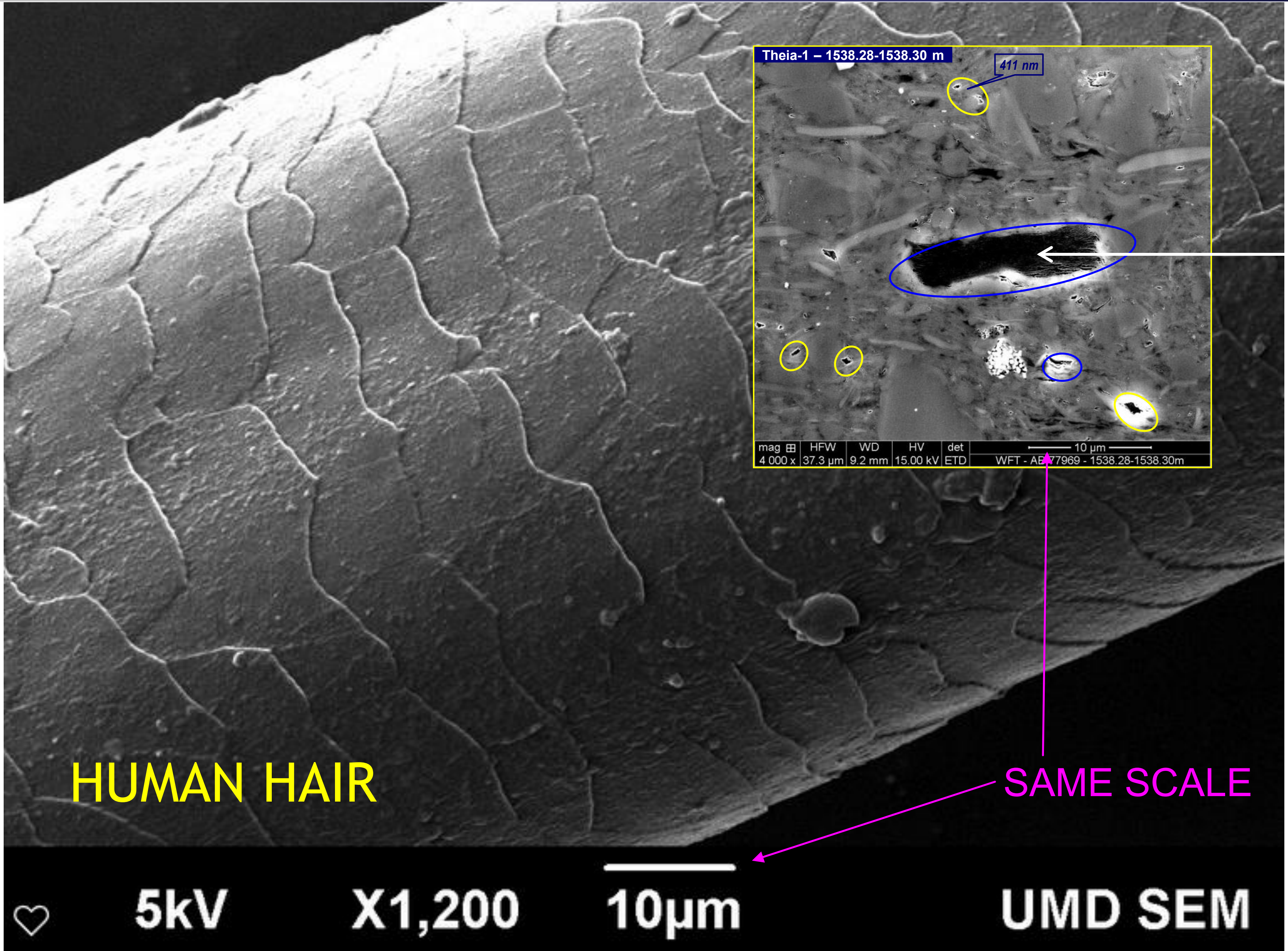
GSWA EIS – not Goldwyer specific

**Dr Ray Johnson**
**(Consultant HFS modelling and design specialist)**

**Steve Broome**
**(Consultant Reservoir Engineer)**

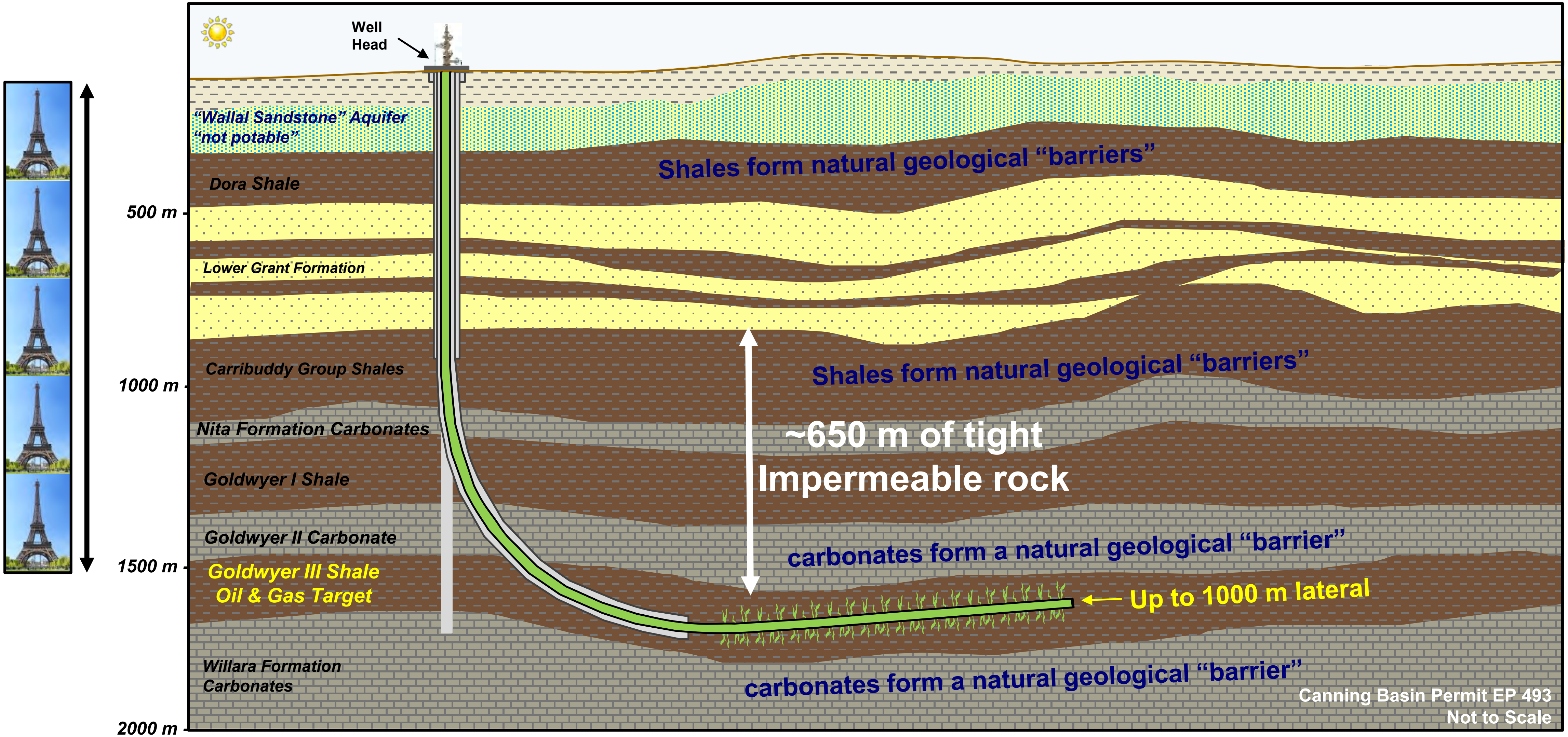
# Theia-1 – Microscopic Images – comparison with human hair






Oil bearing pore space

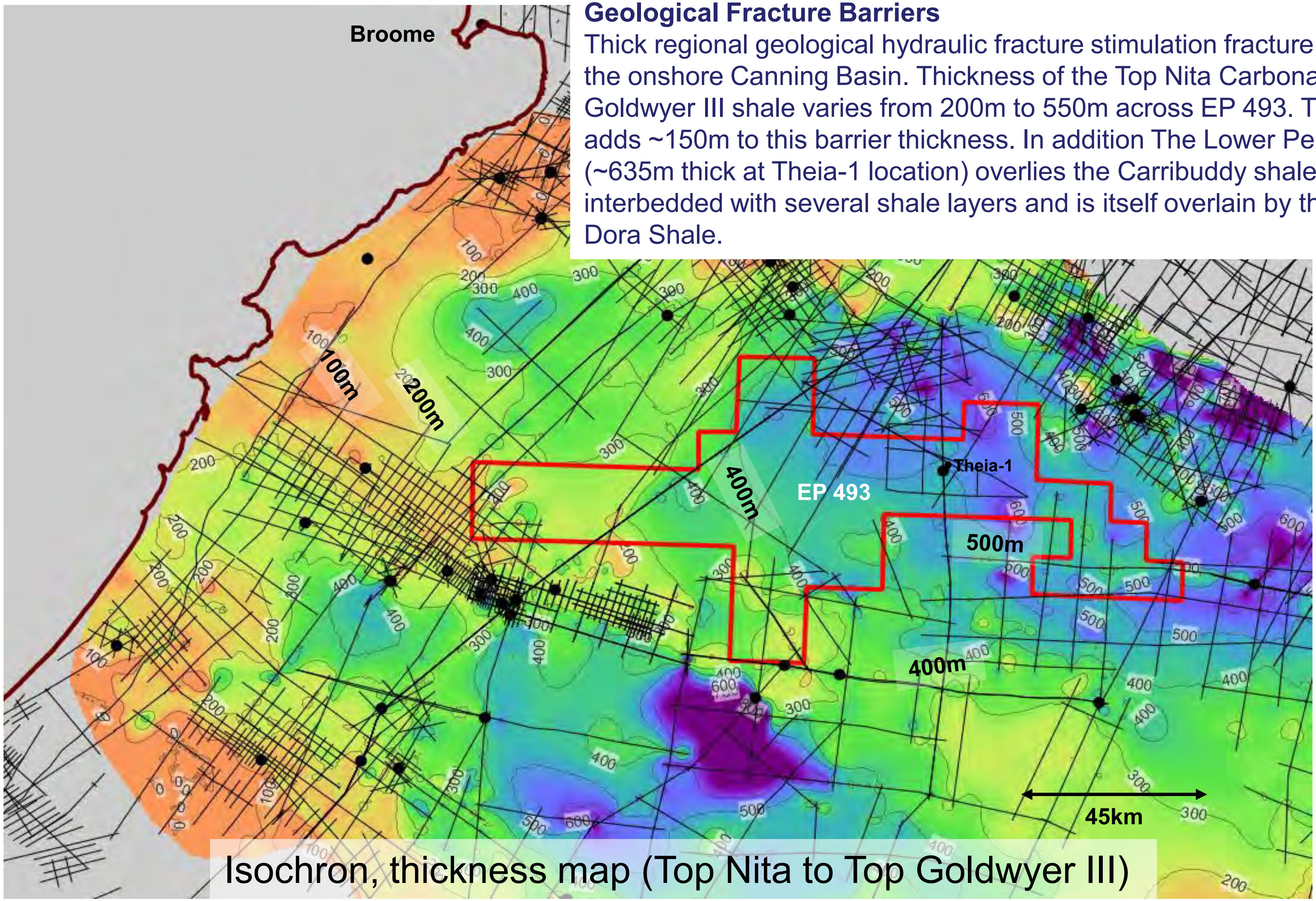
# Multiple HFS fracture barriers separating the aquifers




Formations above the oil and gas bearing Goldwyer III shale are thick, impermeable and form natural HFS fracture barriers. The geomechanical stress properties of the Goldwyer II and Willara Carbonates form stress barriers immediately above and below the shale. No highly overpressured formations (pressures either normal or slightly over pressured) are encountered in the basin (based on regional well review) which significantly reduces well control incident risk.

# Laterally extensive thick impermeable HFS fracture barriers

FINDER EXPLORATION




Isochron, thickness map (Top Nita to Top Goldwyer III)

**Geological Fracture Barriers**

Thick regional geological hydraulic fracture stimulation fracture barriers extend across the onshore Canning Basin. Thickness of the Top Nita Carbonate to the Top of the Goldwyer III shale varies from 200m to 550m across EP 493. The Carribuddy shale adds ~150m to this barrier thickness. In addition The Lower Permian Grant Formation (~635m thick at Theia-1 location) overlies the Carribuddy shale. The Grant is interbedded with several shale layers and is itself overlain by the laterally extensive Dora Shale.

**Summary**

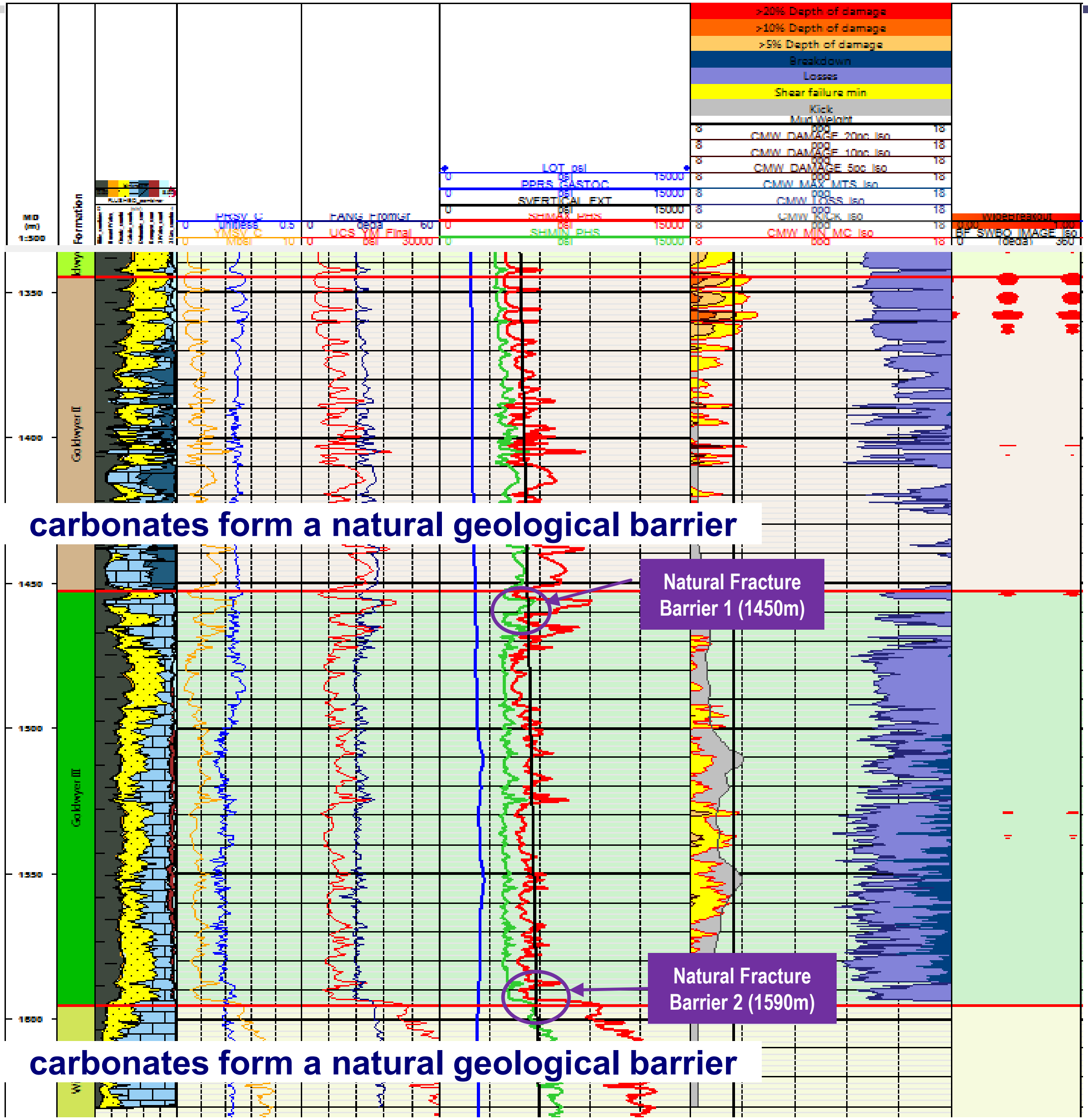
The Goldwyer III oil and gas bearing shale is separated from the near surface Wallal sandstone acquifer by numerous thick impermeable geological barriers which are present across the onshore Canning Basin

**Input data**

2D seismic + wells

# Theia-1, Geomechanical Earth Model (Schlumberger Analysis)

FINDER EXPLORATION




The Goldwyer III shale is located at a depth of ~1.5km overlain with thick (~650m) impermeable geological formations.

The tight carbonate formations above and below the Goldwyer III shale form natural stress barriers to vertical hydraulic fracture growth.

The above conclusions are derived from analysis of all available regional data and extensive data and analysis carried out on the Theia-1 well drilled within EP 493:

Regional data

- well wireline & core data and drilling information integrated into petrophysical evaluations, plus non well data such as regional reprocessed seismic, gravity and magnetic data

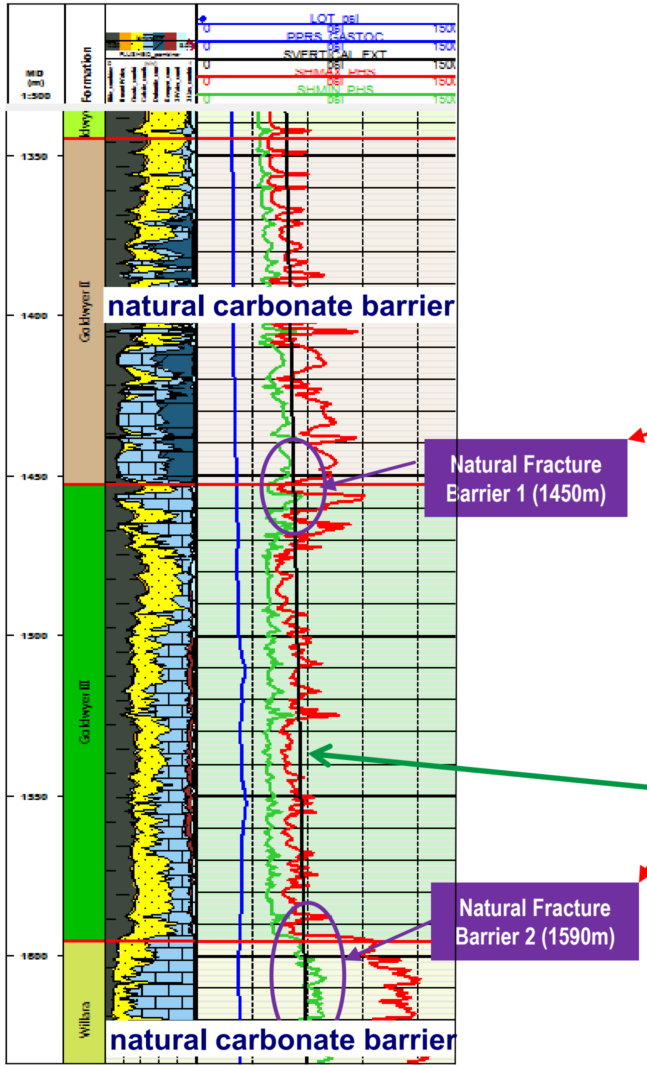
Theia-1 well data and information:

- petrophysical log data evaluation calibrated with rock mechanics core data, and drilling information
- calibrated geomechanical stress profiles show the target shale is contained within carbonate formations which form natural barriers to vertical hydraulic fracture growth

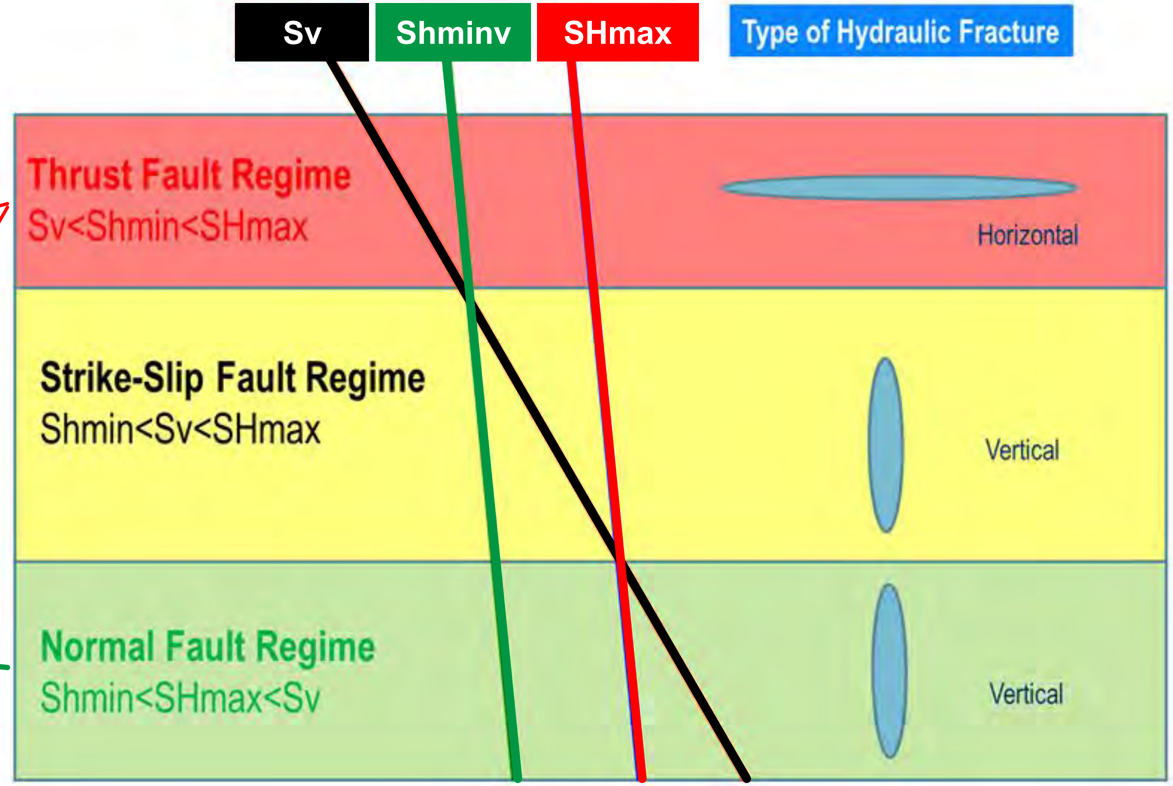
# Theia-1, Geomechanical Earth Model (Schlumberger Analysis)

FINDER EXPLORATION

## Theia-1, sonic data calibrated with core Geomechanical analysis

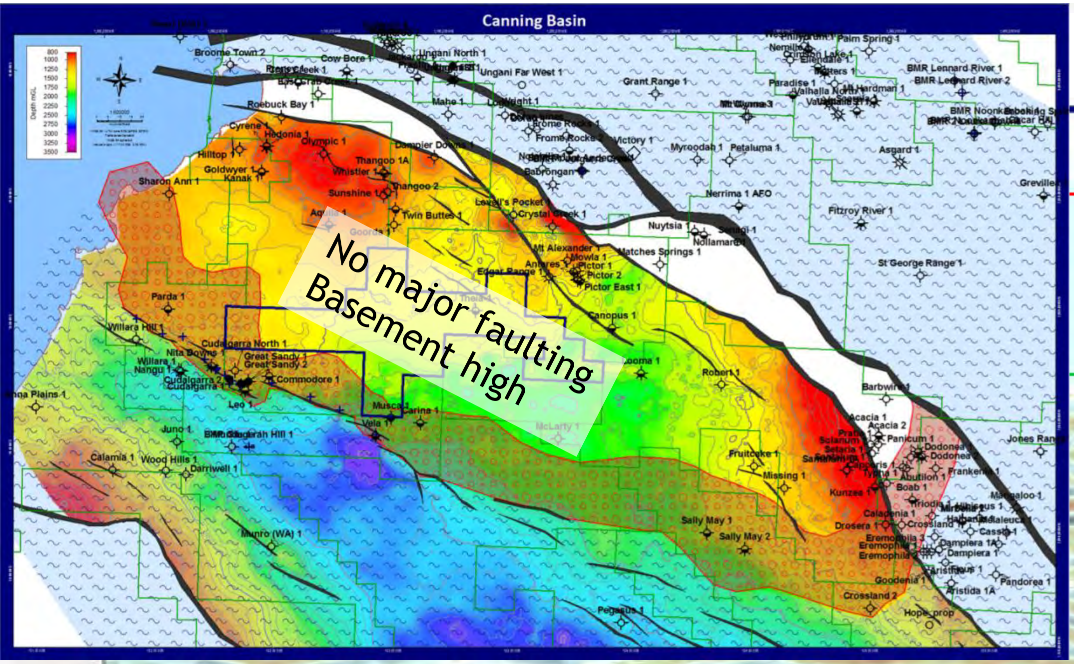



HFS fractures will not propagate through the natural carbonate barriers above and below the target Goldwyer III shale. Carbonates form geomechanical barriers assessed from Theia-1 well data in addition they are impermeable.

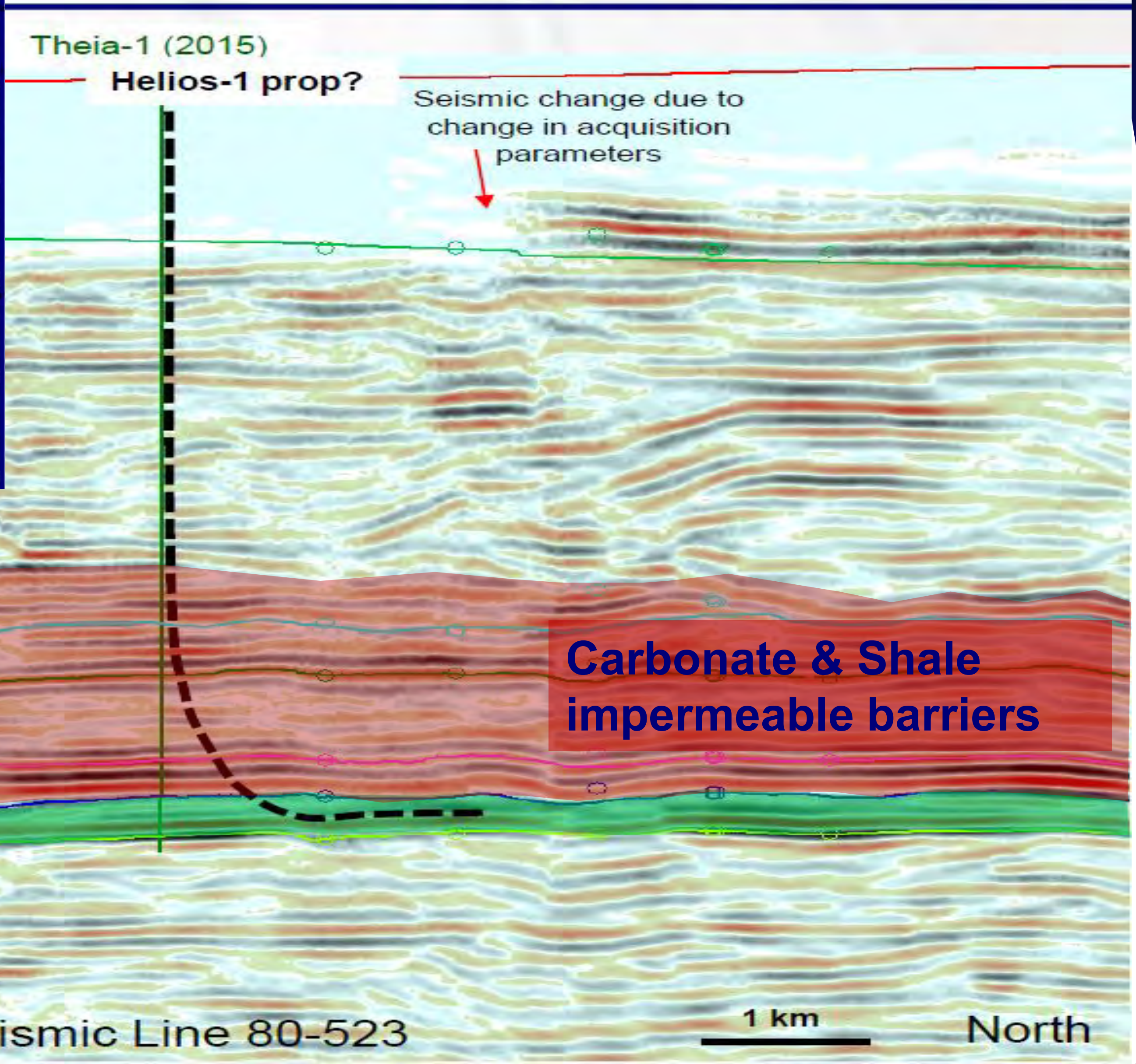


# Prospective area located on basement high (platform) 20km to >100km from major faults

FINDER EXPLORATION



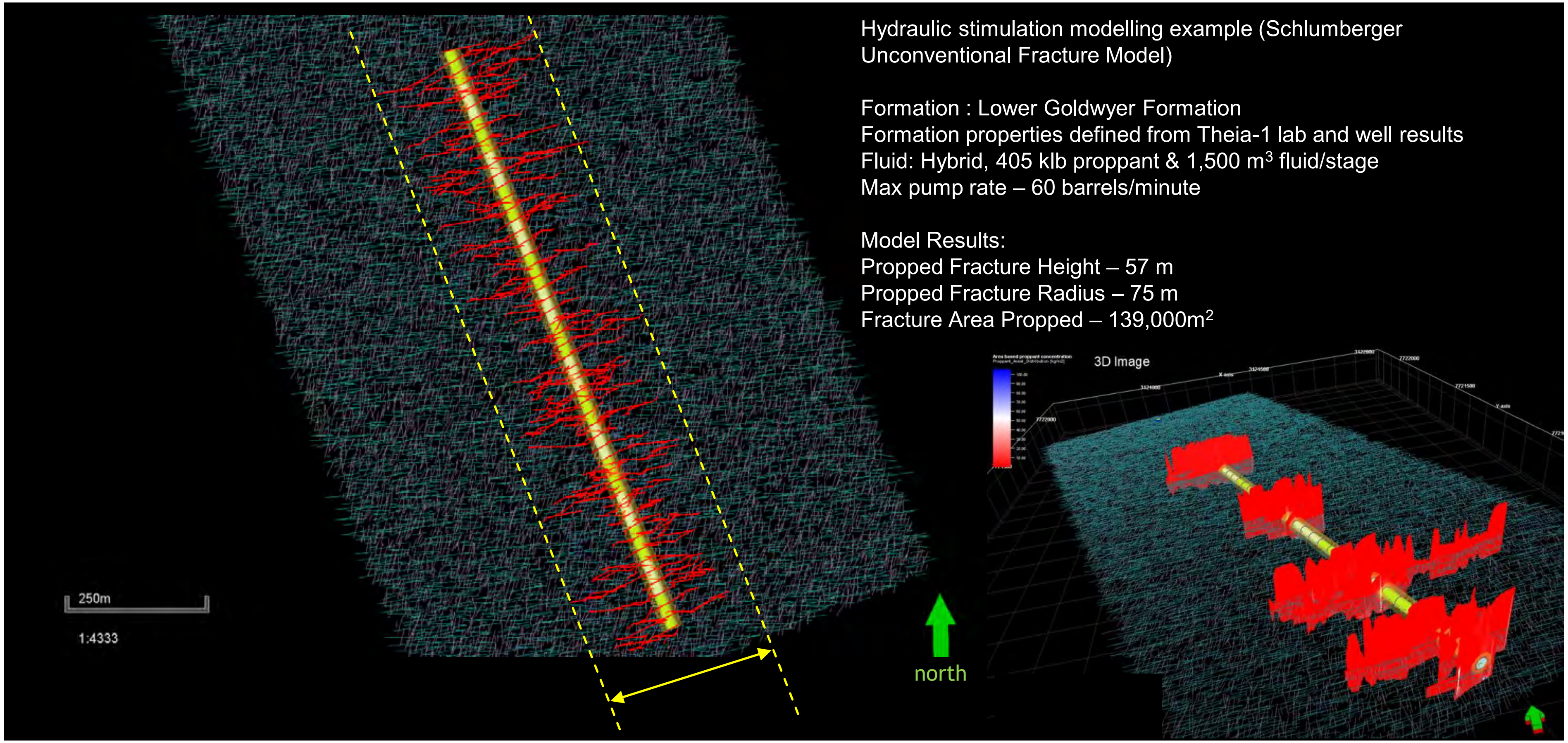

## Seismic Line 80-523



# Great Sandy Desert Project – HFS Modelling

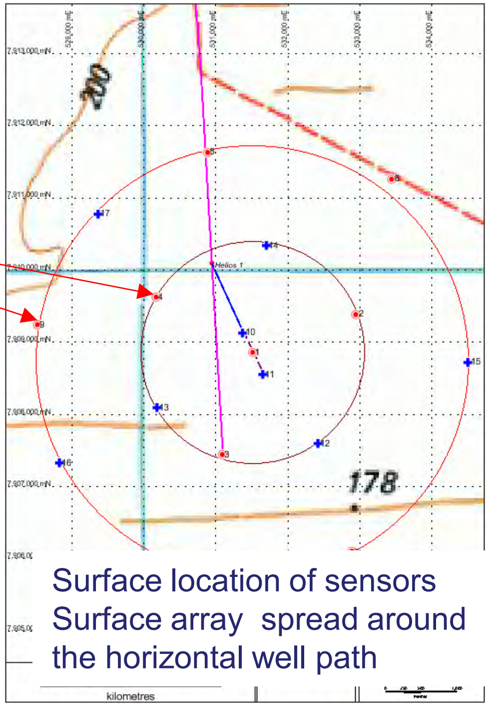
FINDER EXPLORATION

- Schlumberger completed hydraulic fracturing design using Theia-1 data and analysis
- Modelling incorporated parameters such as; horizontal landing point, fluid type selection, cluster spacing, stress interference and total stages/clusters per stage
- More than 13 models evaluated for area/height/length of stimulated zone

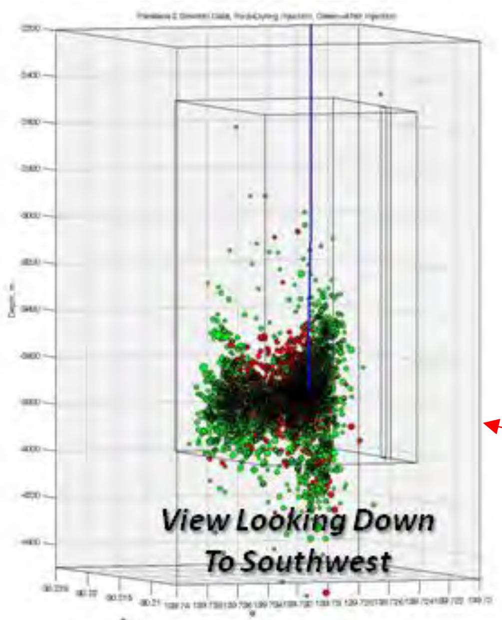


# 3D fracture imaging from micro-seismic monitoring data

2 Hz Oyo Geospace Seismometer



Surface location of sensors
Surface array spread around the horizontal well path




Example of HFS microseismic 3D imaging of HFS fractures

**HFS fractures can be detected and visualised with Micro-Seismic sensors**

A site office contains the central recording facility for the real time monitoring of the HFS fractures. Several geoscientists analyse the data as it comes in and assess the real time propagation of the fractures. Micro seismic events resulting from the fracturing of the sub-surface rocks are recorded, analysed and imaged. This information is then fed back into the HFS main control office which can then be correlated against the real time fluid pumping rates and pump pressure data allowing for real time monitoring of HFS operations.

Example 3D image of the HFS induced fractures are produced from micro seismic recorded data.

Analysis of micro-seismic data and images can then be utilised for planning and optimisation of future hydraulic stimulations.

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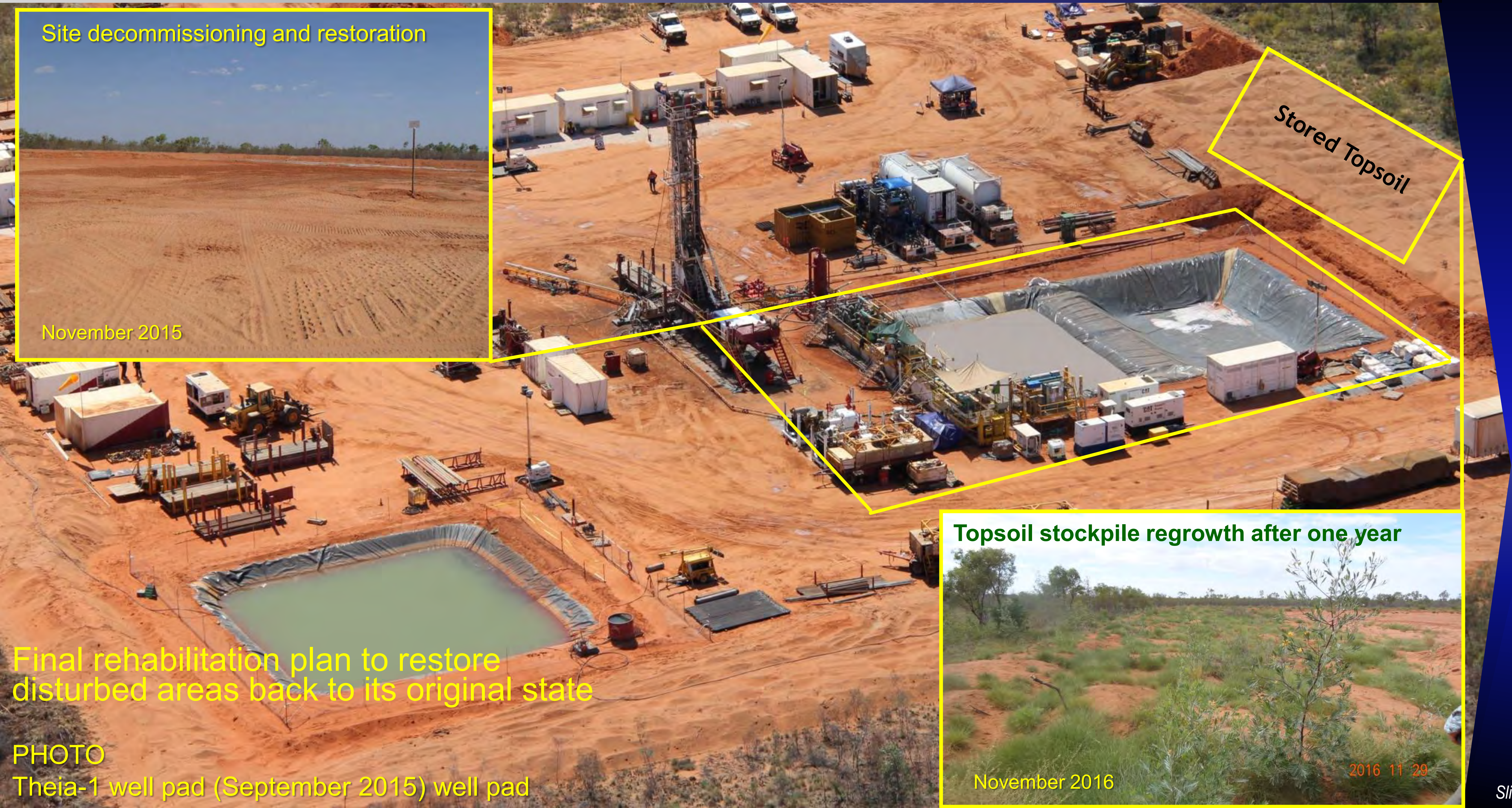
# Environmentally sustainable approach - leave no footprint

FINDER EXPLORATION




Final rehabilitation plan to restore disturbed areas back to its original state

PHOTO
Theia-1 well pad (September 2015) well pad

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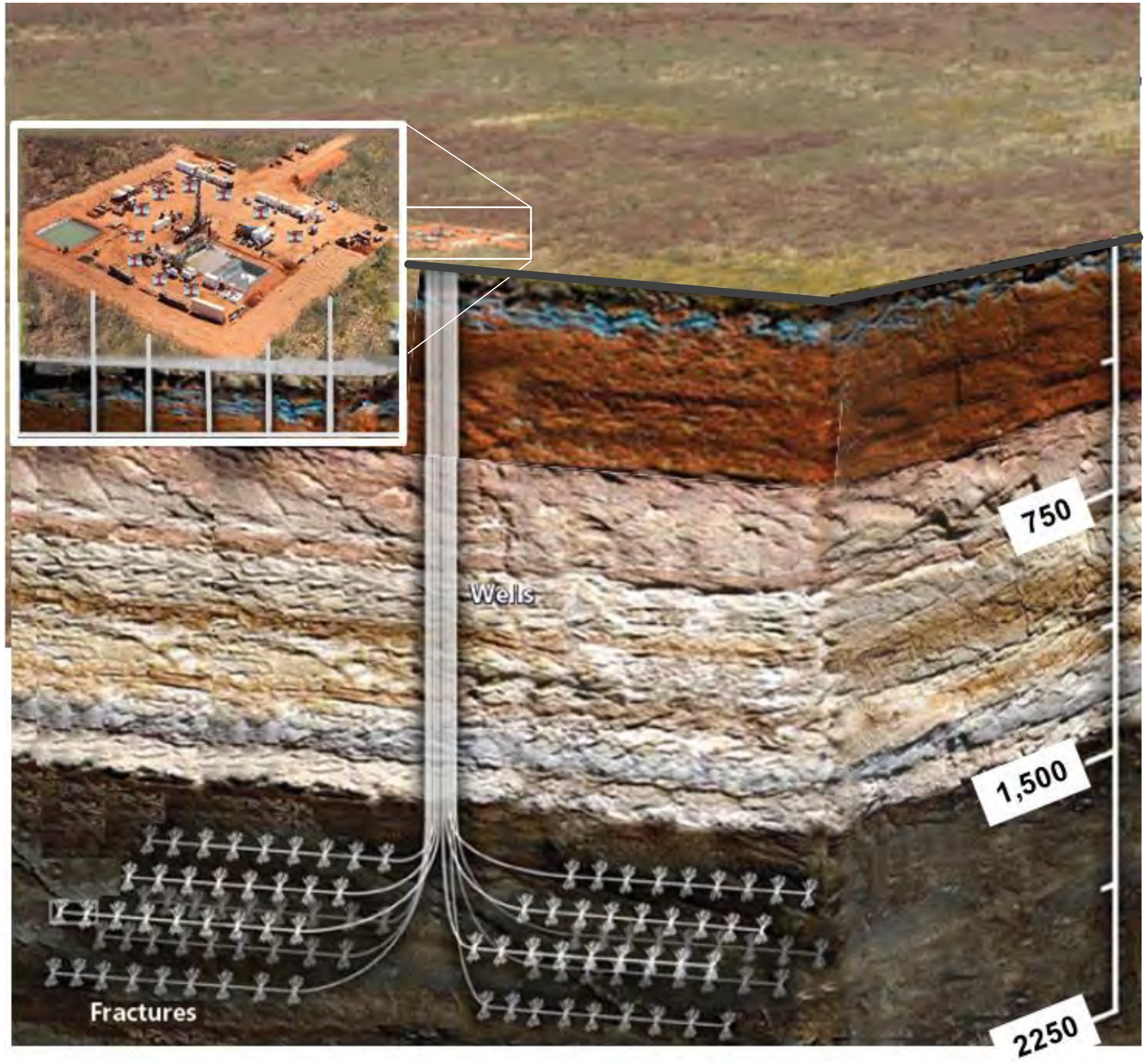
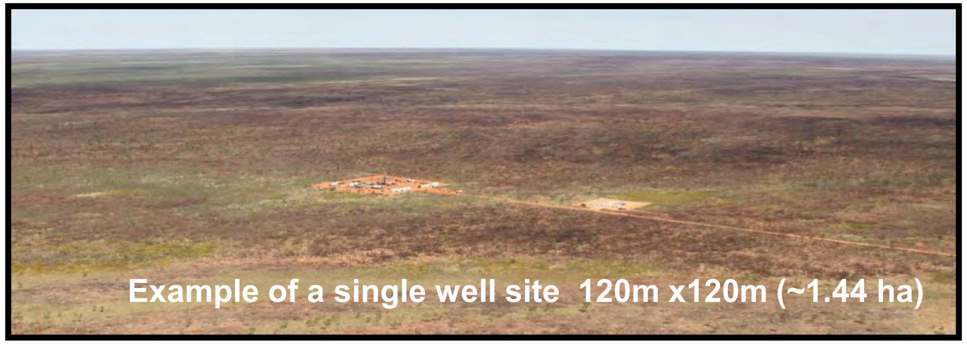
# Sustainable land use - conceptual layout

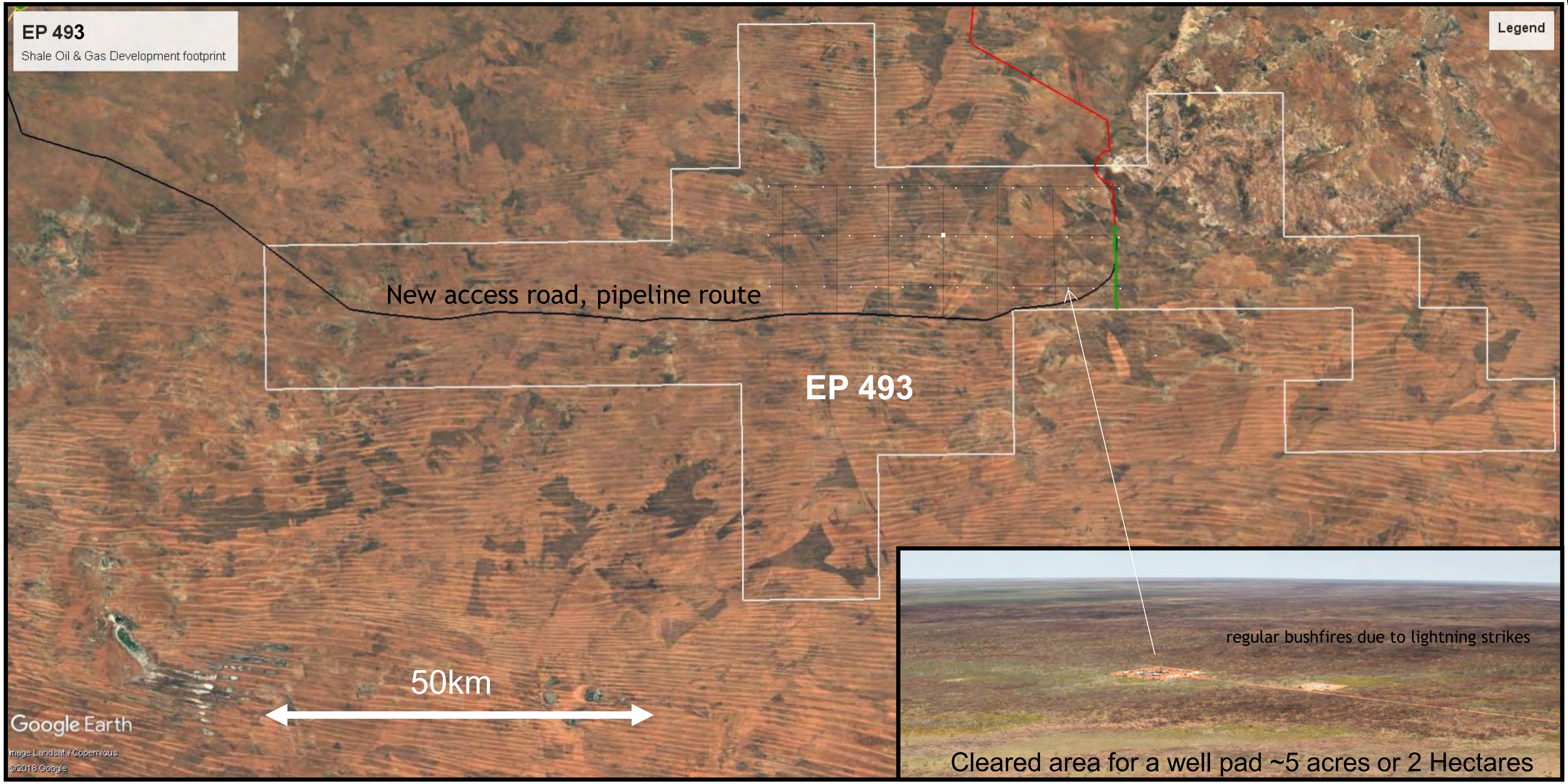



- horizontal drilling and multi wells per pad reduces environmental footprint
- 8 horizontal wells on a single 2ha well site substitutes 36 or more vertical wells
- reduced surface disturbance footprint by 36 times
- less impact to vegetation and fauna
- less disturbance for axillary infrastructure – access roads, pipelines, water storage facilities
- reduced water requirements through reduced well sites and productive re-use of water and wastewater
- better rehabilitation outcomes due to less disturbance



Example of a single well site 120m x120m (~1.44 ha)

# Great Sandy Desert conceptual project development




**Multiple horizontal wells from single pads reducing above ground footprint**

# Development well pad spacing to scale on Perth metropolitan region

FINDER EXPLORATION

# Development well pad spacing to scale on the Wheatbelt


Minimal environmental footprint compared to agriculture

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# Community and social impact (Great Sandy Desert Project)

FINDER EXPLORATION

**Region in and around EP 493**

- no population, no private properties
- no declared conservation significant land, wetlands, national parks or reserves
- no public drinking water source areas and water bores and potable water supplies
- no groundwater users due to no population
- limited groundwater values (not potable)
- limited beneficial use of groundwater due to remote area on Unallocated Crown Land
- no social values such as recreational areas and tourist attractions
- little if any agricultural potential

Tight reservoir oil and gas projects co-exist in populated areas with other land users and industries all the time. In this case a valuable resource happens to be located in a completely undeveloped, remote & arid region of the state.

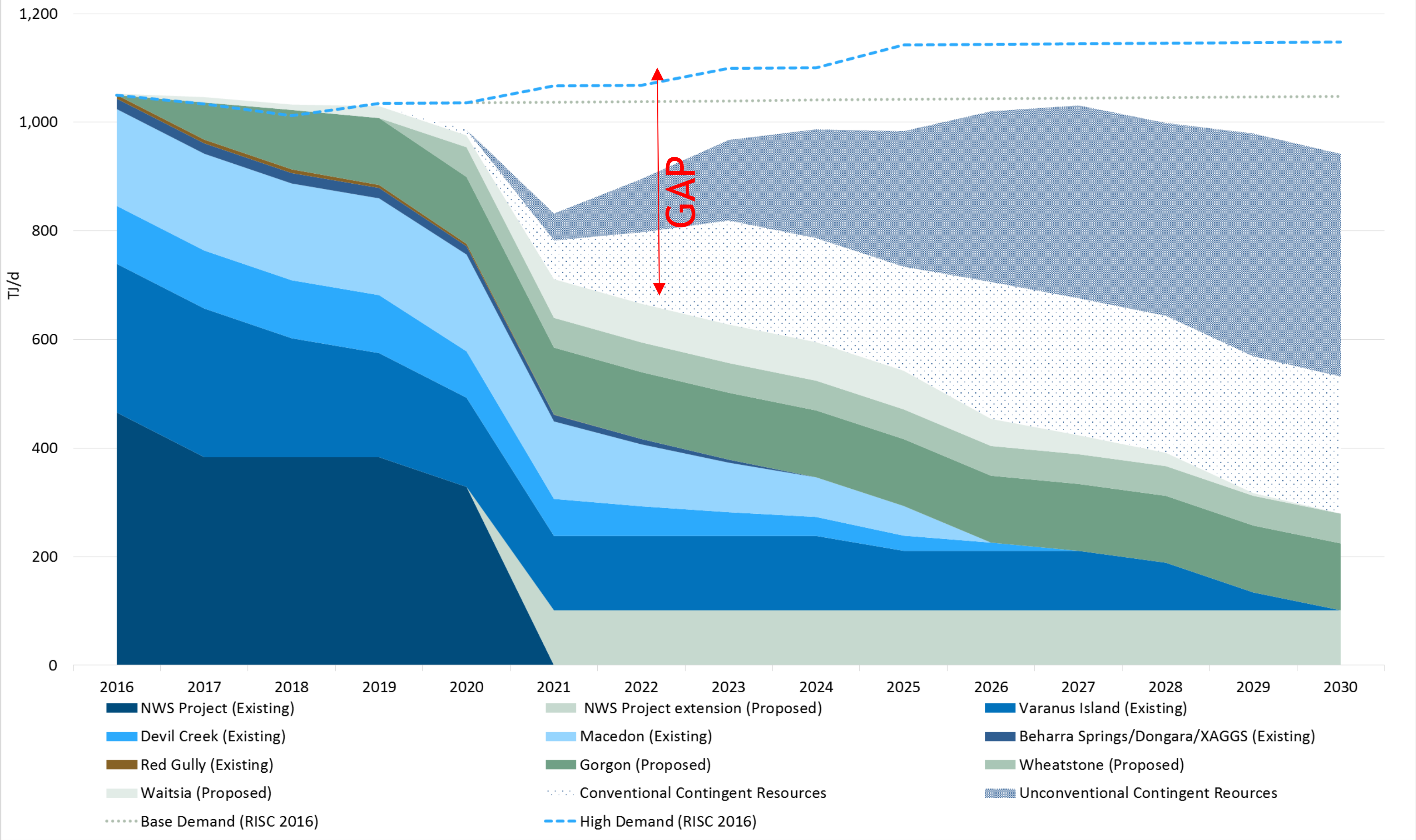
**Benefits**

- Finder have $17Mil invested with plans to invest an additional $35Mil into the Great Sandy Desert shale oil and gas project to prove its viability.
- 5000+ long-term direct and indirect jobs for indigenous and local communities and local businesses
- economic stimulus injected into regional communities such as Broome
- better understanding of the environment from environmental surveys and data collection
- understanding of groundwater aquifers and water quality

# Predicted WA domestic gas supply shortage

## WA domestic gas security of supply

The gap in the supply of gas needed to meet WA domestic demand in 2021 and beyond can potentially be filled through gas from the Great Sandy Desert project.



# Significantly reduce Australia's dependency on foreign oil imports

FINDER EXPLORATION

The Great Sandy Desert project would deliver onshore domestic oil supply of national importance.

Defence White Paper 2016: Dependency on fuel imports 'a risk' amid South China Sea tensions

Jim Molan, former military chief turned NSW senator, issues stark warning over defence capabilities.

- Australia's defence forces could be grounded within weeks of an attack due to a desperate lack of fuel reserves.

Air Vice Marshal (Retired) John Blackburn has focused attention on the energy security shortfall for Australia for some time:

- As an island continent at the bottom of the Asia Pacific region, Australia is heavily dependent upon liquid energy imports and with a rapidly disappearing domestic refinery production capacity, these imports necessarily are with regard to refined end products as well.

Great Sandy Desert Goldwyer III shale oil is a high quality light crude oil 45$^{o}$ (**API gravity of Diesel Fuel is 40$^{o}$ to 45$^{o}$)** which could be refined at minimal cost providing a NW Australian source of domestic transport fuel.

Shale oil and gas projects create a diverse range of **jobs** and need a **diversity of people** and supporting **businesses** to make them successful

FINDER EXPLORATION

**Jobs**

- Kitchen hands & cooks
- Logistics and supply chain managers
- HSE officers and managers
- Truck and bus drivers
- Mechanics
- Environmental specialists
- Indigenous Rangers
- Indigenous heritage inspectors
- Anthropologists
- Administrators

**Service companies**

- Environmental consultants
- Accommodation camp supplies
- Food and provisions
- Civil Engineering
- Well construction engineers

**Jobs**

- Flora & Fauna specialists
- Reservoir engineers
- Geologists
- Geophysicists
- Geochemists
- Chopper pilots
- Surveyors
- Petrophysicists
- Drilling crews
- HFS teams
- Electricians

**Service companies**

- Drilling
- Drilling services
- HFS services
- Seismic
- Proppant supply

**Jobs**

- Pipeline and facility construction crews
- Human resources personnel
- Water bore drilling teams
- Laboratory technicians
  - Water sampling
  - Core analysis
  - Waste analysis
- IT specialists
- Lawers
- Accountants
- And the list goes on and on…

**Service companies**

- Tank storage manufacturing
- Pipeline/facilities construction
- HC processing and refineries
- Transportation
- Maintenance
- Health

# Great Sandy Desert Project (EP 493) – Shale oil and gas

FINDER EXPLORATION

1. Background, location & shale play model
2. Well planning and WA state regulatory approvals
3. Groundwater usage and waste management
4. Well construction, well integrity
5. Below ground geological setting and HFS risk assessment
6. Well site remediation and site rehabilitation
7. Project development utilising current horizontal multi well pad drilling methods
8. Community and Social Impact
9. Finder Concerns

# Finder Concerns

- **Domestic oil and gas security.** The Great Sandy Desert project could fill the projected 2021 WA domestic gas supply shortage ensuring the energy crises seen in the East cost is not replicated in WA. Unnecessary delays are concerning as the lead time to develop a project and deliver domestic oil and gas is about 6 years.
- **Overregulation.** In Western Australia we are highly regulated and the concern is the outcome of this current inquiry and political process will result in further increases in regulation adding to the cost and further delay or stop projects from being developed. For example a standard onshore well in Canada is approved in less than a week, in WA the timeframe is 4 to 6 months.

# Finder Exploration Contact Details

**For further information on the Great Sandy Desert Project:**


**Ryan Taylor-Walshe**
**Manager - Onshore**

**Lana Volkova**
**Senior Environmental Engineer**

**Jan Ostby**
**Director**

**Finder Exploration Pty Ltd**
[redacted]

[redacted]


*PHOTO - EP 493 – Theia-1 operations - Great Sandy Desert, WA – September 2015*

Attachment #2 – Theia-1 Geomechanics Report

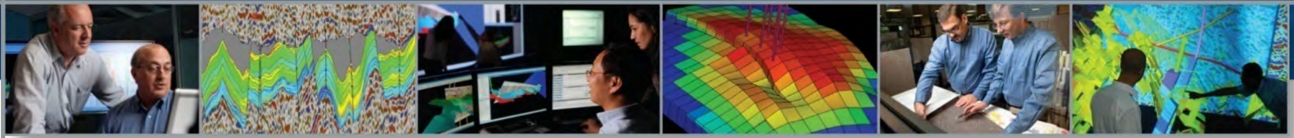
Finder Exploration

# Geomechanics Analysis for Theia-1 (Calibrated with Core Data)

Schlumberger SIS Geomechanics

14 Mar 2016

Ver. 5.0



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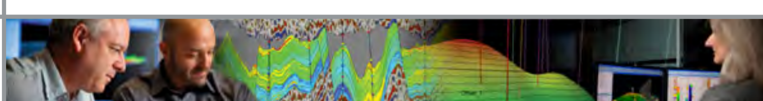


# Event History, Document Version, People Involved:

| Version | Event | Date | Description | Prepared by | Reviewed by |
|---|---|---|---|---|---|
| 1.0 | Presentation | 20 Jan 2016 | Discussions with AB and RW on observations from input data | SH | ZJ |
| 4.0 | Presentation | 16 Feb 2016 | Presentation | SH | ZJ, CT |
| 5.0 | Email | 14 Mar 2016 | Few corrections were applied on presentation file. | SH | ZJ |

**Project Engineers:**

Geomechanics Engineer: Saeed Hafezy (SH)

**Project Reviewers:**

Geomechanics Team Lead: Zach John (ZJ)

Geomechanics Advisor: Dr. Chee Tan (CT)

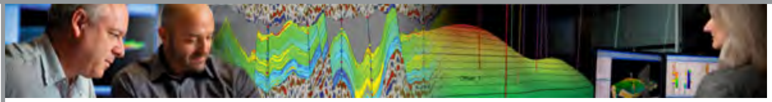
**Client Representatives:**

Senior Geoscientist: Aaron Bond (AB)

Chief Operating Officer: Ryan Taylor-Walshe (RW)

# Outline

- Executive Summary
- Data Audit
- Stress Orientation and Magnitude
- 1D Mechanical Earth Model (1D MEM) and Wellbore Stability Analysis (WBS)
    - Vertical Stress and Pore Pressure
    - Rock Mechanics Test & Mechanical Properties
    - 1D MEM Validation
    - Effect of Elastic Anisotropy on Horizontal Stress
- Bedding Plane Failure
- Observations
- Recommendations
- Way Forward



# Project Background

- Finder Exploration drilled exploration well **Theia-1** in July to August 2015.
- **Theia-1** is located in Canning Basin targeting Goldwyer Shale formation.
- **Theia-1** showed indications of oil shale reservoir in Goldwyer III Member (Lower Goldwyer)
- This Geomechanics study is part of a larger study consisting of Reservoir Quality (RQ) ,Completion Quality (CQ), Hydraulic Fracture simulation and Production Forecasting.

# Project Objectives

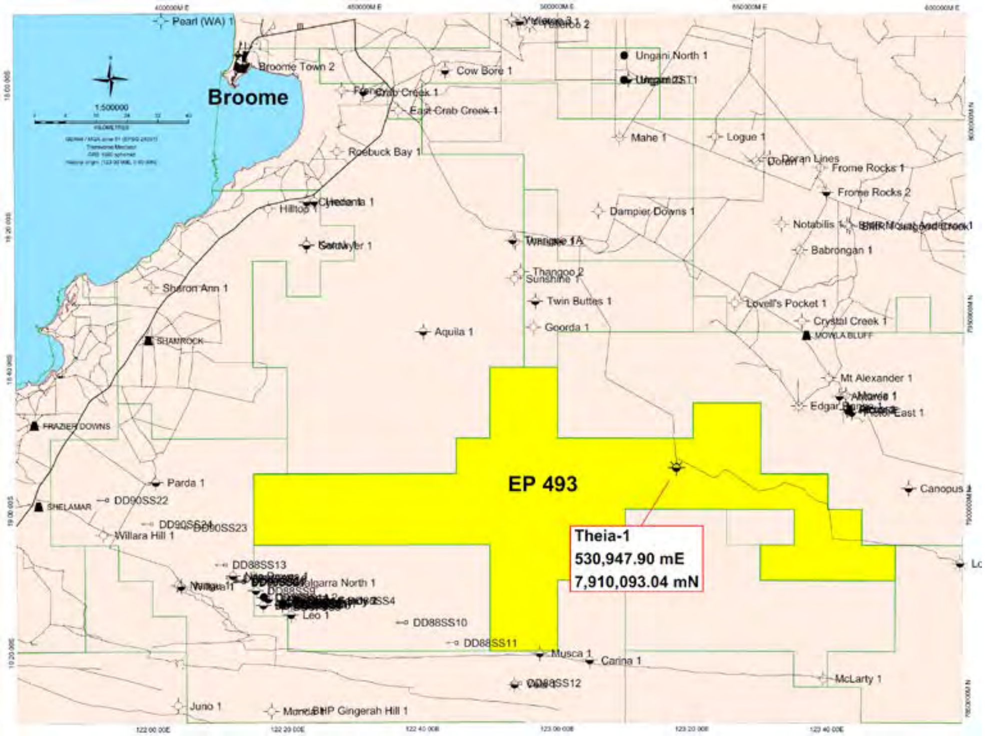
To conduct post-drill review for:

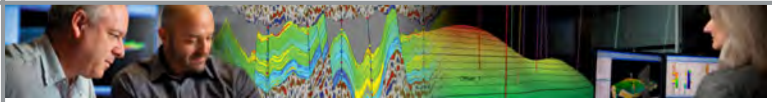
- Completion Quality characterization (CQ)

and to provide:

- 1D Mechanical Earth Model (1D MEM)
- Wellbore Stability (WBS) analysis

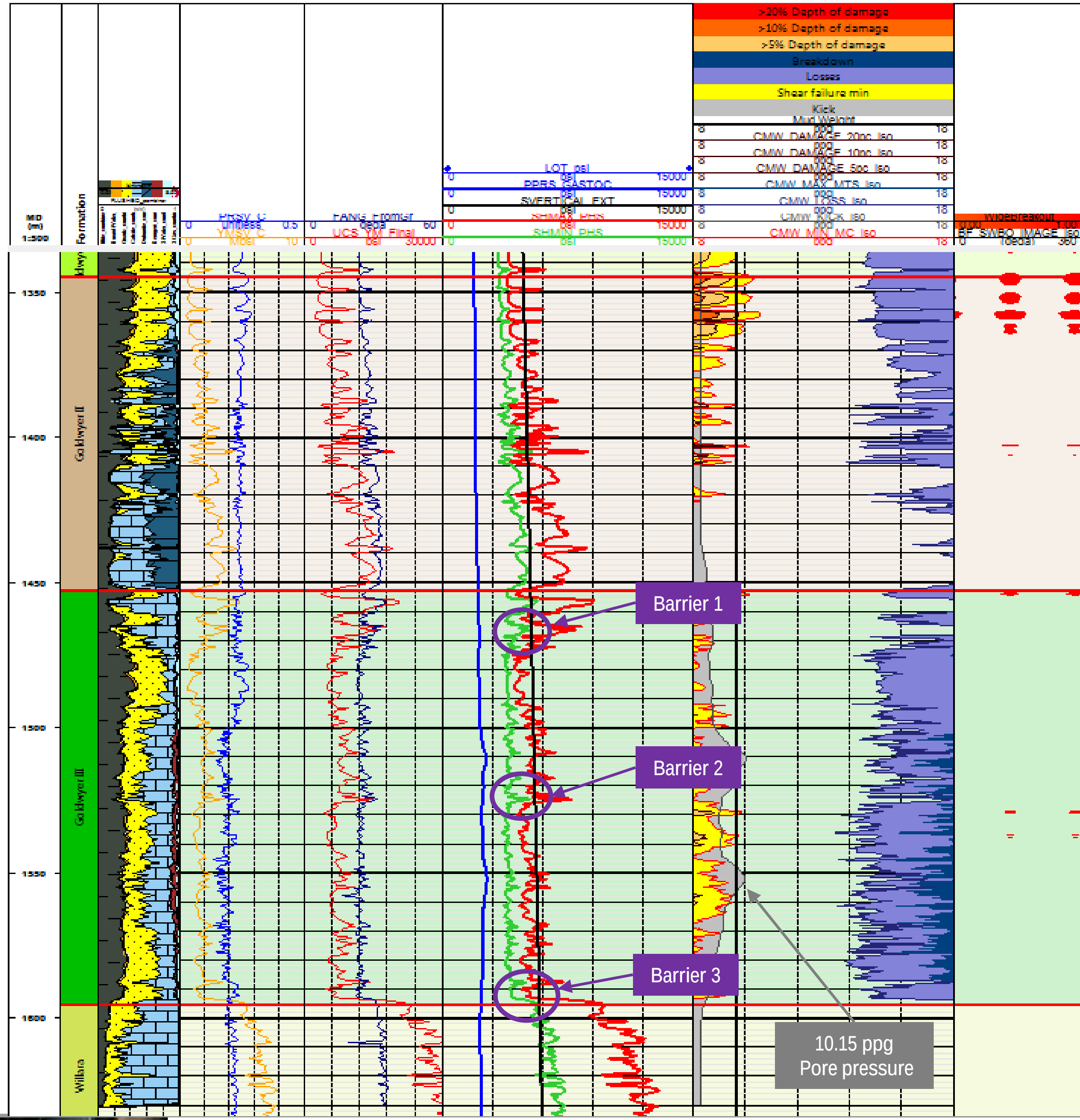
for **Theia-1** to be used for hydraulic fracture design optimization and production forecasting.

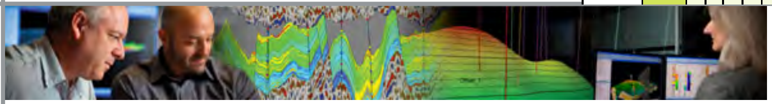


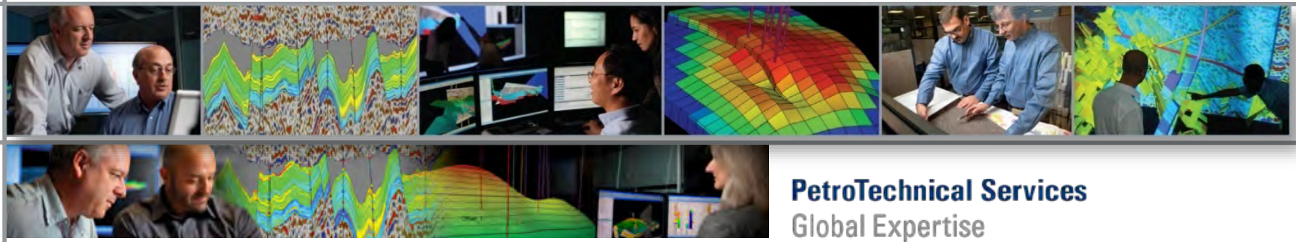
# Executive Summary

- There are clear indications of overpressure in Goldwyer III formation. In this formation maximum pore pressure is estimated to be around 10.15 ppg.
- In Goldwyer III formation, the horizontal stress profiles indicate that there are three possible stress barriers to vertical hydraulic fracture growth.



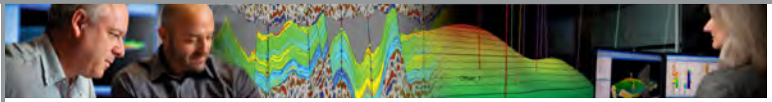



# Data Audit



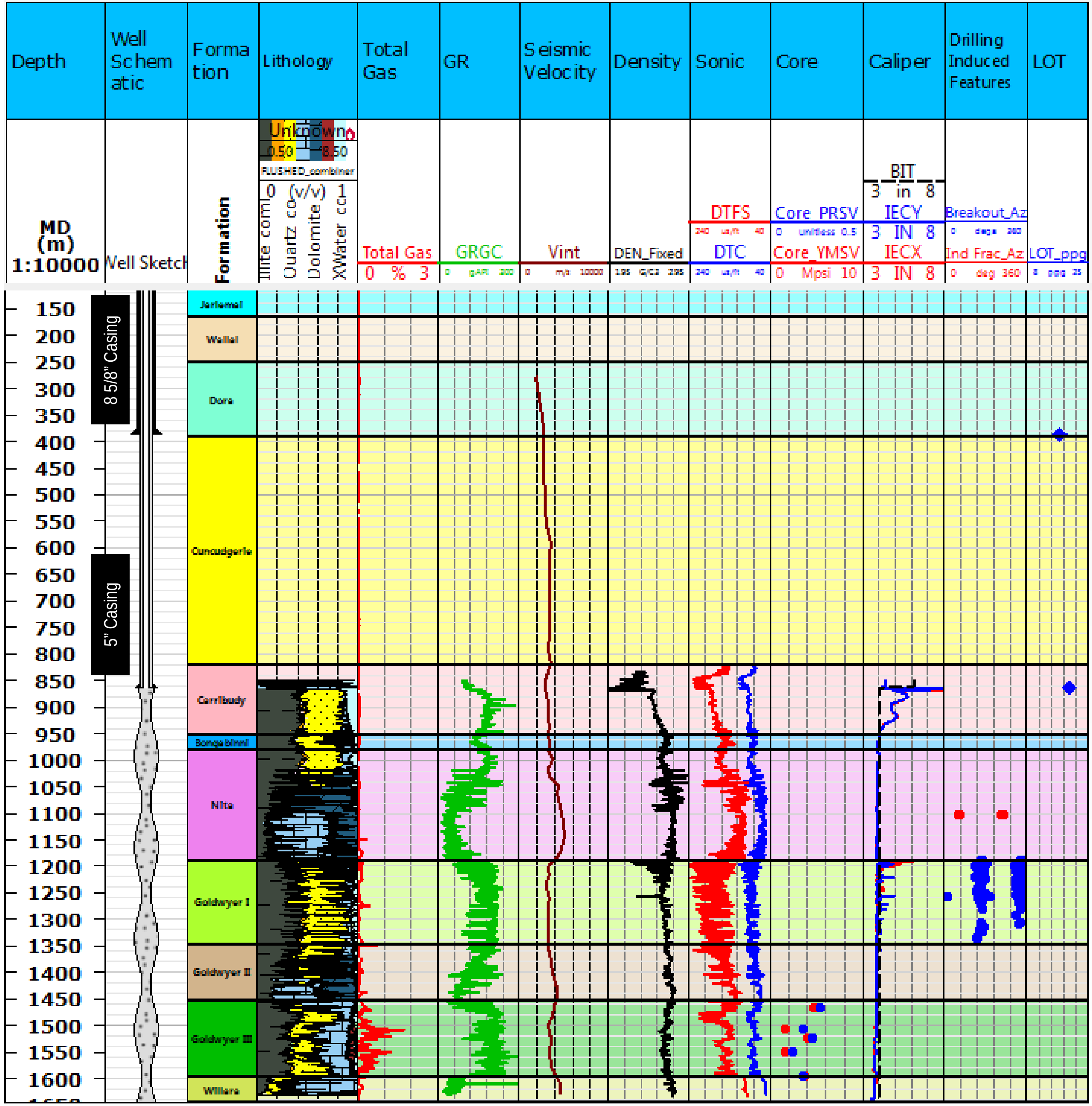
# Data Availability

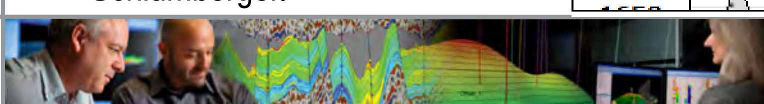
| Number | Data Item | Provider | Availability |
|---|---|---|---|
| 1 | Sonic DT Compressional, Shear and Stoneley | Weatherford | Y |
| 2 | Neutron, Density, Resistivity, GR and Caliper Log | Weatherford | Y |
| 3 | Borehole Image Log | Weatherford | Y |
| 4 | Petrophysical Analysis | Schlumberger | Y |
| 5 | Formation Pressure Data | - | X |
| 6 | Leak Off Test | Weatherford | Y |
| 7 | Well Trajectory - Survey | Weatherford | Y |
| 8 | Daily Drilling Report | Finder | Y |
| 9 | Daily Geological Report | Finder | Y |
| 10 | End of Well Report | Weatherford | Y |
| 11 | Gas Log | Weatherford | Y |
| 12 | Mud Log | Weatherford | Y |
| 13 | Core Data and Rock Mechanics Test Data | Weatherford | Y |
| 14 | Image Log Interpretion | Task Frontier | Y |
| 15 | Formation Tops | Finder | Y |
| 16 | Well Location Map | Finder | Y |



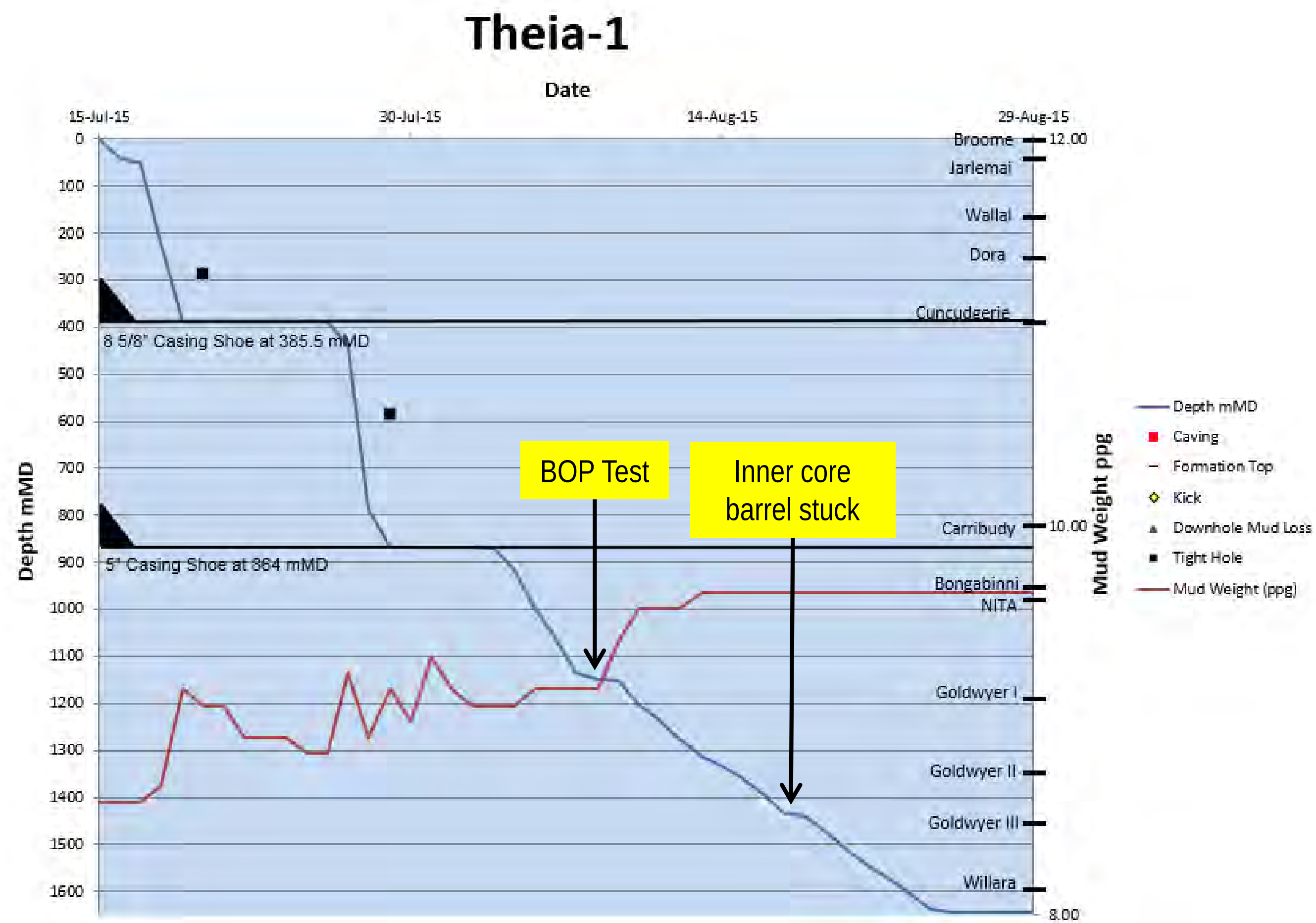
# Data Availability

- Petrophysical analysis data are used as input to develop rock properties models.
- Surface seismic velocity is used for vertical stress calculation.
- GR, density, sonic, calipers and petrophysical analysis data are available for open hole sections.
- Initial density log was reading high due to wrong calibration. Density log is corrected by Weatherford and corrected density (DEN_Fixed provided 15-Jan-16) is used for this analysis.
- Rock mechanics core test data are available for Goldwyer III and Willara formations.
- No pump data are available for both leak-off tests. Only pressure vs. time data are available.
- Borehole features were picked by Task Frontier and some additional breakouts were picked by Schlumberger.

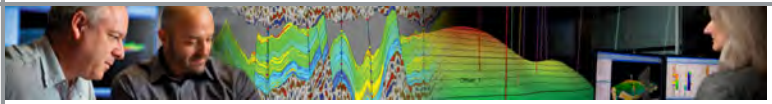


# Drilling Events Plot

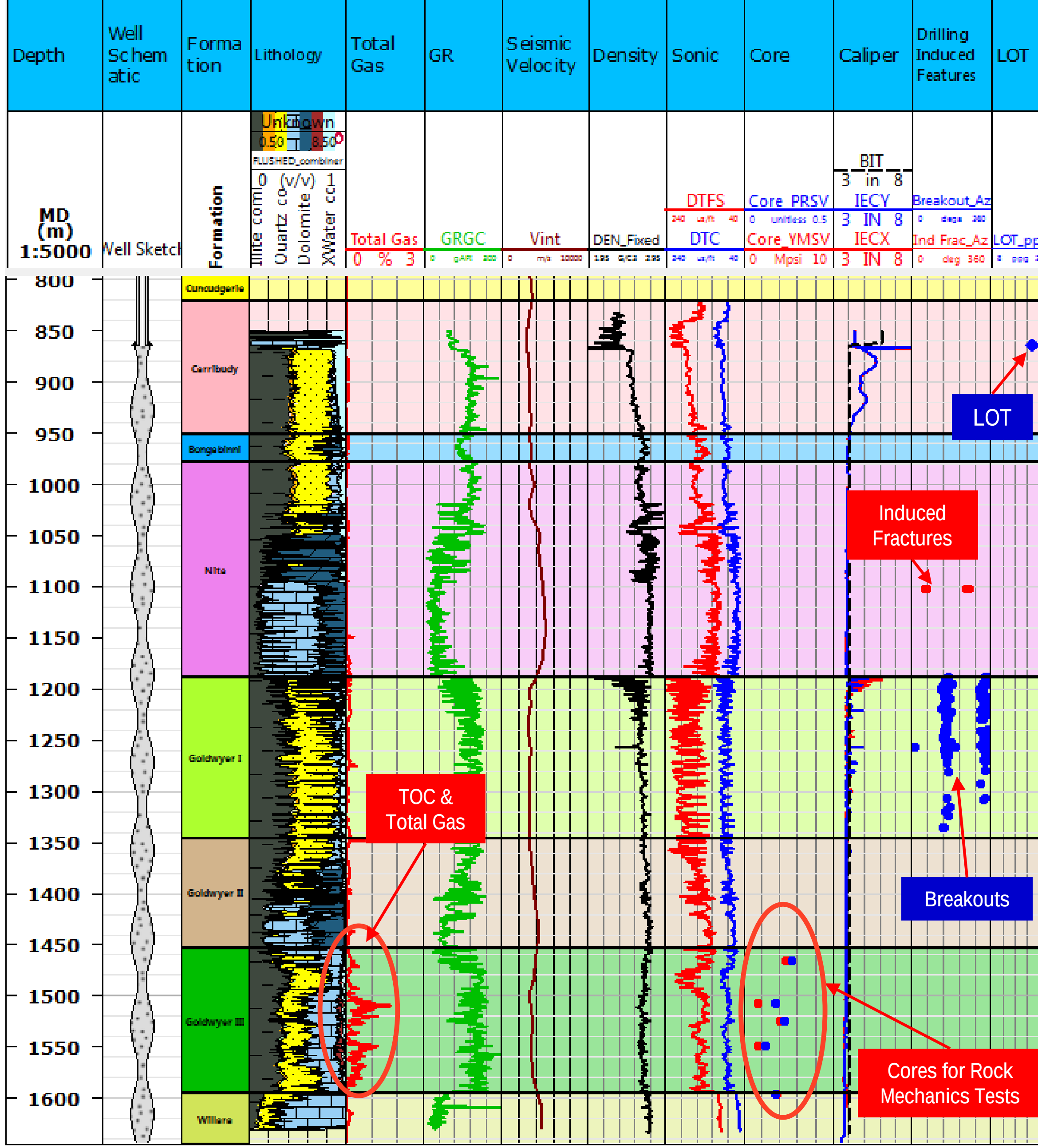


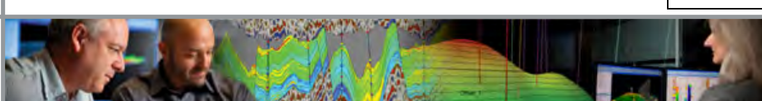

- Few tight holes are observed in Cuncudgerie Formation.
- No significant drilling events (cavings, kicks or mud losses) were observed in DDR.



# Observations

- **Calipers:** Calipers show washouts below casing shoe and breakouts in Goldwyer I. Other intervals show good borehole condition. Cross-arm Calipers show under-gauged hole size close to TD but Density Calipers show correct hole size at TD.
- **Drilling-induced Features:** Borehole breakouts were observed in Goldwyer I from borehole image interpretation results. Few low quality drilling-induced fractures were observed over one meter interval in Nita.
- **Gas Data:** Total gas increase is observed in lower section of GW II and entire GW III.
- **Leak-off Test (LOT):** There is low confidence on leak-off pressure due to lack of pump data.
- **Rock Mechanics Test Data:** Rock mechanics test data are used for calibration for elastic and strength properties, elastic anisotropy and bedding plain failure analysis.
- **Sonic Processing:** Fast shear azimuth from sonic processing is used to cross-check the direction of maximum horizontal stress.





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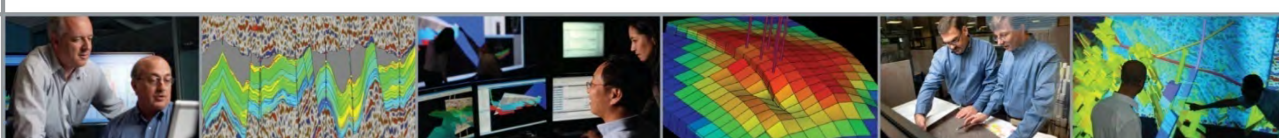
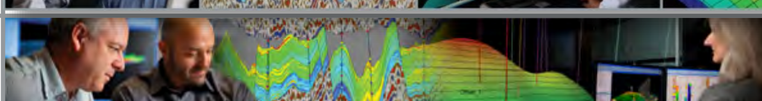
# Stress Orientation





# Borehole Features*

Drilling-induced Failures:

- Borehole breakout (BO): BOs from image log interpretation were picked in Goldwyer I. The hole has BOs especially in the upper section of Goldwyer I. Drilling-azimuth of BOs is generally N160 deg E.
- Drilling-Induced Fractures (DIF): Low quality DIFs were observed in Nita formation from 1,101.5 to 1,102.5 mMD. Azimuth of the DIFs is generally N70 deg E.

Natural Fractures and Faults (NF):

- NF do not show a specific orientation.

* Borehole Image Log interpretation results were provided by Task Frontier.

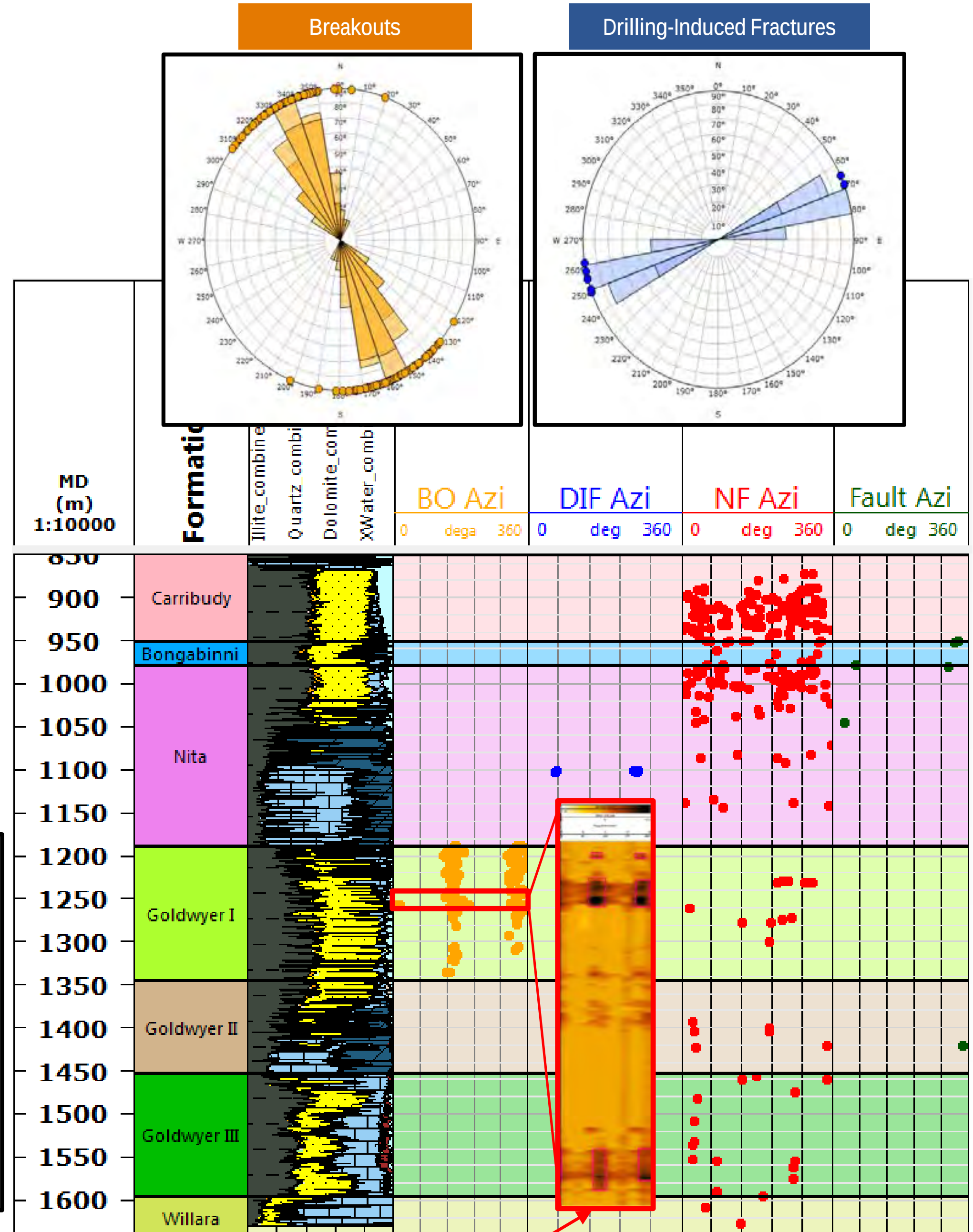
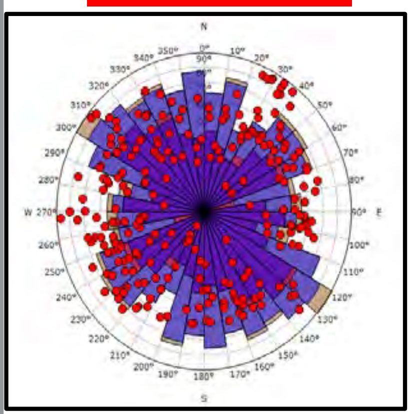
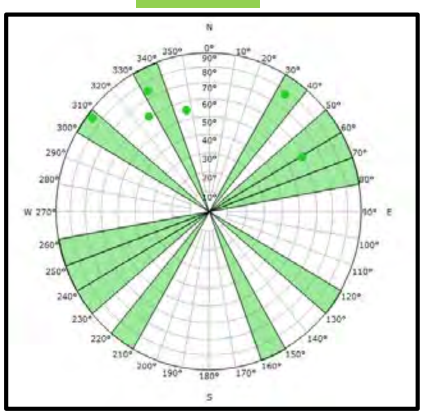


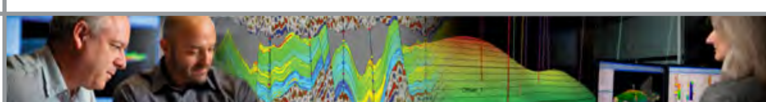

Image from Weatherford

Natural Fractures



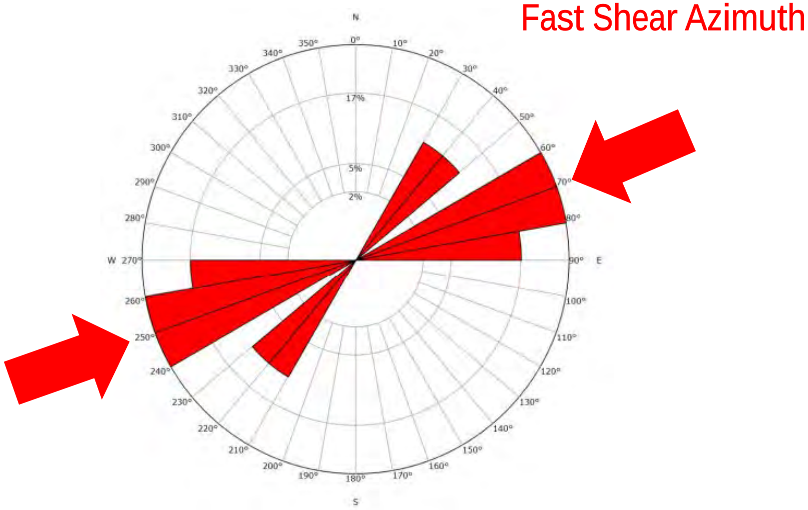
Faults

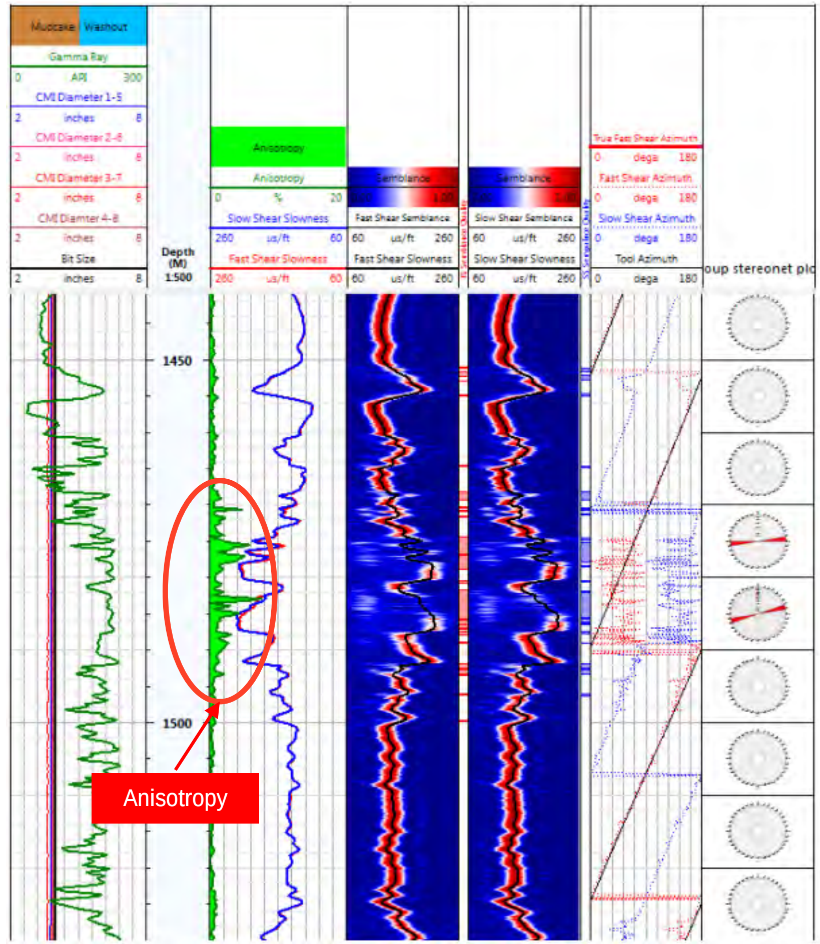




# Observations from Sonic Processing (Energy Difference)*

- Fast Shear Azimuth from sonic processing is generally N70 deg E. This orientation may be as the azimuth of maximum horizontal stress.



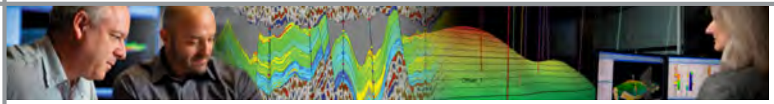




Reference: Theia-1 CXD Anisotropy Processing Result, Weatherford.

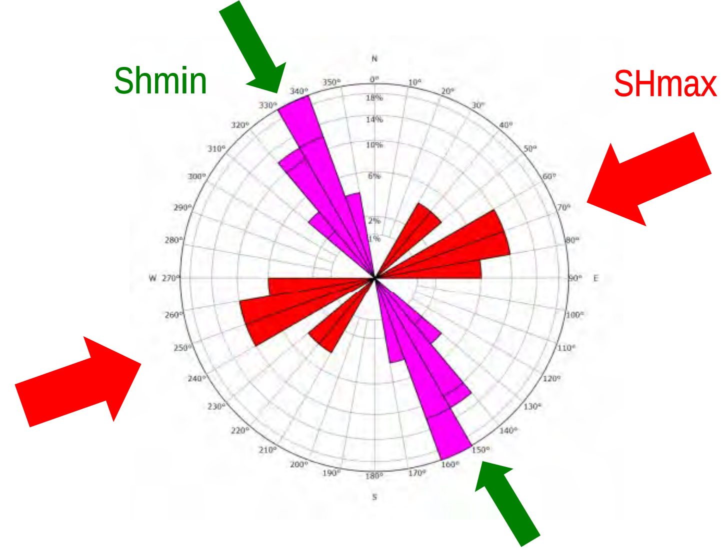
- Observed shear anisotropy from sonic is small.
- Average shear anisotropy is less than 1% and maximum shear anisotropy is approximately 6%.
- Stoneley shear is used for anisotropic stress model.

* Fast Shear Azimuth from sonic processing is provided by Weatherford.



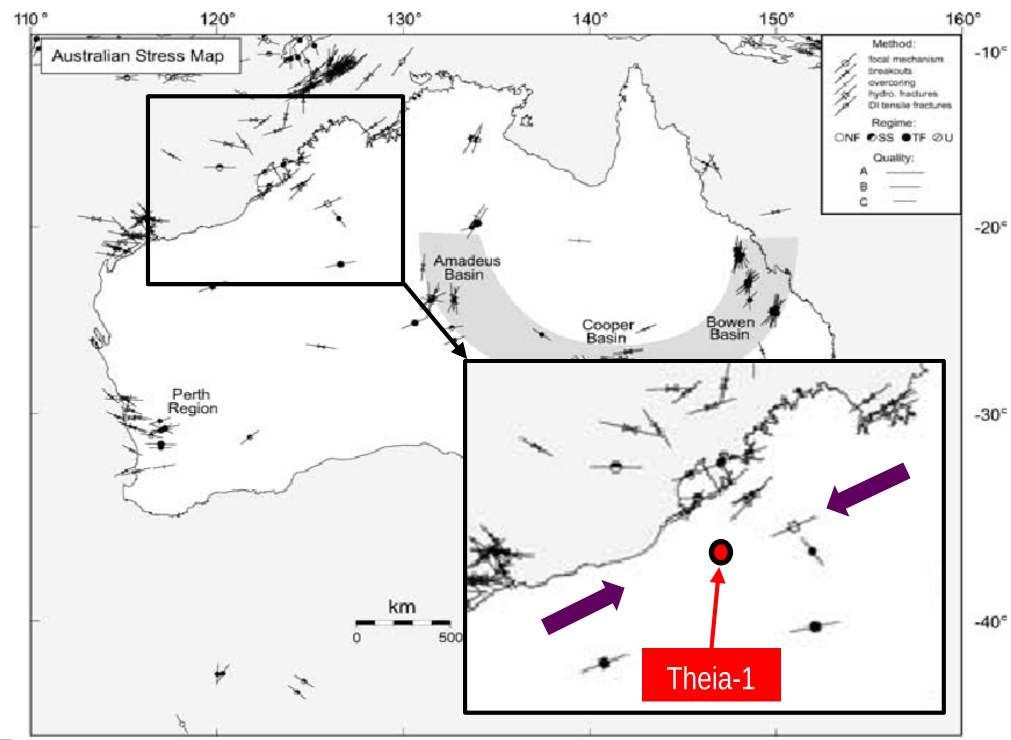


# Stress Orientation



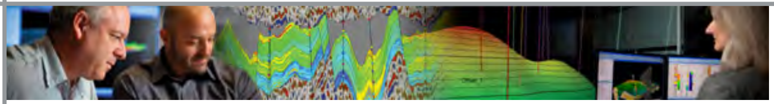

1. Possible SHmax Azimuth from Sonic Anisotropy (Energy Difference):
Fast Shear Azimuth orientation from sonic processing is generally N70 deg E. This orientation is indication of maximum horizontal stress direction.

2. SHmax Azimuth from Borehole Image logs:
Breakout orientation is generally N70 deg E based on borehole image log interpretation. This is consistent with regional stress orientation and Fast Shear Azimuth from sonic processing.

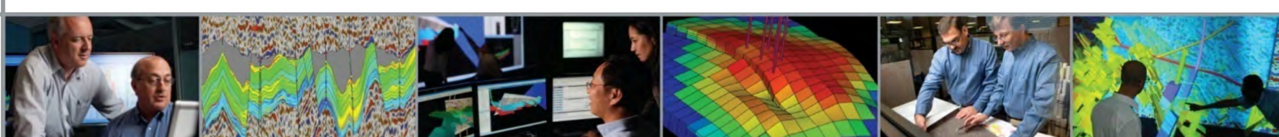


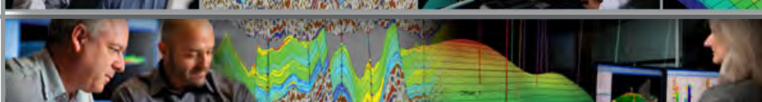

**SHmax Azimuth: N70 deg E**

Reynolds, S.D., Mildren, S.D., Hillis, R.R., Meyer, J.J., Flottmann, T.,2005. Maximum Horizontal Stress Orientation in the Cooper Basin, Australia: Implications for Plate-Scale Tectonics and Local Stress Source. Geophys. J. Int. 160, 331–343.



# Stress Magnitude





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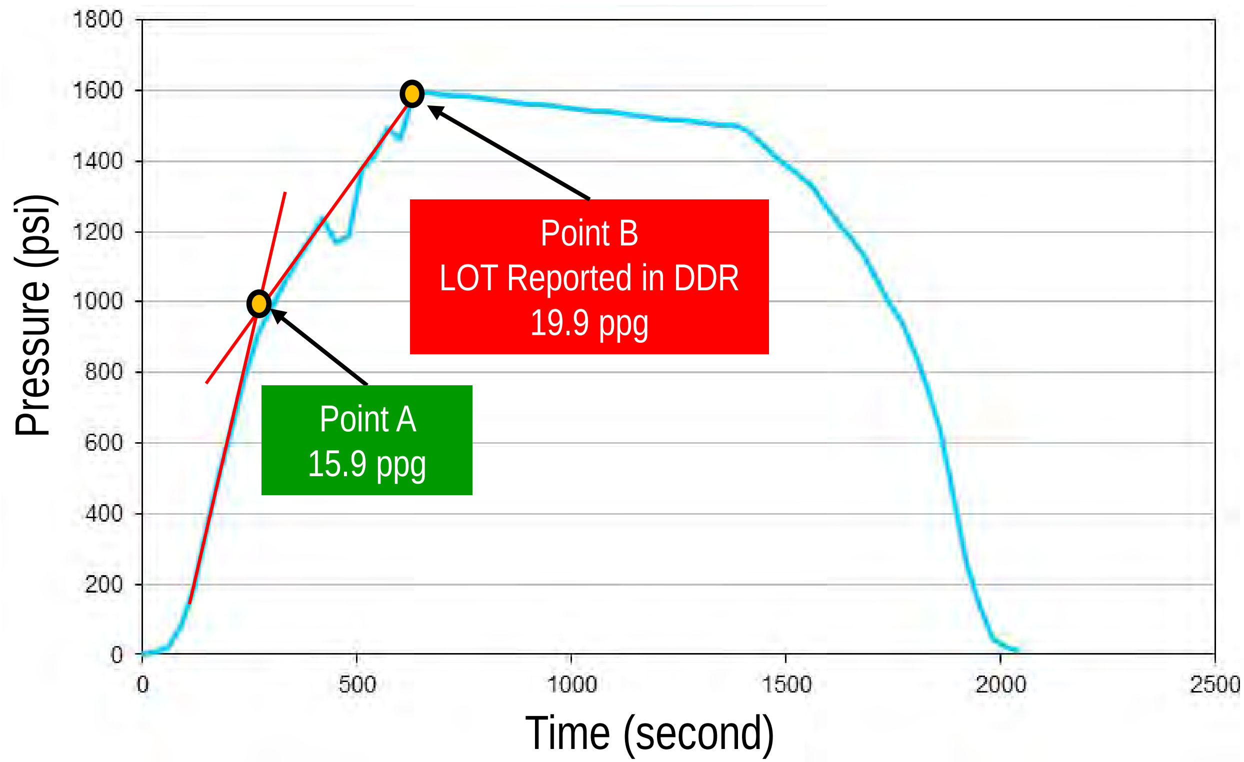
# LOT at 864m (5” Casing Shoe)

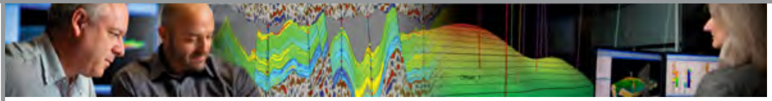
LOT:
TVD = 864 m
Mud Weight = 9.1 ppg

Point A:
Surface Pressure = 990 psi
EMW Surface Pressure = 6.8 ppg
LOPA = 6.8 + 9.1 = **15.9 ppg**

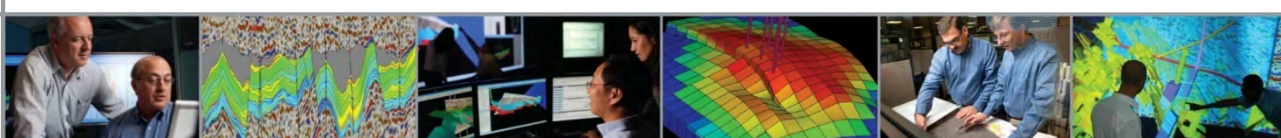
Point B (Reported in DDR):
Surface Pressure = 1590 psi
EMW Surface Pressure = 10.8 ppg
LOPB = 10.8 + 9.1 = **19.9 ppg**

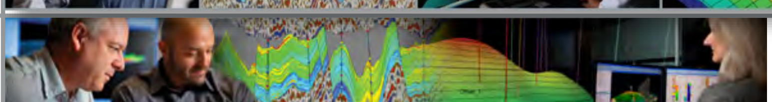



- No LOT is available at similar depth in offset wells (Cyrene-1, Leo-1, Looma-1, McLarty-1, Nicolay-1, Willara-1).
- In absence of pump data, interpretation of LOP from LOT has significant uncertainty as inflection at Point A could be due to pump rate change.
- Point A is the likely LOP value if pump rate is constant.

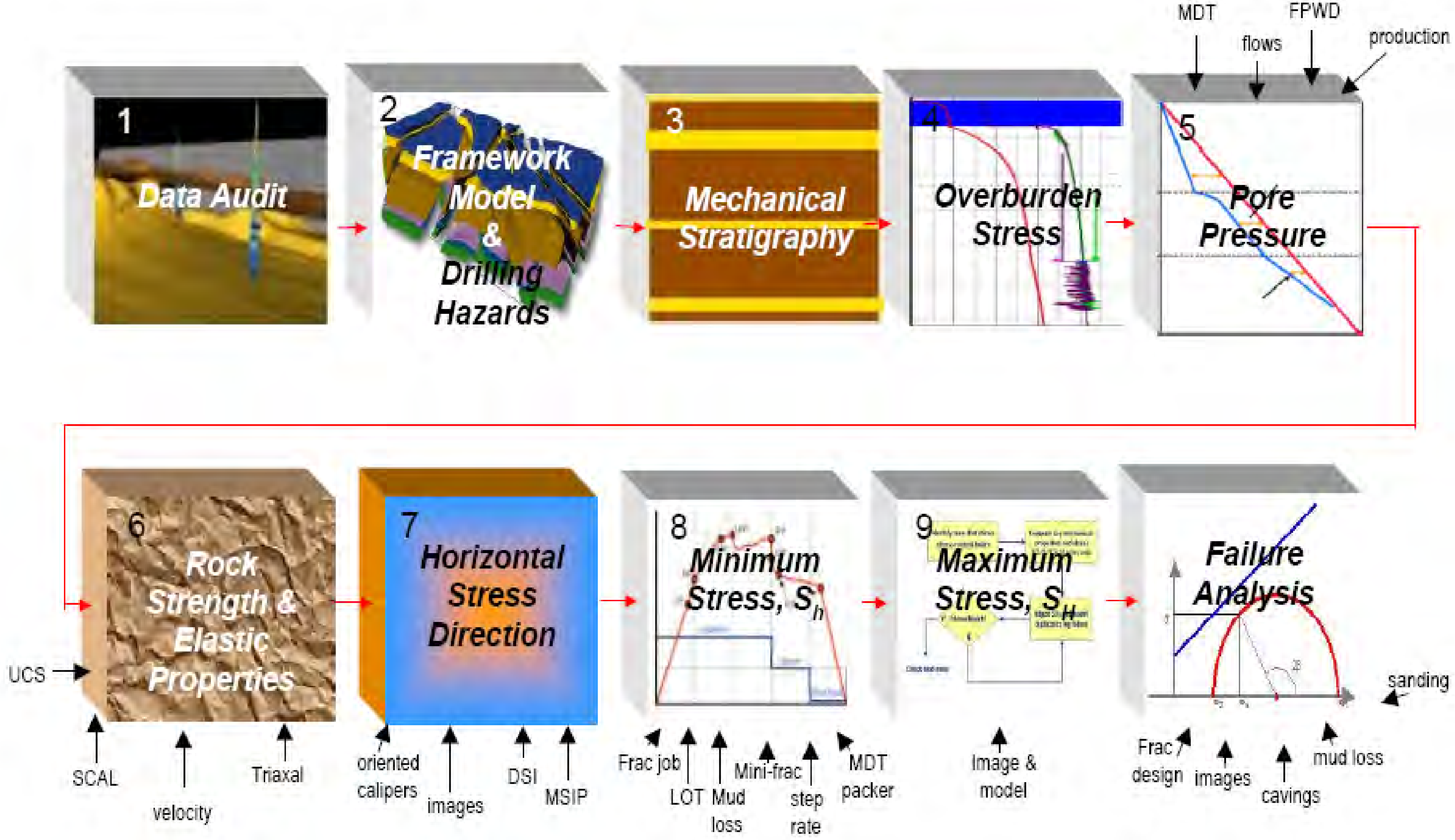


# 1D Mechanical Earth Model (1D MEM) and Wellbore Stability (WBS) Analysis



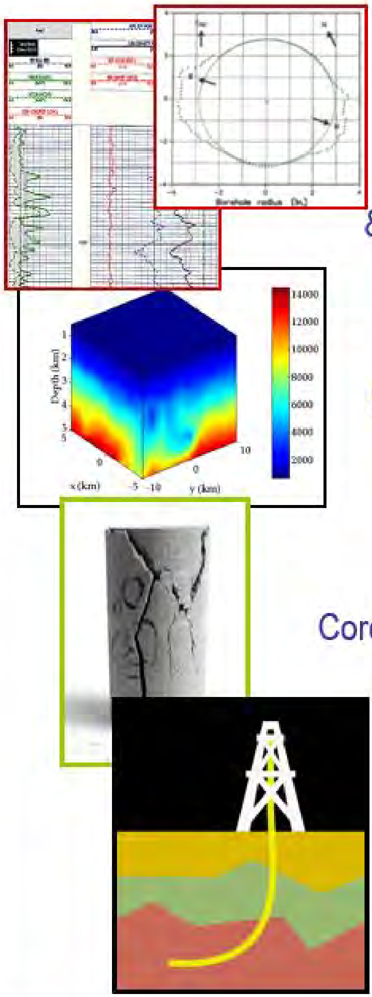


# Building and Calibration of 1D MEM



# 1D Mechanical Earth Model

## Input Data



Wireline & LWD Logs

Seismic

Core Data

Drilling Data

## Mechanical Earth Model

A. Mechanical Properties

Youngs Modulus

Poisson's Ratio

UCS.....

B. Downhole Stresses

**In Situ Stresses & Pore Pressure**


Sv ✓

Shmin ✓

SHmax?

## History match

SHmax ✓

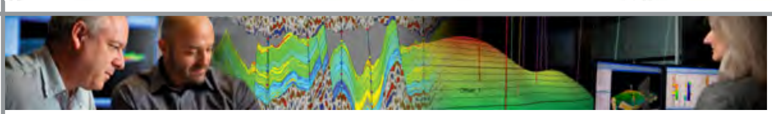
Borehole Images

## Results

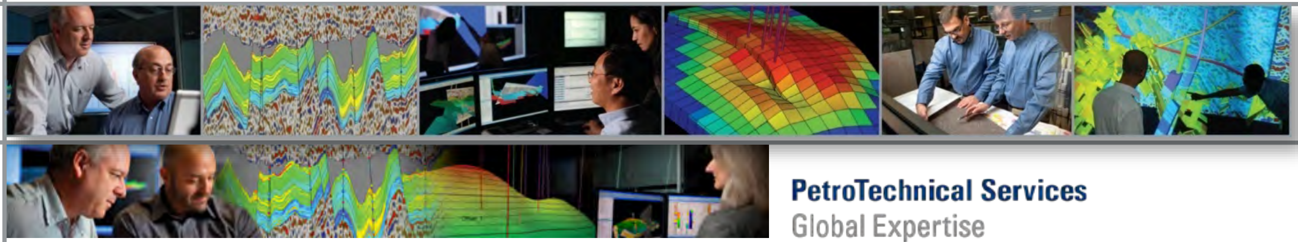
**Analysis and Design for:**

**WBS**
**Frac Design**
**Compaction**
**Subsidence**
**Sanding**
**Res. Simulation**
**etc.**





# Vertical Stress



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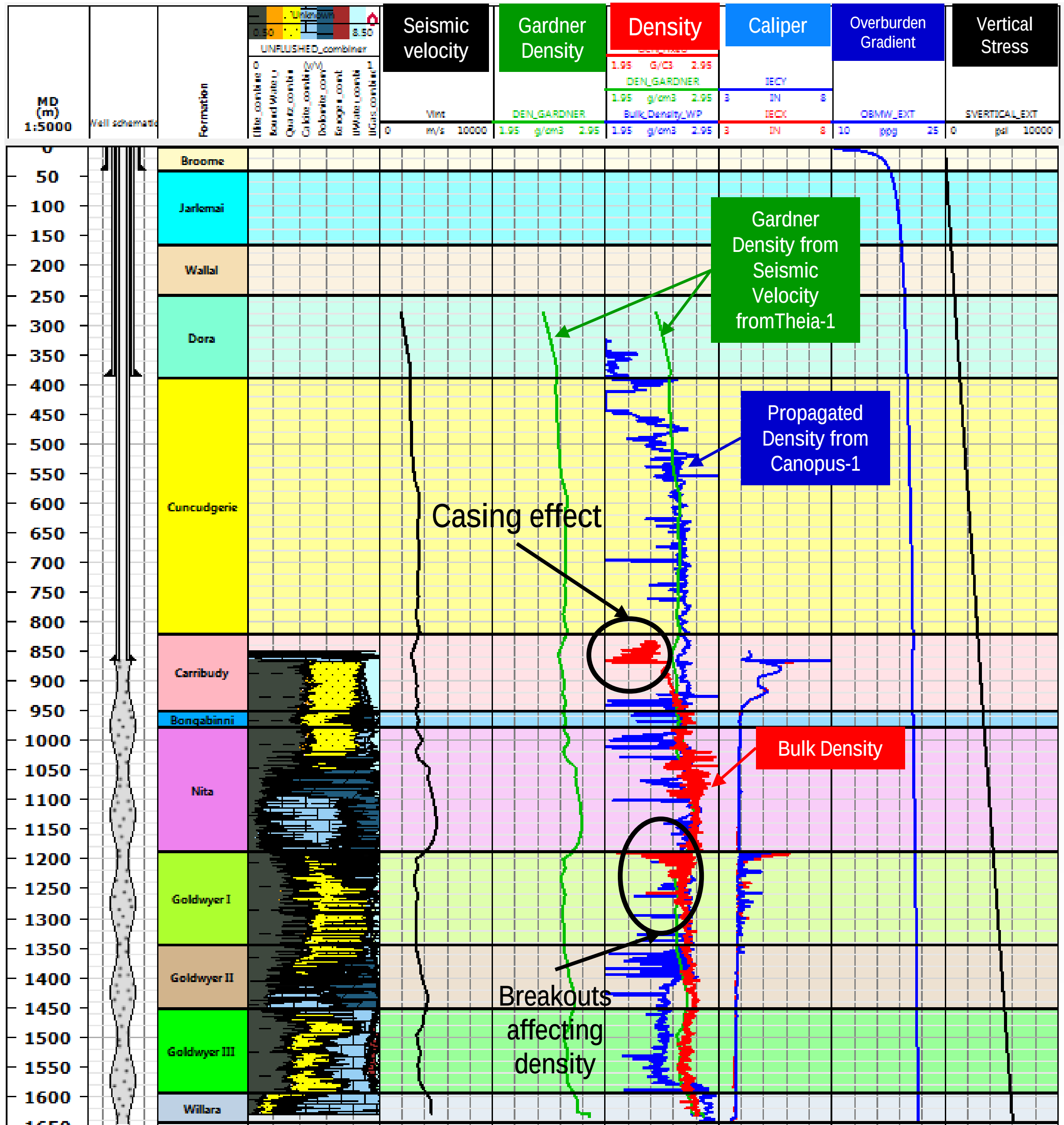
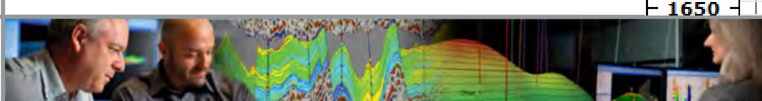
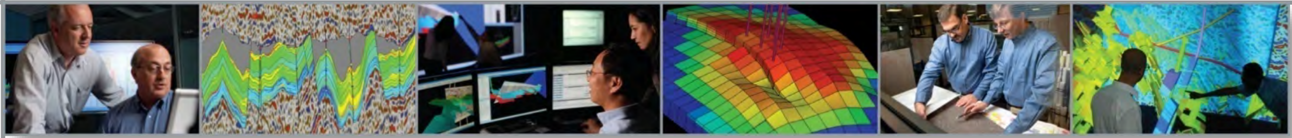
# Vertical Stress

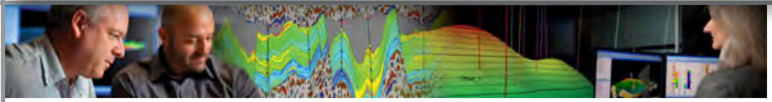
- Density log from 864mMD to TD is used to calculate vertical stress (Sv) in the interval.
- Seismic velocity is used for density estimation in Dora and Cuncudgerie formations.
- Density from offset well Canopus-1 was propagated to Theia-1 (adjusted for formation tops) to estimate density in Cuncudgerie formation.
- The Gardner density profile from seismic velocity shows good match with propagated density in Cuncudgerie formation.
- Vertical stress was extrapolated up to surface based on density and seismic velocity.
- Vertical stress gradient is approximately 1.1 psi/ft.



# Pore Pressure





# Pore Pressure Estimation

Drilling Observations:

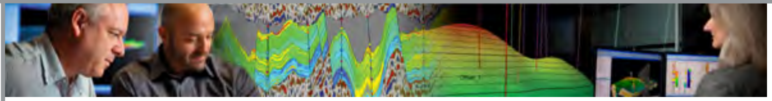
- While drilling, high Total Gas was observed in bottom section of Goldwyer II formation and entire Goldwyer III formation.
- After bit trip to TD, gas was observed during bottoms up. This could be an indication of underbalance condition.

Pore Pressure Modeling:

- Pore pressure estimation was performed using methods like Eaton Sonic, Eaton Resistivity and Bowers methods.
- Sonic data was corrected for carbonate effect and used to estimate pore pressure by Eaton Sonic method as a qualitative estimation of overpressure.
- Total Organic Content (TOC) and Total Gas were used to estimate pore pressure instead.
- The final pore pressure adopted is average of TOC pore pressure and Total Gas pore pressure.

Pore Pressure Conclusions:

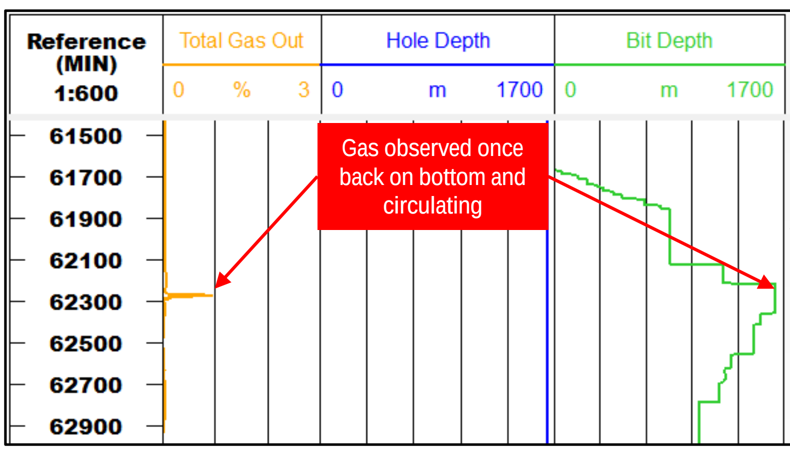
- Pore pressure is observed to be present in the Goldwyer III and estimated to be approximately 10.15 ppg

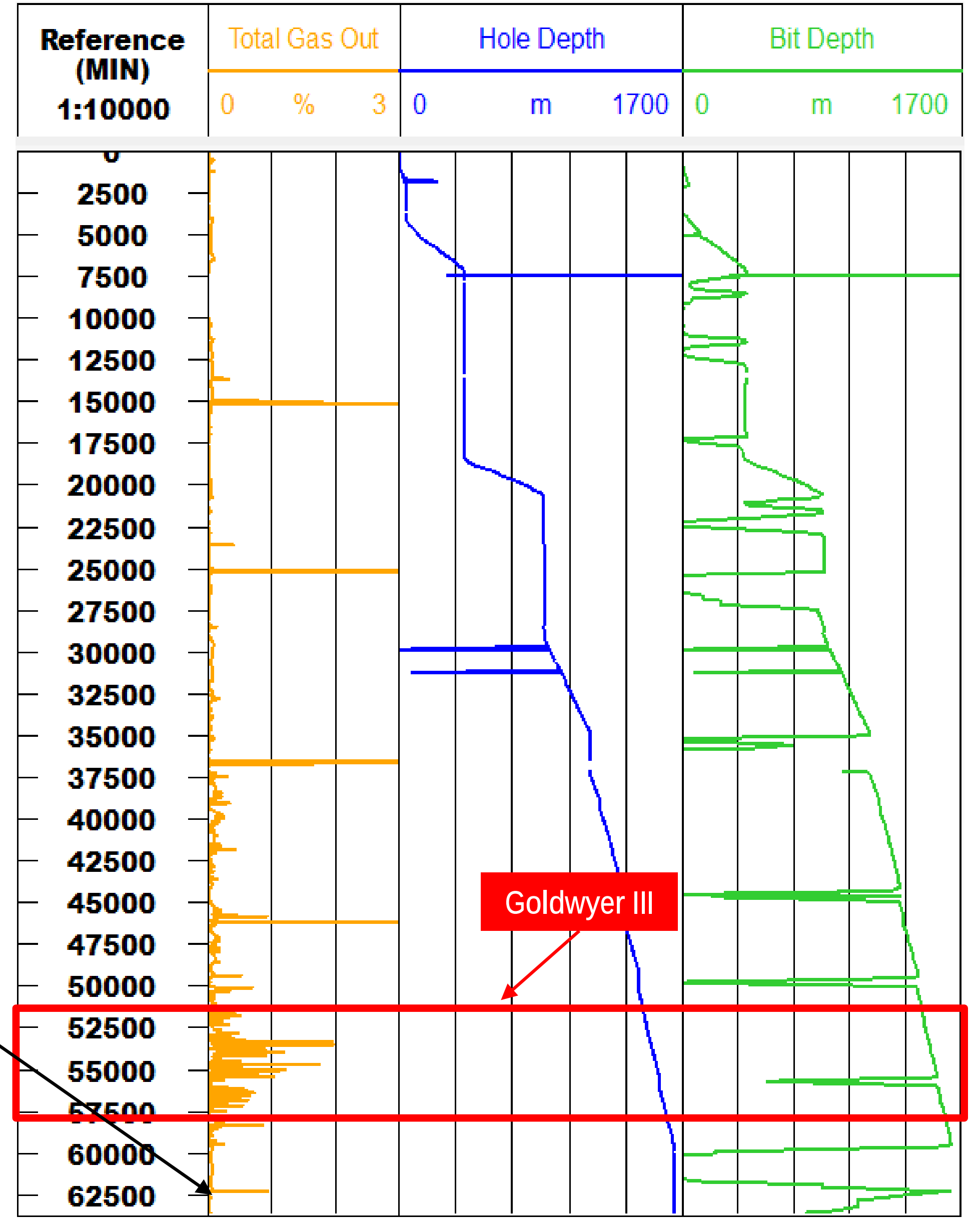


# Drill Monitoring Log

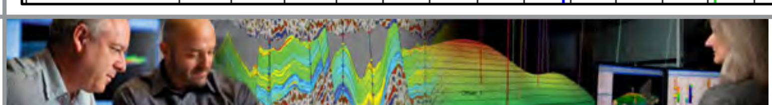
## (Time-based log during drilling)

- Drill Monitoring Log shows clear increase of “Total Gas Out” over Goldwyer III formation.
- Gas increase observed when drill-bit is back on bottom and circulating. This is an indication that PP > ESD (9.65 ppg) for gas to migrate into the mud column.



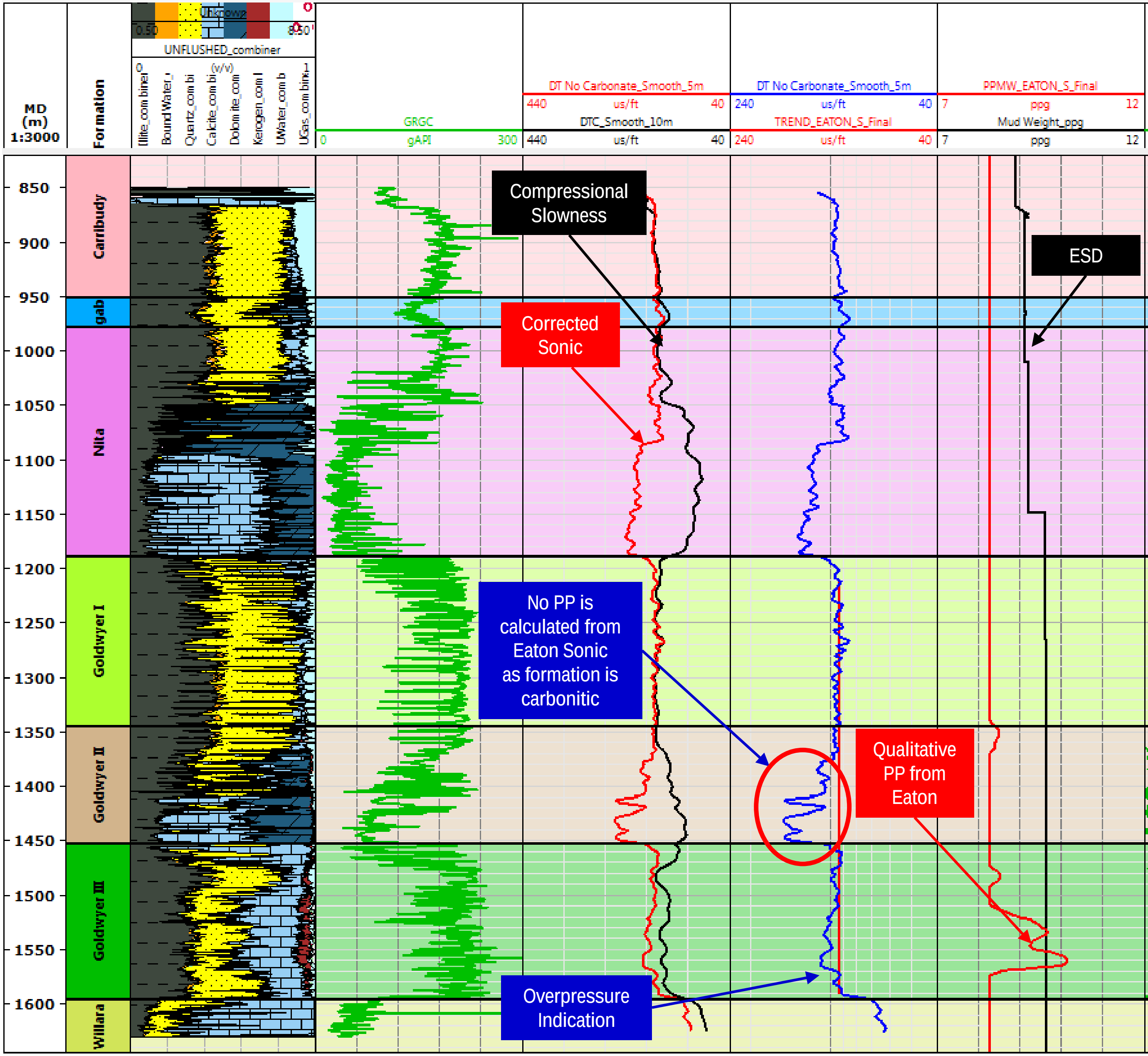





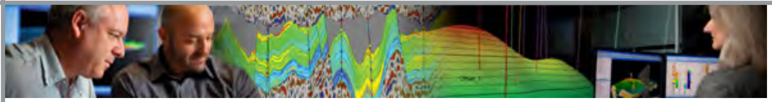



# Pore Pressure from Sonic

- Different methods- Eaton Sonic and Bowers methods were used for PP estimation.
- The response of sonic to PP is masked by the presence of carbonate.
- Sonic data were re-processed using mineral volumes to remove the effect of carbonate (Corrected Sonic).
- This Corrected Sonic is used to analyze pore pressure in Goldwyer III formation.
- The analysis shows that the PP from sonic is still sensitive to lithology (absence of Lst) and shows pore pressure in those zones that has high volume of carbonate. Therefore, the PP profile from sonic alone has high uncertainty. In subsequent slides, PP profile from other methods are investigated.

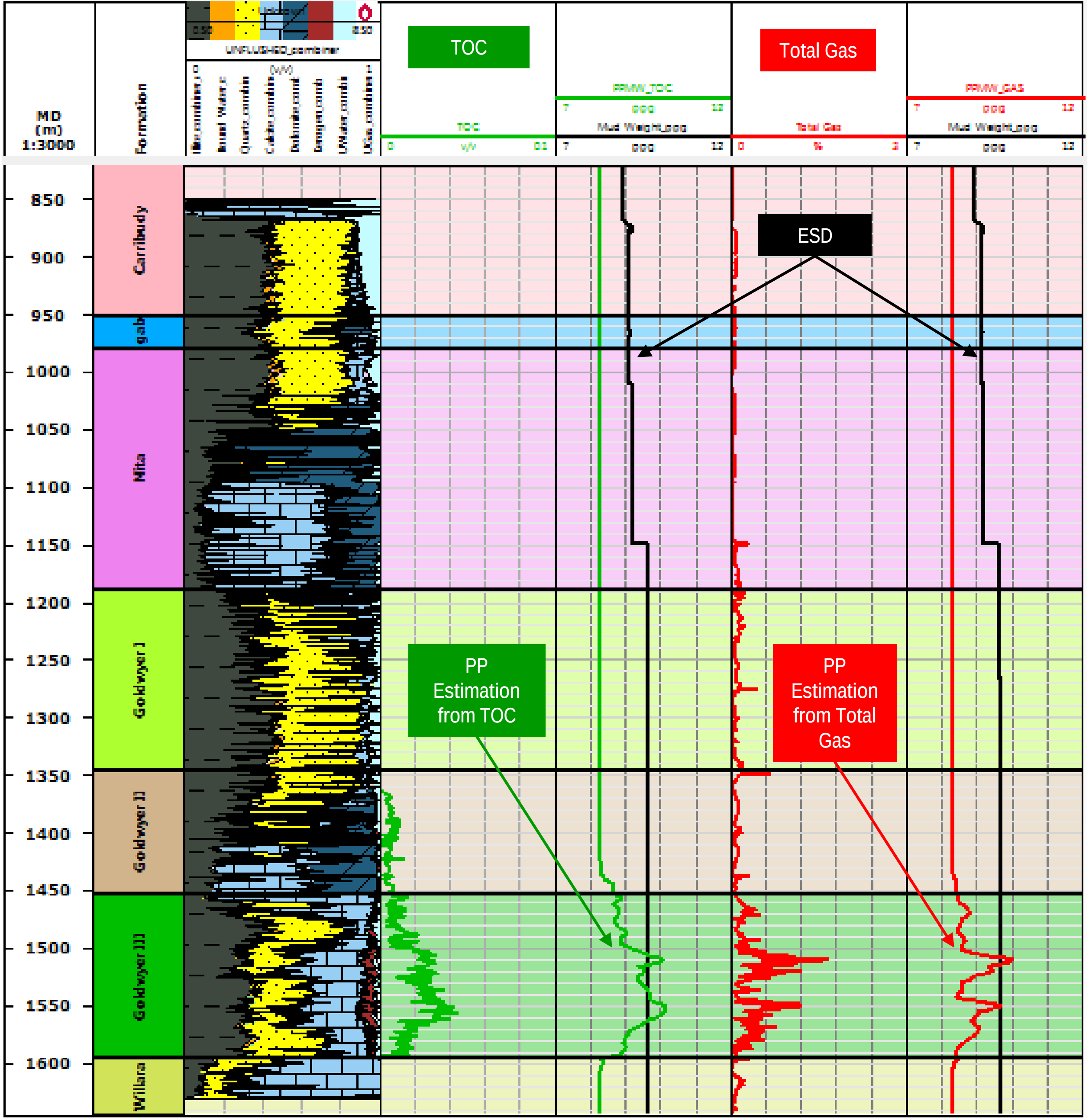


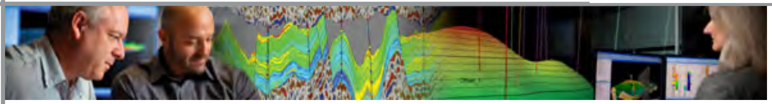


# Pore Pressure from TOC and Total Gas

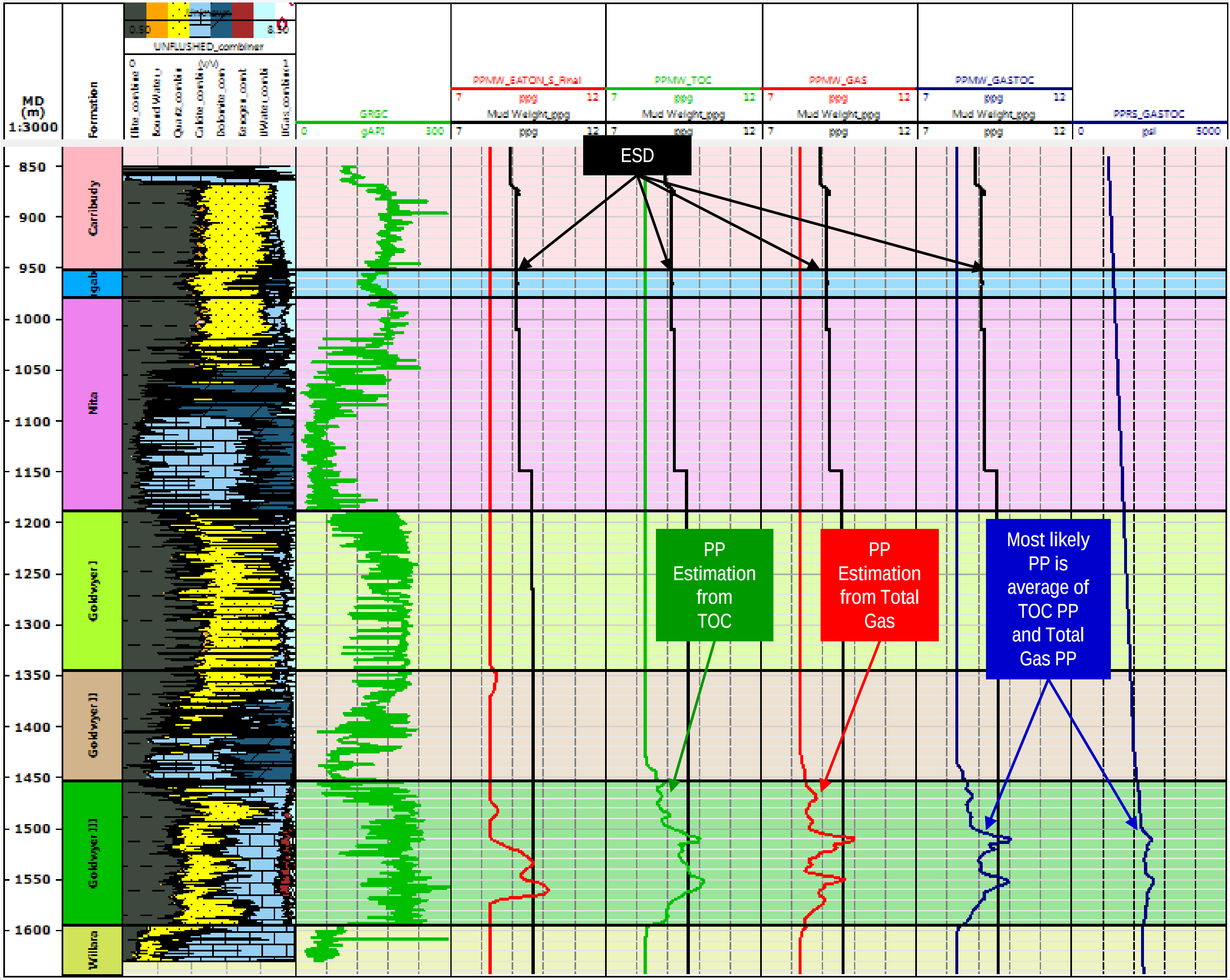
- Observation of increase in Total Gas after bit trip (point 2 on slide 26) is used as a possible indicator of PP to be higher than ESD.
- Relationships were established between PP and TOC (assuming PP is generated due to kerogen cracking)
- Relationships were also established between PP and Total Gas.
- Final adopted PP is the average of PP-TOC and PP-Total Gas.
- Pore pressure in other formations is assumed to be hydrostatic pressure.

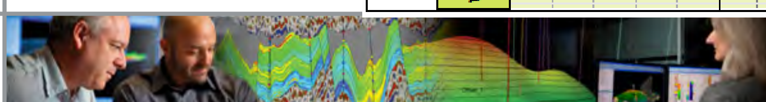


# Most Likely Pore Pressure Profile

- Due to high uncertainty in PP from sonic, it is not used to calculate final PP.
- Most likely PP is the average of PP-TOC and PP-Gas pressures.
- Pore Pressure in other formations is considered to be hydrostatic.



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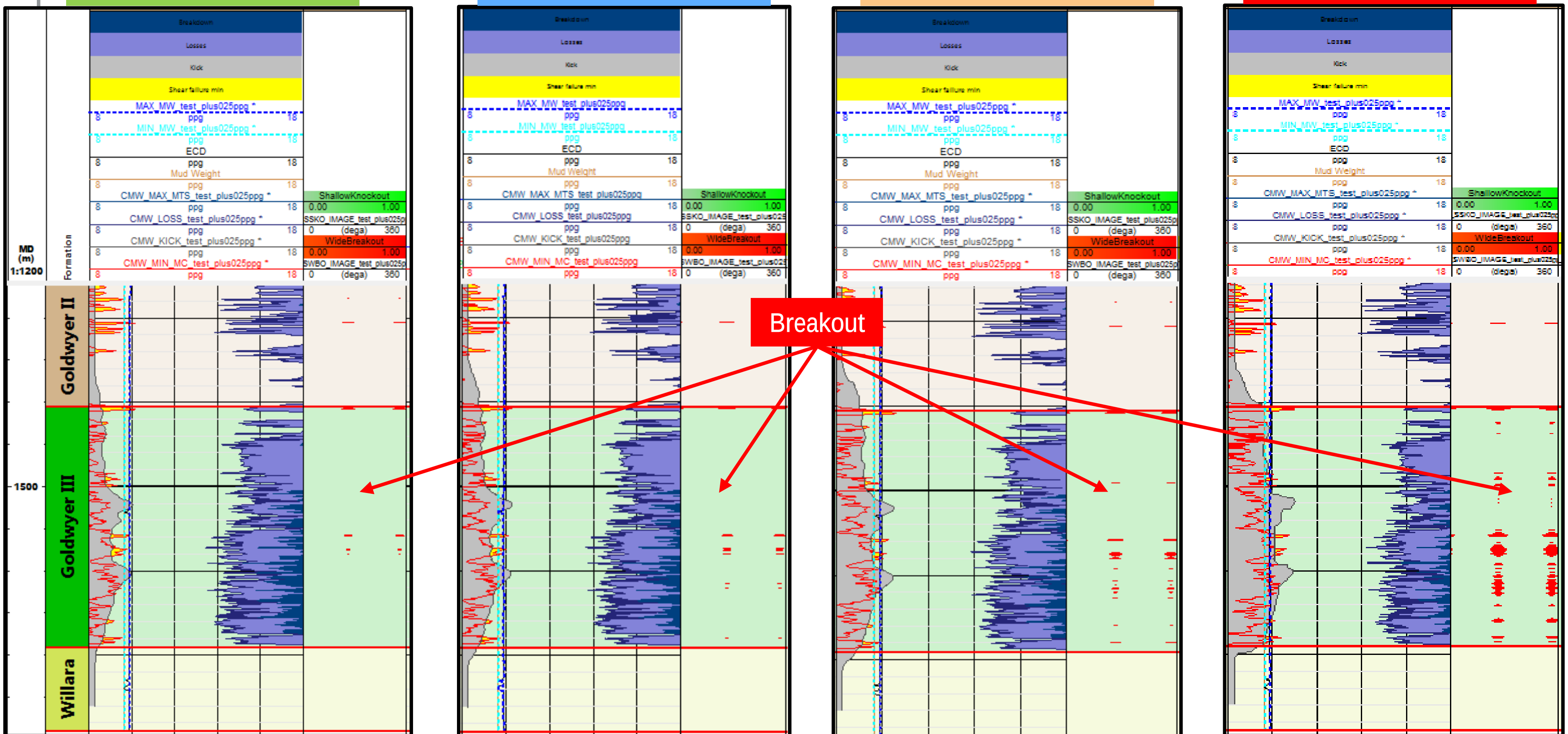
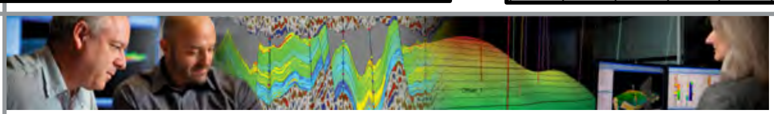
# Pore Pressure Sensitivity Analysis

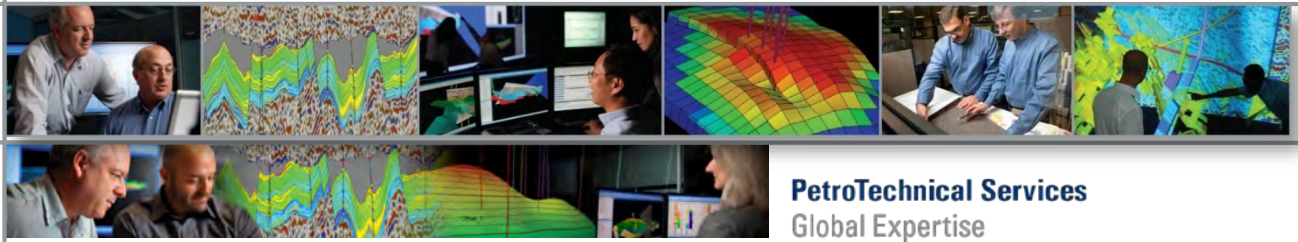
- A sensitivity analysis is conducted on pore pressure to determine the effect of underbalance drilling. The result shows that 1.5 ppg underbalance significantly increases the breakouts in Goldwyer III formation.
- Since no breakout is observed in Goldwyer III formation, we can conclude that maximum pore pressure in Goldwyer III is most likely 10.15 ppg (ESD + 0.5 ppg).

0.5 ppg underbalance | 0.75 ppg underbalance | 1.0 ppg underbalance | 1.5 ppg underbalance



# Rock Mechanics Test & Mechanical Properties



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# Rock Mechanics Tests

- The rock mechanics tests were performed by Weatherford Laboratory in Houston (Finder Theia-1 Acoustic Velocities Rock Mech Report AB-77969).
- Rock mechanics tests were conducted using plugs from conventional cores in Goldwyer III (6 core slabs) and Willara (1 core slab) formations.
- Test program was designed to obtain elastic and rock strength properties.
- One core (032P) has been tested for anisotropic properties and one core (026P) has been tested for bedding plane strength (results are shown in Bedding Plane Failure section).
- Please refer to Appendix for two slides on re-interpretation of UCS and FANG.

| Core Depth m | Core Name | Formation | Lithology | Test |
|---|---|---|---|---|
| 1466.43 | 004P | Goldwyer III | Carbonitic | BTZ[1], UCS[2], TXC[3] |
| 1506.76 | 018P | Goldwyer III | Shaly sand | UCS[2], TXC[3] |
| 1524.97 | 024P | Goldwyer III | Carbonitic | BTZ[1], UCS[2], TXC[3] |
| 1530.71 | 026P | Goldwyer III | Shaly sand | TXC[3] |
| 1548.76 | 032P | Goldwyer III | Shaly sand | BTZ[1], UCS[2], TXC[3] |
| 1560.79 | 037P | Goldwyer III | Shaly sand | BTZ[1] |
| 1595.66 | 050P | Willara | Carbonitic | BTZ[1], UCS[2], TXC[3] |

1. BTZ – Brazilian Test.
2. UCS – Unconfined Compressive Strength Test.
3. TXC –Triaxial Compressive Strength Test

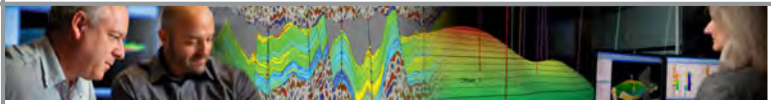
| Core | Core | Bulk | Ultrasonic | | Dynamic Elastic Properties | | | | Static Elastic Properties | | | | | | Rock Strenght | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth m | Name | Density g/cc | DTC us/ft | DTS us/ft | PRv | YMv Mpsi | BMv Mpsi | SMv Mpsi | PRv | PRh | PRi | YMv Mpsi | YMh Mpsi | YMi Mpsi | UCS psi | Re-interpreted UCS psi | FANG deg | Re-interpreted FANG deg | TSTR psi |
| 1466.43 | 004P | 2.69 | 53.84 | 100.43 | 0.30 | 9.31 | 7.70 | 3.59 | 0.27 | - | - | 4.77 | - | - | 6658 | 9015 | 40.70 | 38.11 | 576 |
| 1506.76 | 018P | 2.46 | 84.26 | 135.59 | 0.19 | 4.27 | 2.26 | 1.80 | 0.18 | - | - | 1.60 | - | - | 6657 | 9014 | 54.20 | 52.14 | - |
| 1524.97 | 024P | 2.67 | 57.82 | 105.82 | 0.29 | 8.27 | 6.48 | 3.21 | 0.23 | - | - | 3.99 | - | - | 6831 | 16623 | 45.30 | 31.12 | 744 |
| 1530.71 | 026P | - | - | - | - | - | - | - | - | - | 0.18 | - | - | 3.09 | - | 5147 | - | 21.32 | - |
| 1548.76 | 032P | 2.44 | 89.18 | 142.32 | 0.18 | 3.82 | 1.97 | 1.62 | 0.12 | 0.22 | - | 1.58 | 3.10 | - | 9507 | 9507 | 24.00 | 24.00 | 772 |
| 1560.79 | 037P | - | - | - | - | - | - | - | - | | - | - | - | - | - | - | - | - | 620 |
| 1595.66 | 050P | 2.64 | 56.78 | 101.97 | 0.28 | 8.73 | 6.47 | 3.42 | 0.18 | - | - | 3.72 | - | - | 6329 | 9879 | 35.50 | 30.96 | 1212 |

PRv = Vertical Poisson's Ratio (vertical plug)
PRh = Horizontal Poisson's Ratio (horizontal plug)
PRi= Inclined Poisson's Ratio (inclined plug)

YMv = Vertical Young's Modulus (vertical plug)
YMh = Horizontal Young's Modulus (horizontal plug)
YMi = Inclined Young's Modulus (inclined plug)

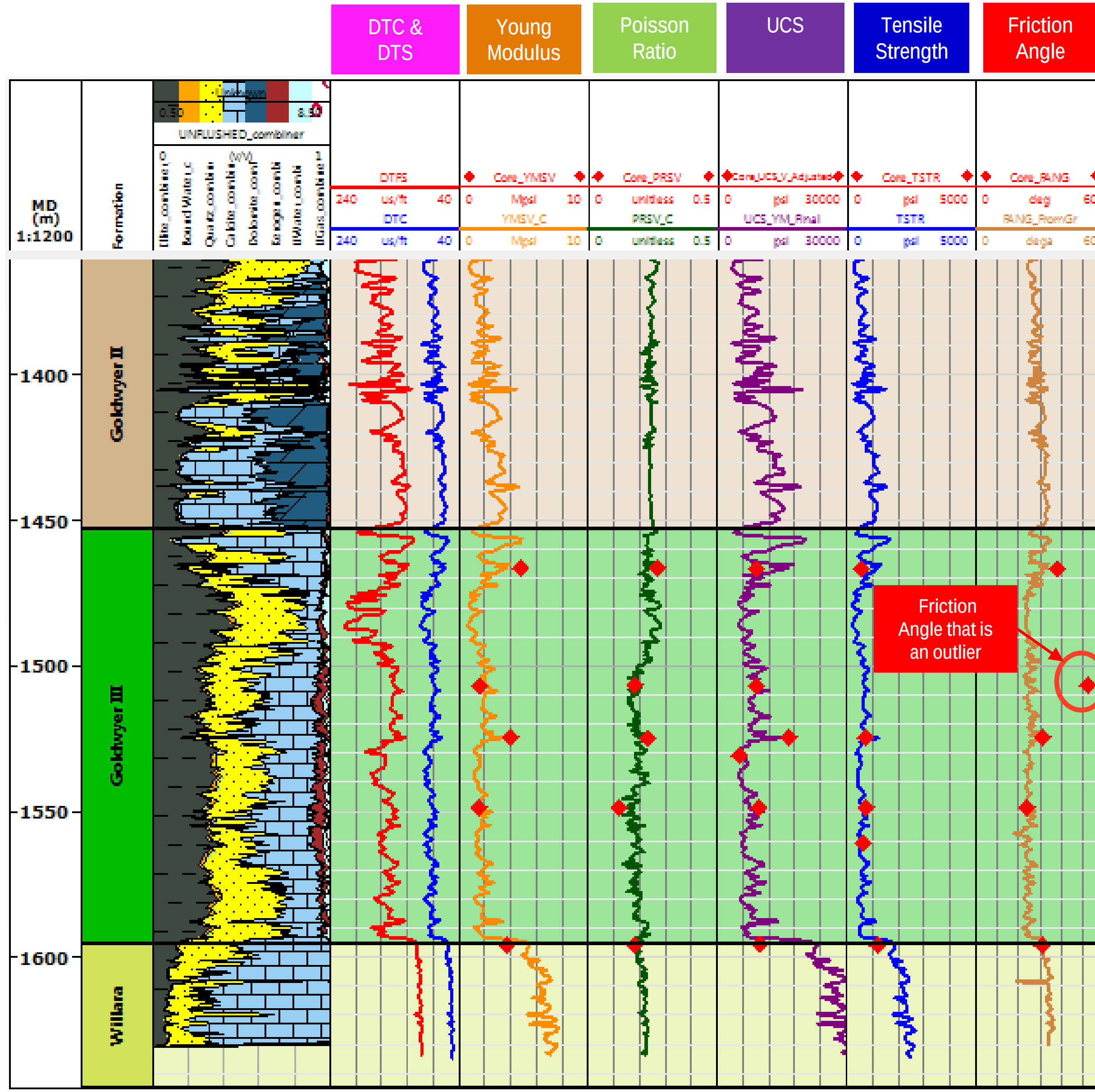
UCS = Unconfined Compressive Strength
FANG = Friction Angle
TSTR = Tensile Strength

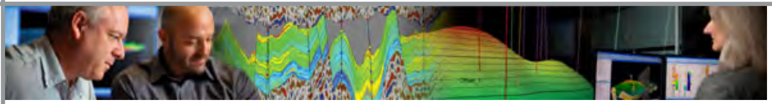
BMv = Vertical Bulk Modulus
SMv = Vertical Shear Modulus



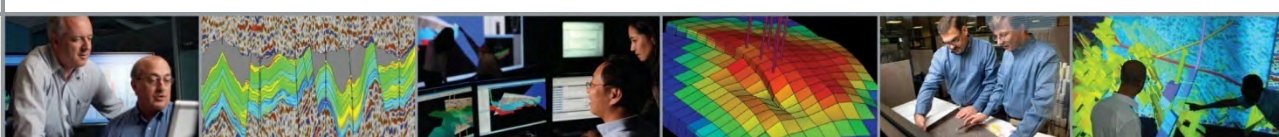
# Elastic and Strength Properties

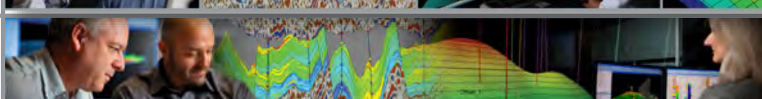
- Density, Compressional Slowness and Shear Slowness are used to calculate rock elastic and strength properties.
- Elastic and strength properties models are calibrated with rock mechanics test data in Goldwyer III and Willara formations.
- The friction angle from core 018P in shale is reported to be 54.2 deg which is abnormally high and considered an outlier. Hence, the data point was not used in the friction angle profile calibration.



# 1D MEM Validation





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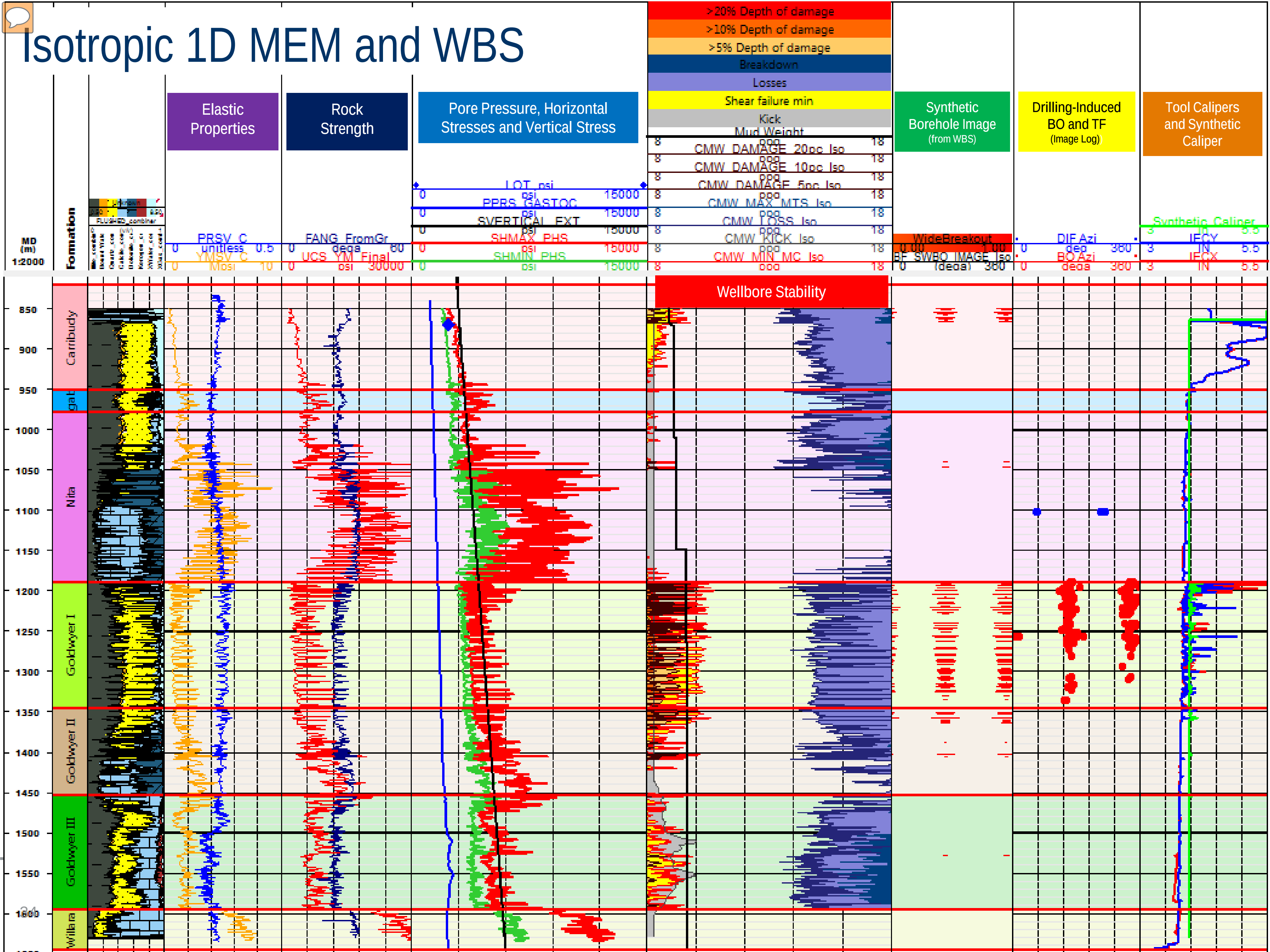
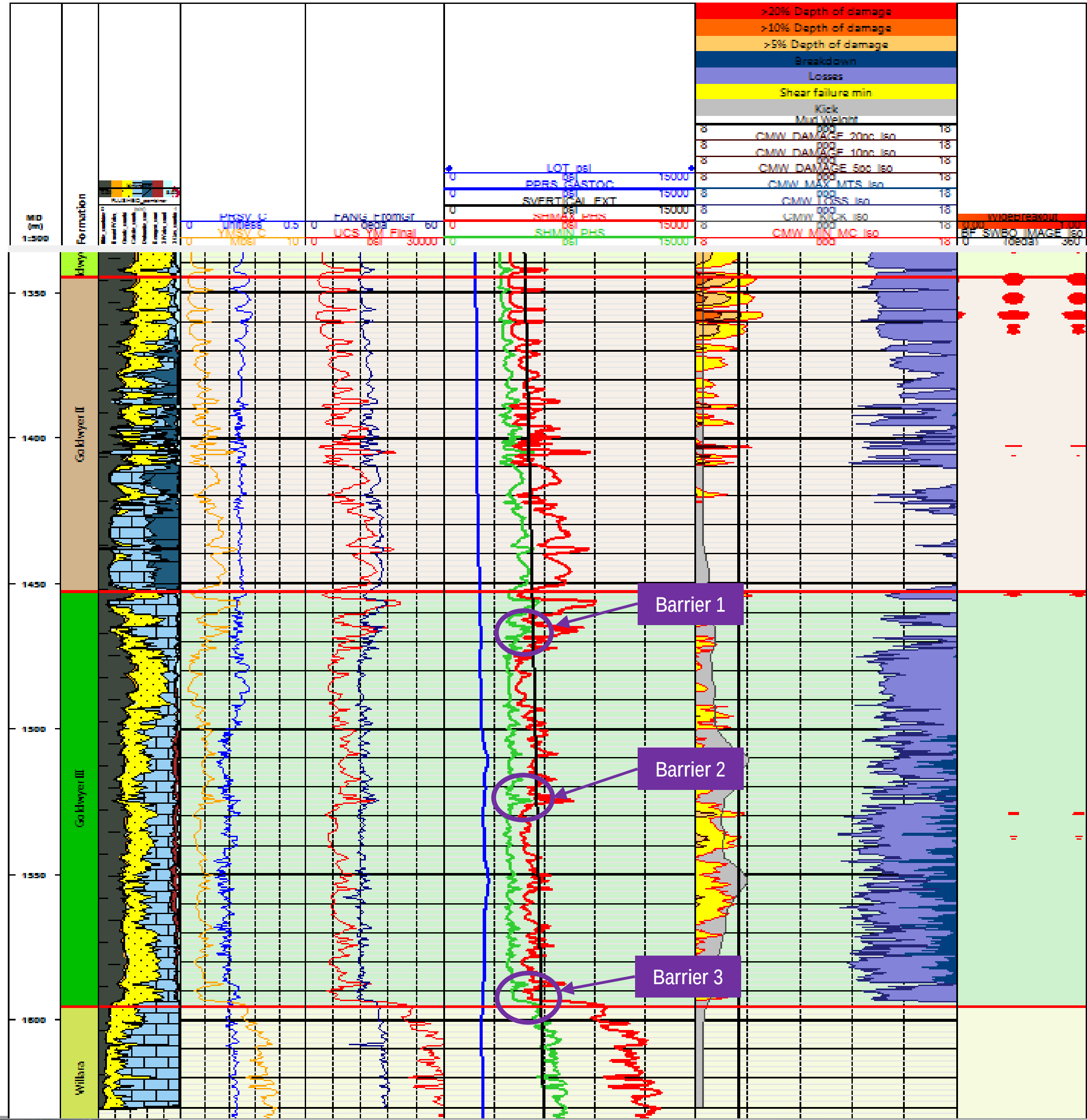
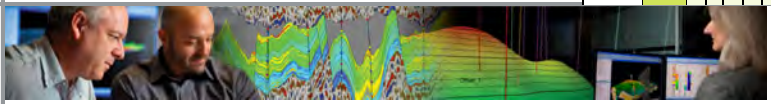
# Isotropic 1D MEM and WBS



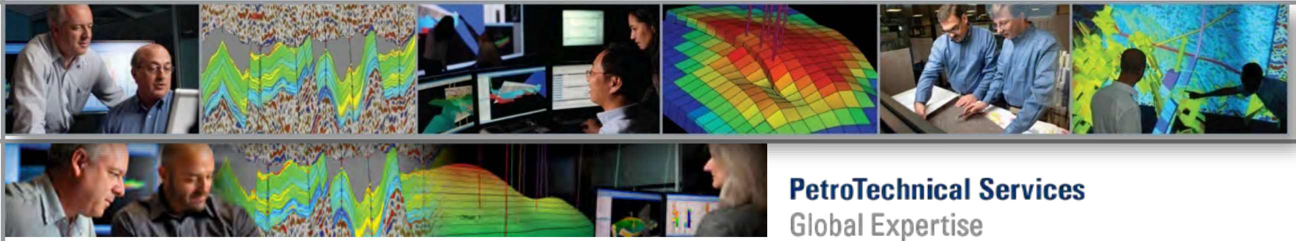
# Isotropic 1D MEM and WBS in Goldwyer III Formation

- In Goldwyer III formation, the stress profile indicates that there are three possible stress barriers to vertical hydraulic fracture growth.
- Barrier 1 is carbonitic section at top section of Goldwyer III formation.
- Barrier 2 is carbonate strike at 1524 m MD.
- Barrier 3 is top of Willara formation.
- Minimum horizontal stress gradient is approximately 0.77 psi/ft in Goldwyer III formation.
- Maximum horizontal stress gradient is approximately 0.97 psi/ft in Goldwyer III formation.



# Effect of Elastic Anisotropy on Horizontal Stress



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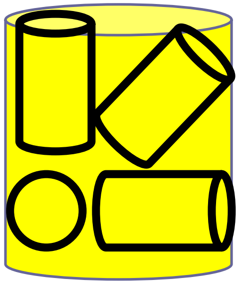
# Anisotropic Elastic Properties for Horizontal Determination



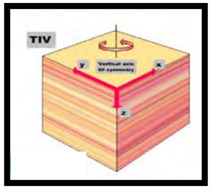
Traditional Method

Isotropic properties

$$\sigma_h - \sigma_p = \frac{\upsilon_v}{1-\upsilon_v}\left(\sigma_v - \sigma_p\right) + tectonics$$

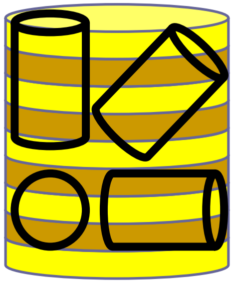
**DTc, DTs, Rhob**

Conventional Dipole Sonic tool (DSI)




TIV = Transversely Isotropic Vertical

Anisotropic properties



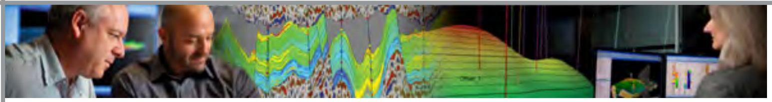
$$\sigma_h - \sigma_p = \frac{E_h}{E_v}\frac{\upsilon_v}{1-\upsilon_h}\left(\sigma_v - \sigma_p\right) + tectonics$$

**DTc, DTs, Rhob, C33, C44, C66**

Sonic Scanner tool

Sonic Scanner Tool determines elastic properties
=> Anisotropic Stress Profile
(SPE 115736, Shannon Higgins)



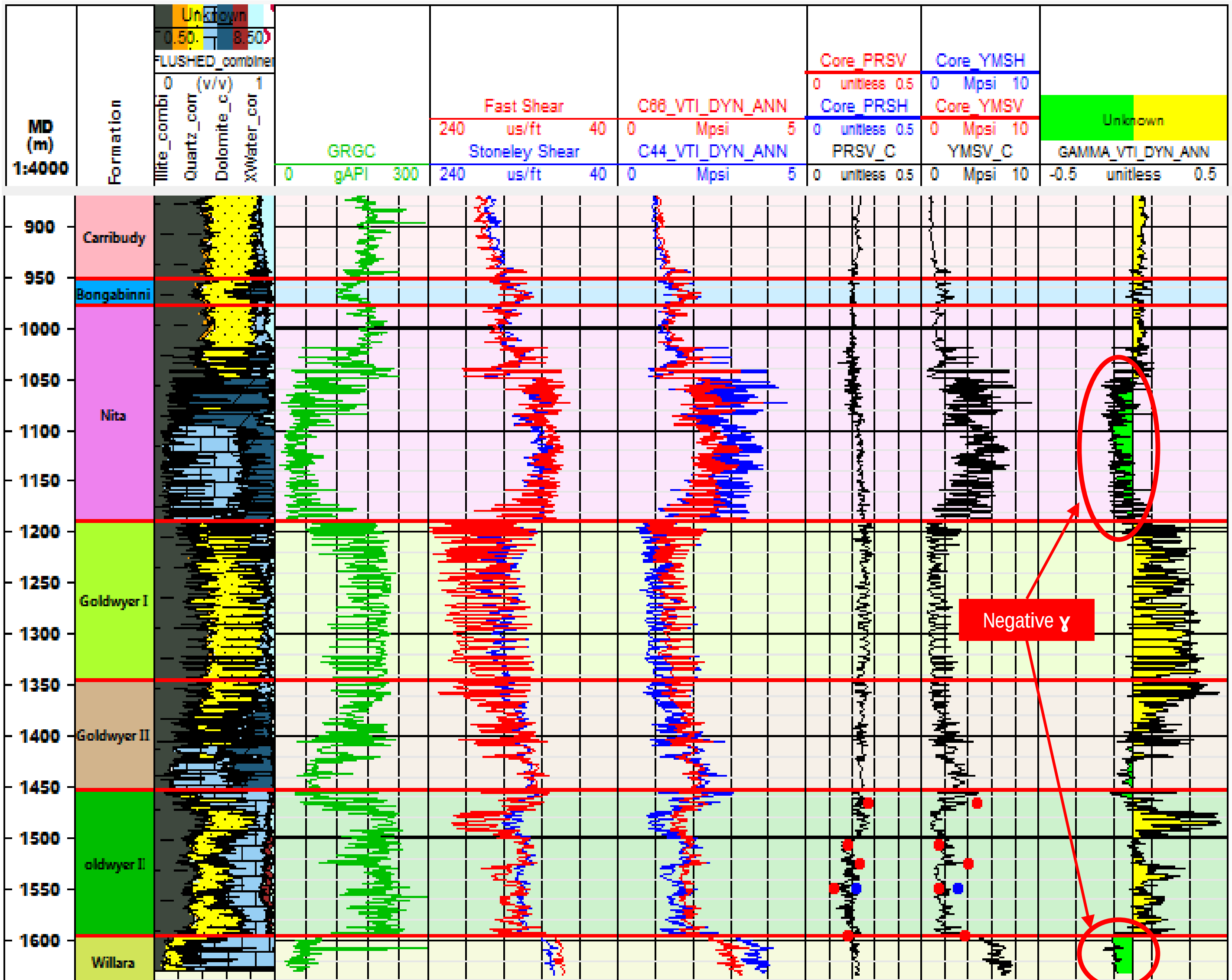


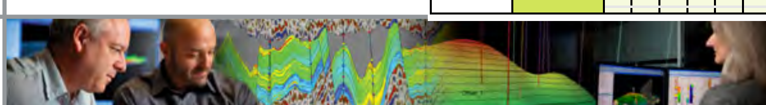
# Stoneley Shear and Shear Moduli

- The C66 obtained from Weatherford sonic tool has high uncertainty* as it shows negative ɣ (Gamma) in Willara formation. Willara formation is tight and ɣ in the formation is expected to be zero or positive.
- Positive Gamma indicates presence of elastic anisotropy in shale intervals.

* Stoneley shear accuracy is highly dependent on sonic tool characterization, mud slowness and frequency based processing to account for radial alteration and dispersion effects. Without these considerations, C66 has considerable errors.

Gamma= (C66-C44)/(2*C44)





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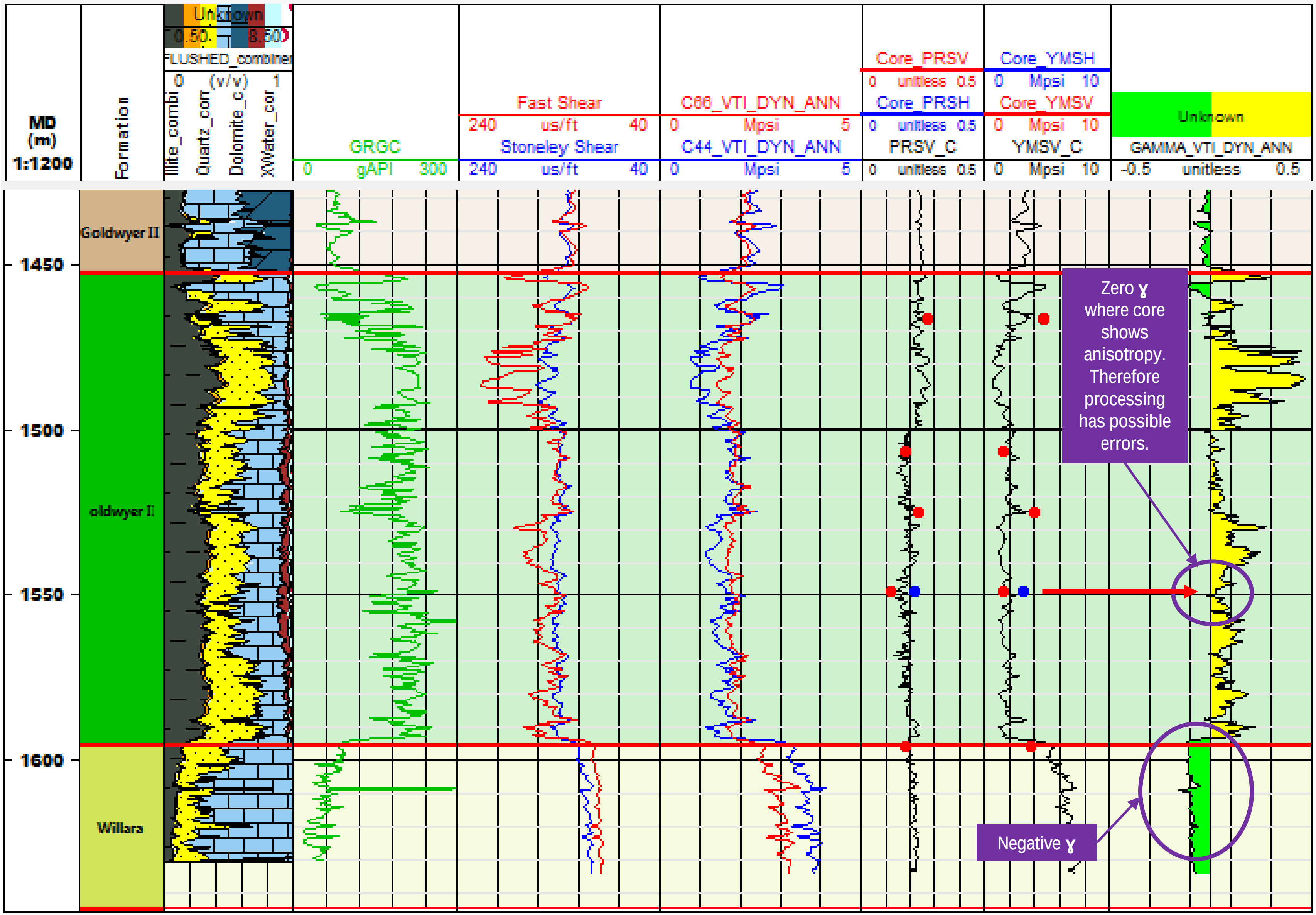
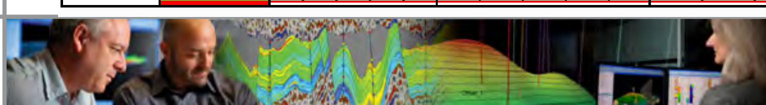
# Stoneley Shear and Shear Moduli in Goldwyer III



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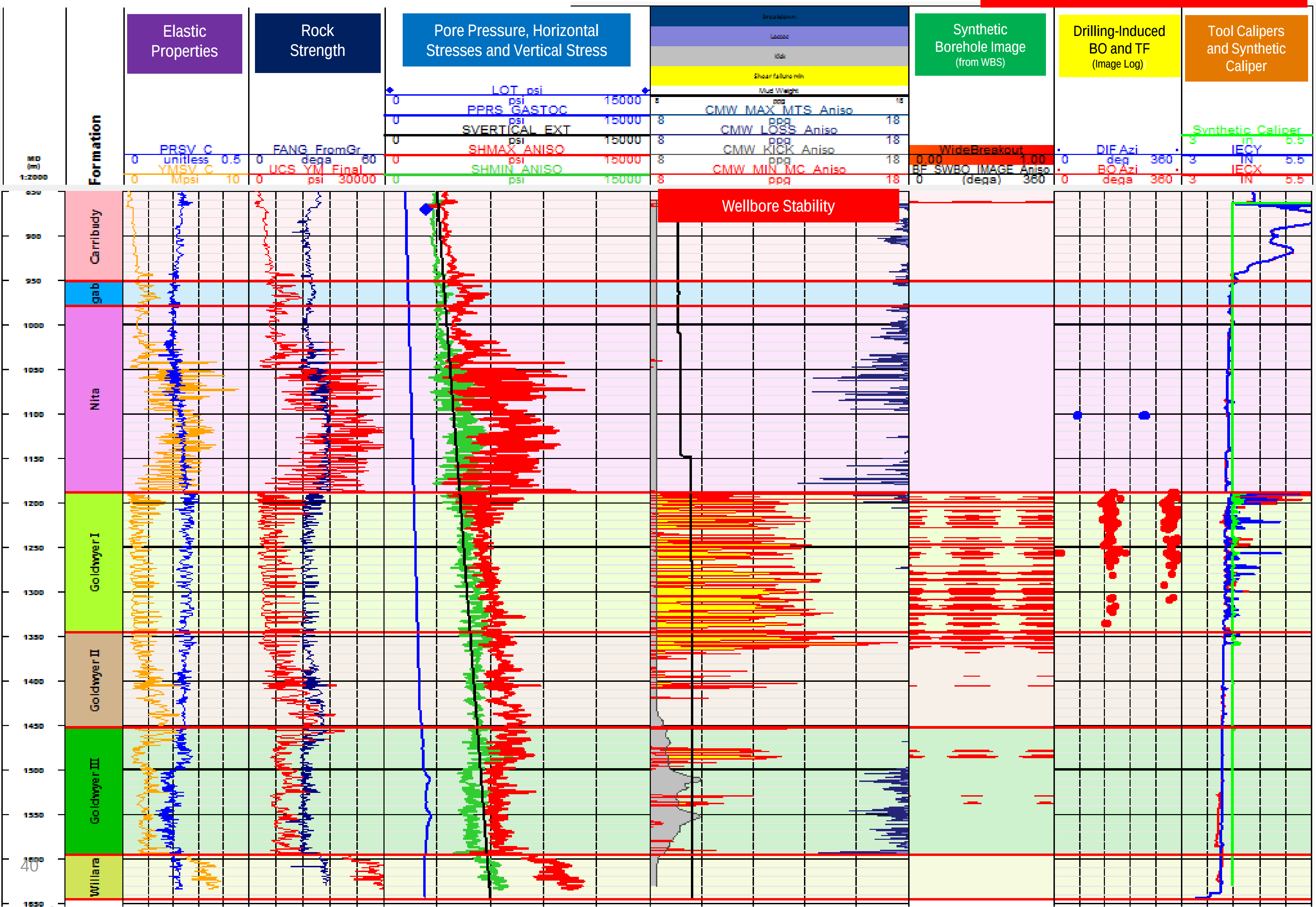
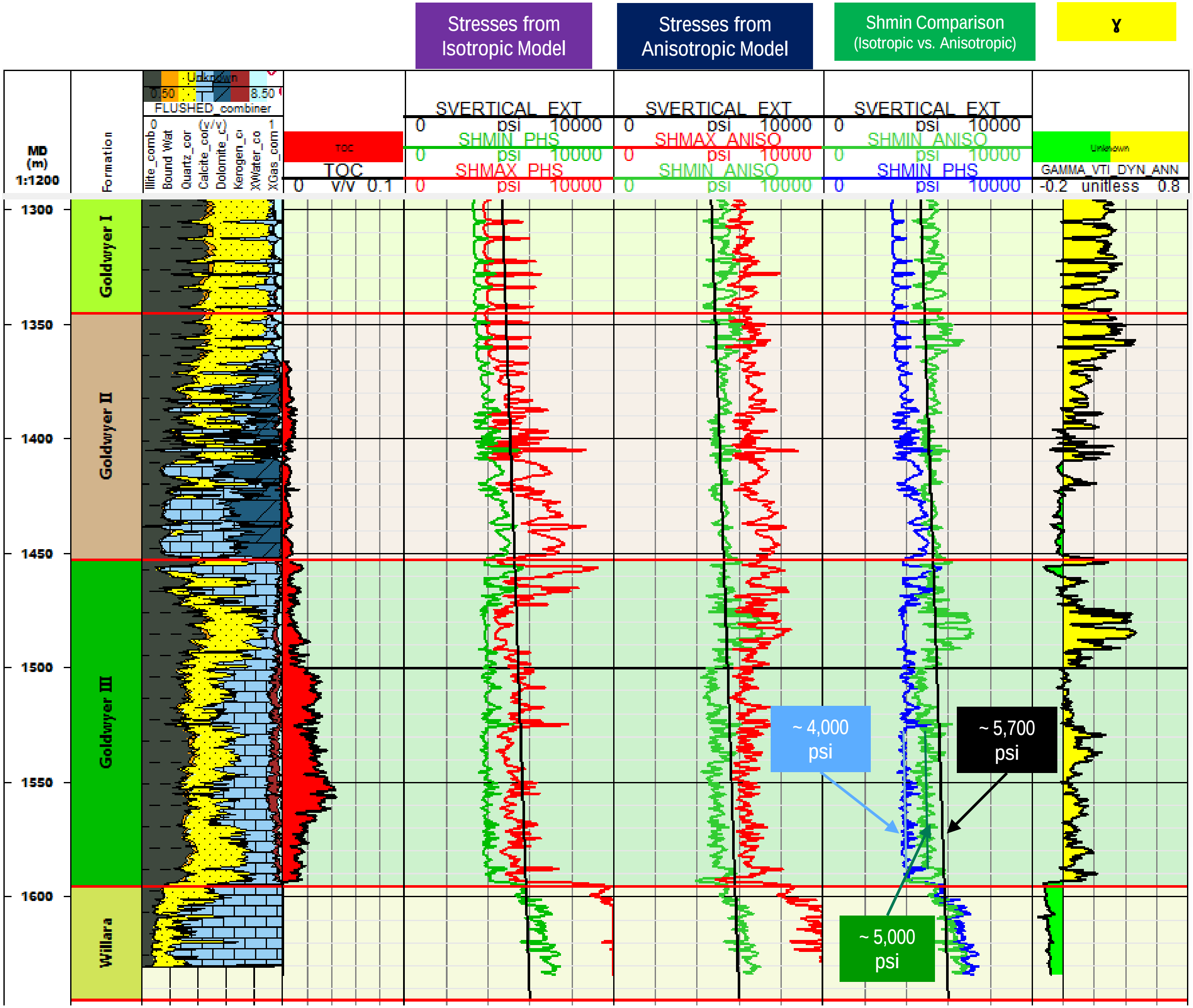
# Anisotropic 1D MEM & WBS

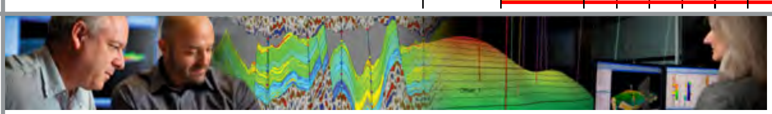
High uncertainty in this model due to uncertainty in C66



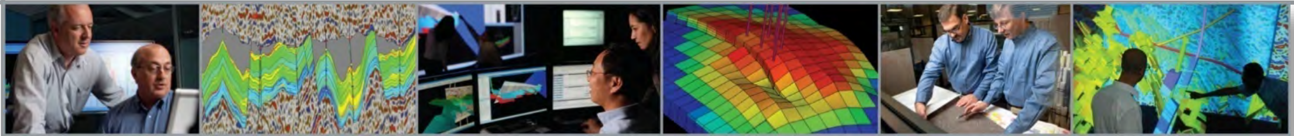
# Stresses in Goldwyer II and III Formations

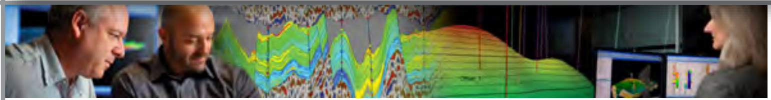
Due to uncertainty in C66, anisotropic minimum and maximum horizontal stresses are not reliable but may be used to have an understanding of the anisotropic horizontal stresses trend only.



# Bedding Plane Failure





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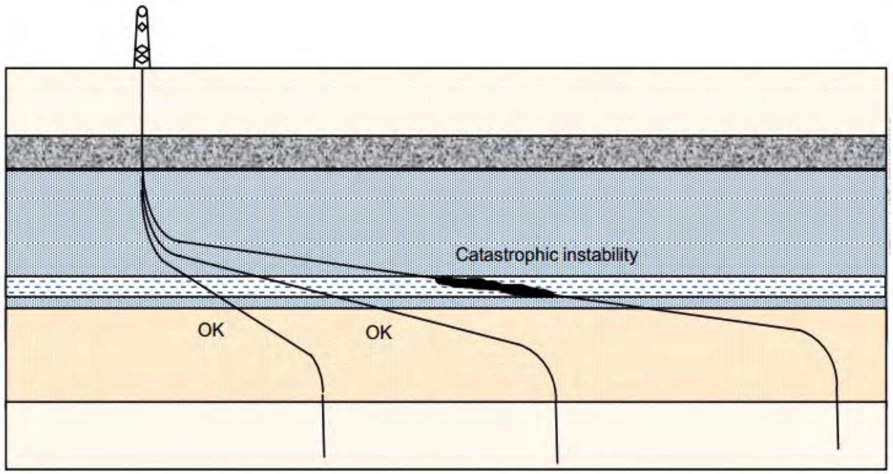
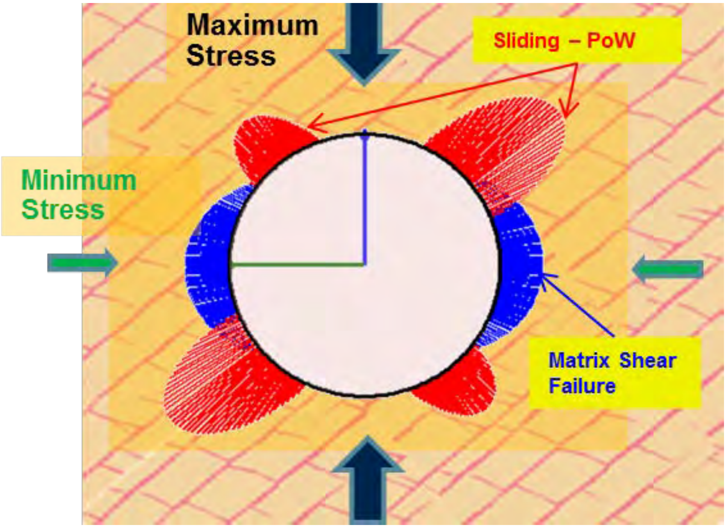
# Bedding Plane Failure

- It is important to identify the failure mechanism to develop appropriate solution to manage wellbore instability.
- Bedding plane failure may be dominant failure mechanism in shales.

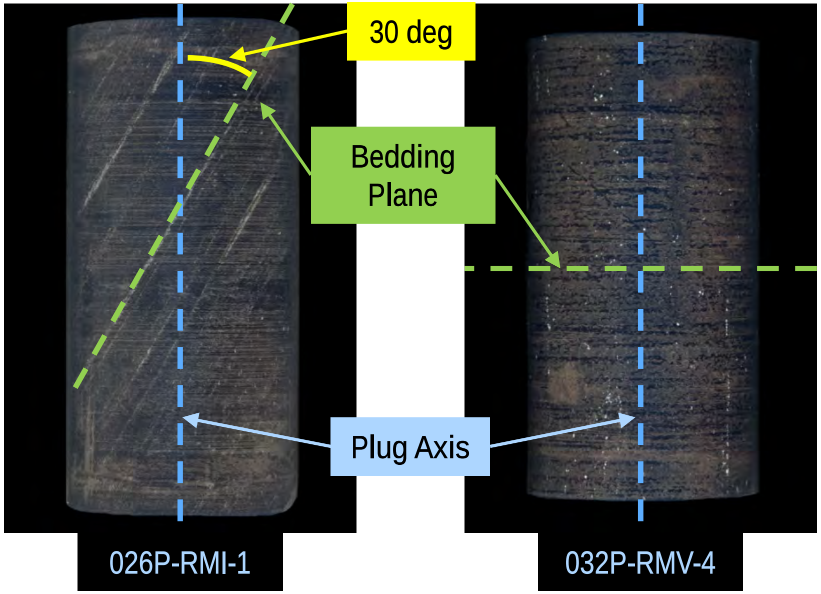


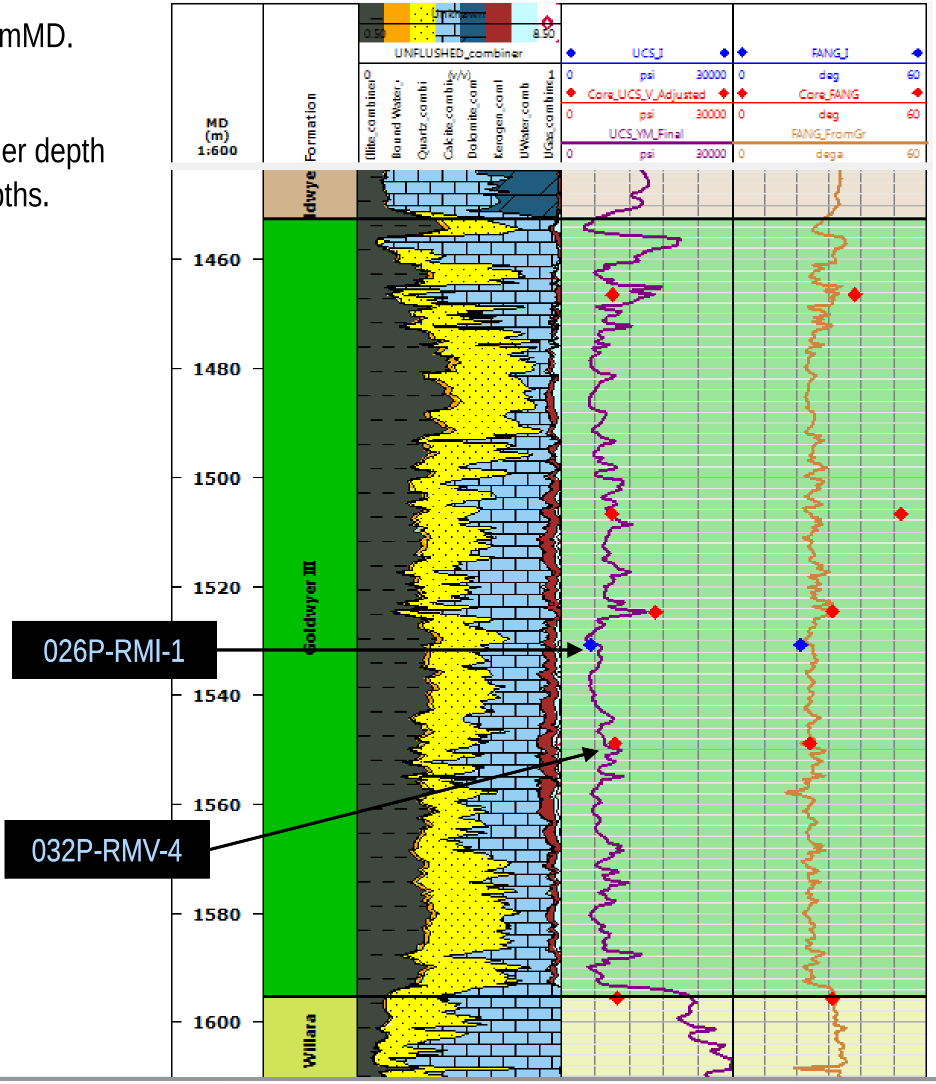



# Bedding Plane Failure

- Core 032P is used to evaluate bedding plane failure due to lack of core material for testing at the same depth as 026P.
- UCS from 032P inclined test plug is close to log-derived at 1530 mMD.
- The possibility of bedding plane failure at this depth is low.
- Tests need to be conducted on inclined test plugs and also at other depth to further evaluate bedding plane strength properties at other depths.

| Core Name | plug Number | Depth m | Litholoy | UCS psi | FANG deg |
|---|---|---|---|---|---|
| 026P | RMI-1 | 1530.71 | Shaly Sand | 5146.6 | 21.3 |
| 032P | RMV-4 | 1548.76 | Shaly sand | 9507.0 | 24.0 |



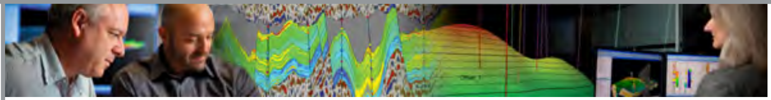
# Observations

- There are clear indications of overpressure in Goldwyer III formation. In this formation, maximum pore pressure is estimated to be around 10 ppg.

- In Goldwyer III formation, the horizontal stress profiles indicate that there are three possible stress barriers to vertical hydraulic fracture growth based on Isotropic MEM (as shown in slide number 34).

- The mud weight used in this well is adequate for maintaining stable wellbore apart from Goldwyer I formation.

- Based on UCS test conducted on one inclined test plug, the strength anisotropy between bedding plane and rock matrix appears to be low at that depth.

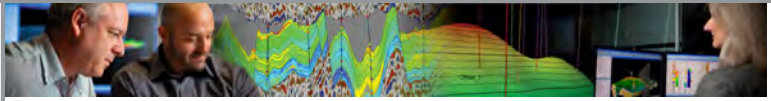


# Recommendations

- Shmin magnitude is currently calibrated with LOT data with no pump data. It is recommended to perform MDT Mini-Frac before hydraulic fracturing job to measure fracture closure pressure for calibrating Shmin to reduce horizontal stress uncertainties. As a back up plan, DFIT on drill pipe with straddle packer is recommended.

- The one core test for determining rock anisotropy indicates that Goldwyer III formation is elastically anisotropic. However, the current C66 obtained from Weatherford Sonic Tool has high uncertainties (reasons explained in earlier slide). It is therefore recommended to run Sonic Scanner in any future vertical well (if hole size permits), to derive robust C66 (as the tool is designed for this purpose) for the construction of Anisotropic Mechanical Earth Model. The formation in Goldwyer III has elastic anisotropy and therefore does increase Shmin in those zones where anisotropy is high. This will impact the hydraulic fracture modeling.

- If Sonic Scanner is logged, then further rock mechanics tests should be performed to characterize the elastic and strength anisotropies.



# The Way Forward

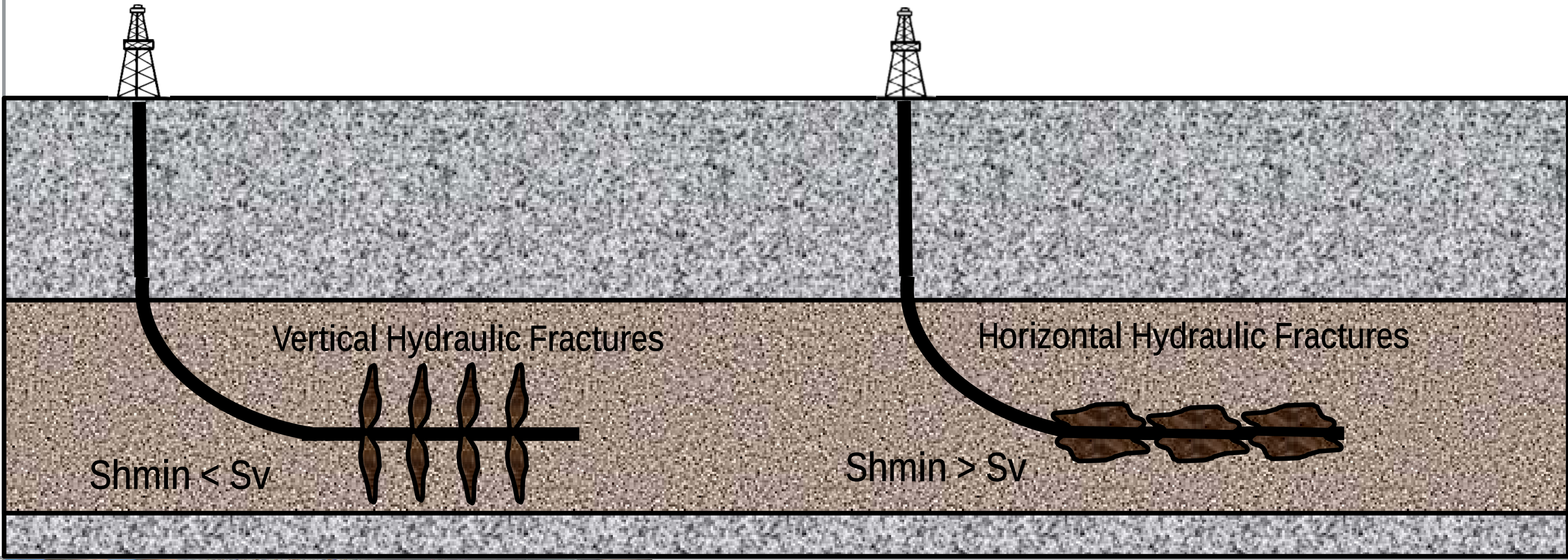
- There is high uncertainty in current Shmin from MEM Isotropic model due to questionable LOP value interpretation at the 5” csg shoe.
- There is high uncertainty in the current Shmin from MEM Anisotropic model due to questionable value of C66.

As a result of the above two points, the Shmin can be higher than Sv or close to Sv. If Shmin is higher than Sv, hydraulic fractures will propagate horizontally instead of vertically.

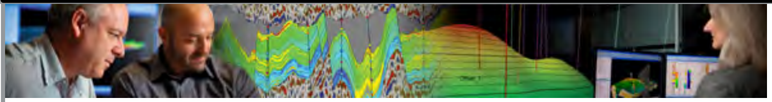
Therefore, it is important to determine the accurate value of Shmin in Goldwyer III. Accurate value of Shmin can be derived in the next well drilled by using

1st Preference: MDT-C packer (MDT C packer which has a high pressure rating) with a flow back sub (for conducting flow back)

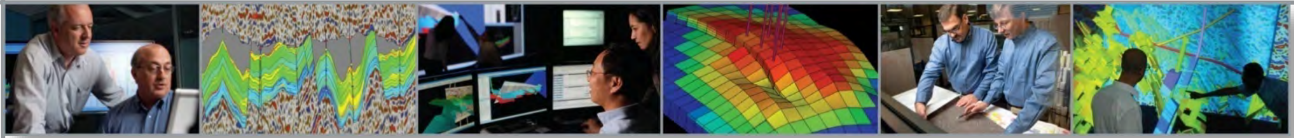
2nd Preference: DFIT conducted using straddle packers with ability to flow back.

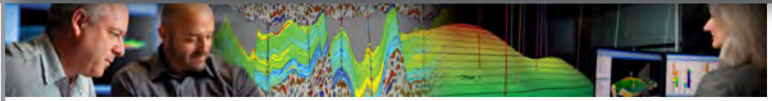




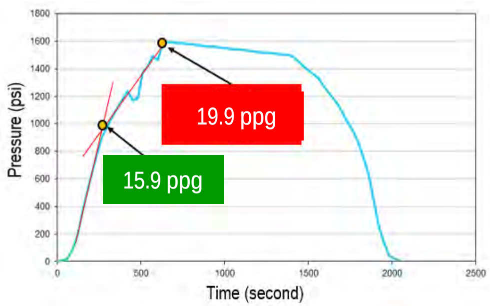



# Appendix



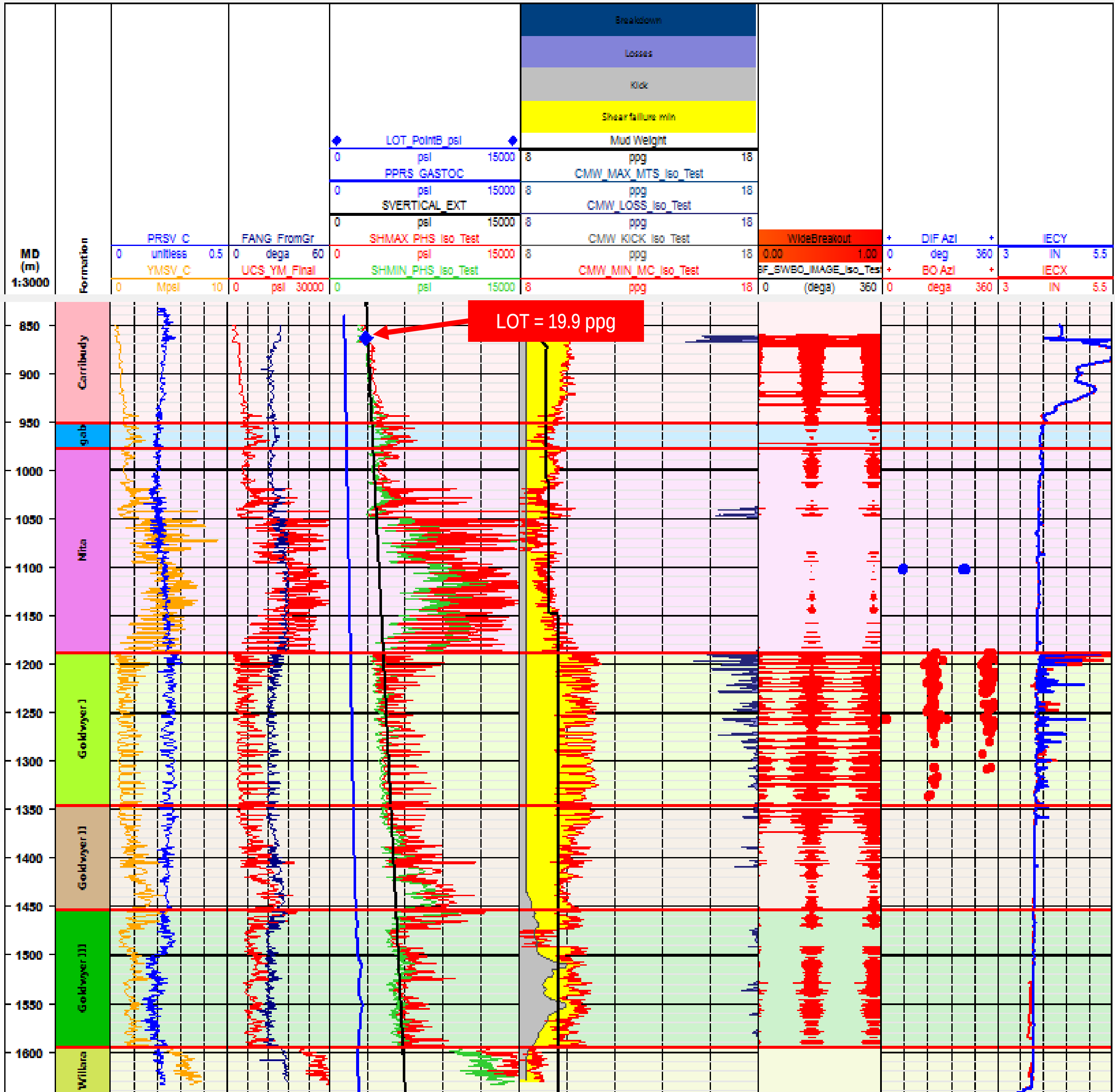


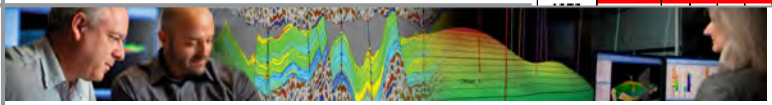
# Could the LOT value be as high as 19.9ppg at the 5" Csg shoe (864mMD)?



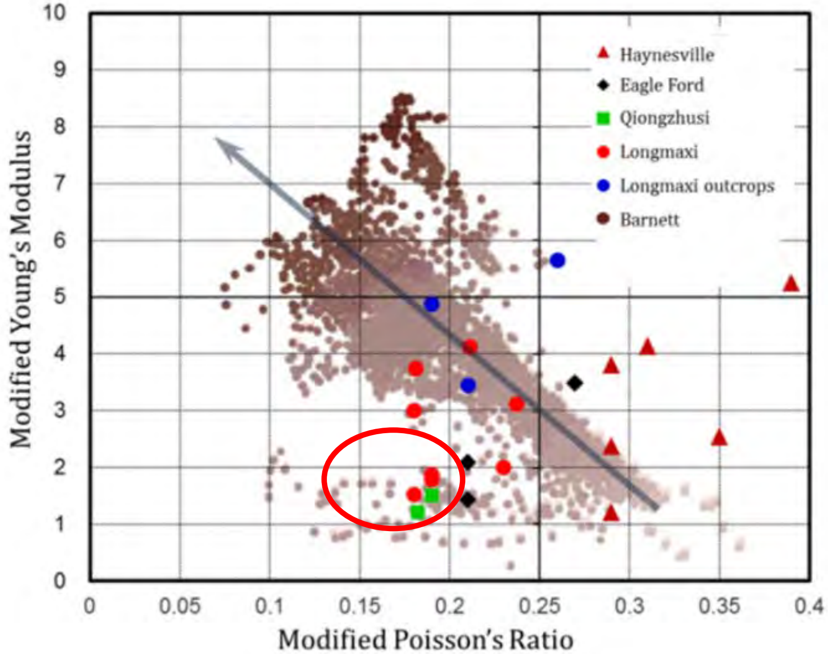

Isotropic 1D MEM and WBS calibrated to LOT of 19.9 ppg

- This slide shows horizontal stresses and WBS calibrated to LOT of 19.9 ppg.
- The purpose of this slide is to test the possibility of LOT = 19.9 ppg as reported in daily drilling reports.
- By increasing minimum horizontal stress to match the LOT of 19.9 ppg, there will be lots of breakouts in all formations from Carribudy down to Goldwyer III.
- It can be concluded that LOT at 864mMD can not be as high as 19.9 ppg and the value of 15.9 ppg is more reasonable.



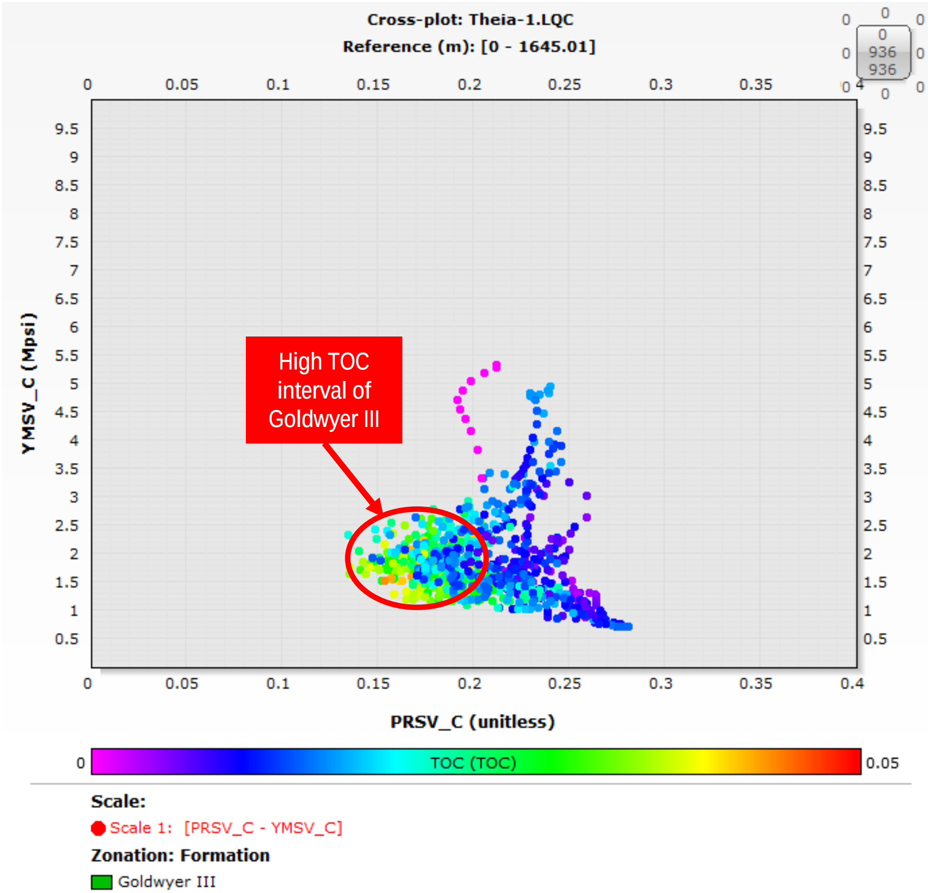
# Comparison between Elastic properties of Goldwyer III and Some Other Shale Gas Reservoirs

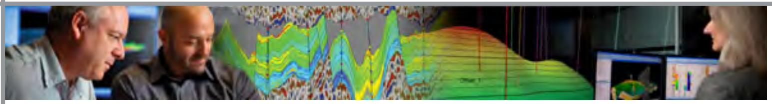



**IPTC 16580**

**Rock Mechanical Properties of Shale Gas Reservoir and Their Influences on Hydraulic Fracture**

Qinghui Li, Mian Chen, Yan Jin, Yu Zhou, China University of Petroleum in Beijing, Fred P. Wang, University of Texas at Austin, and Rixing Zhang, CNPC Tarim Oilfield Company

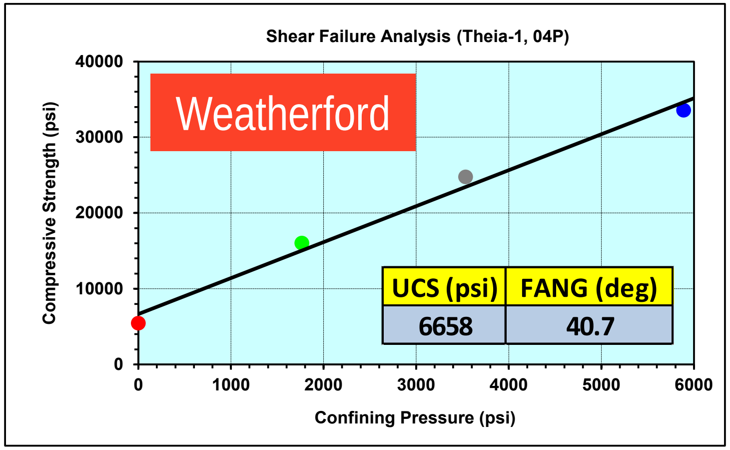


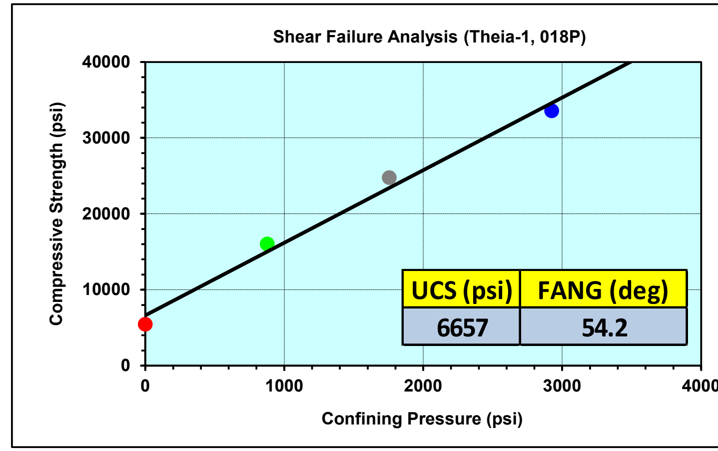
# Rock Mechanics Tests - UCS and FANG Re-Interpretation (1)

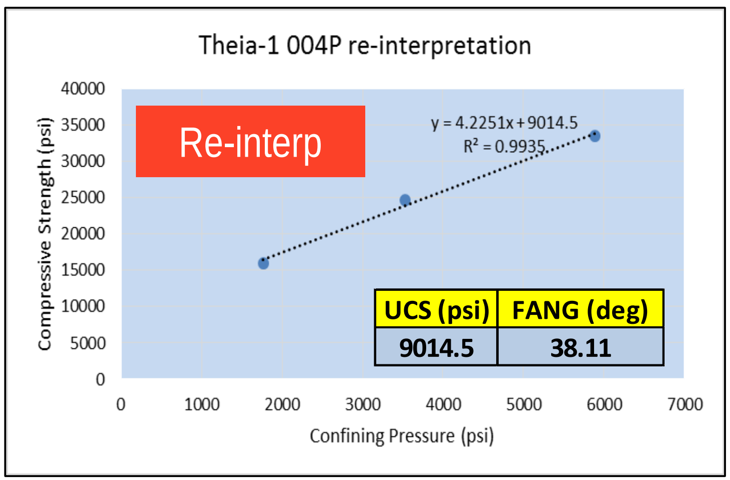
- UCS and FANG were recalculated for core 004P, 018P, 024P and 050P by fitting the line to 3 confining pressure and excluding zero confining pressure from Mohr-Coulomb failure envelope.
- Plots below shows UCS and FANG re-interpretation for core 004P an core 018P.

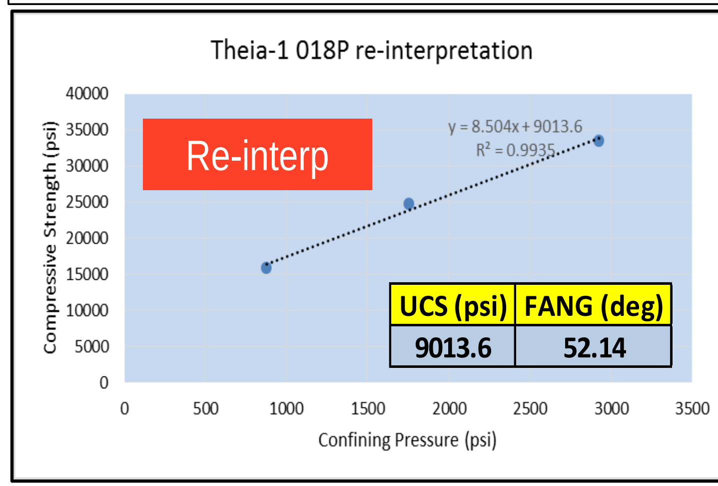
Core 004P



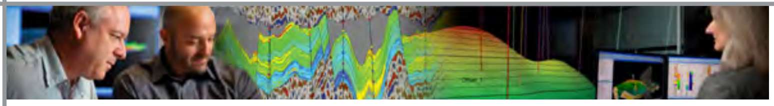

Core 018P



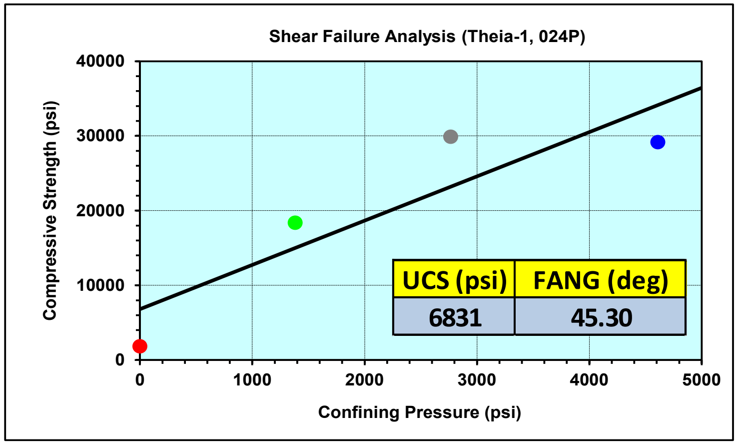


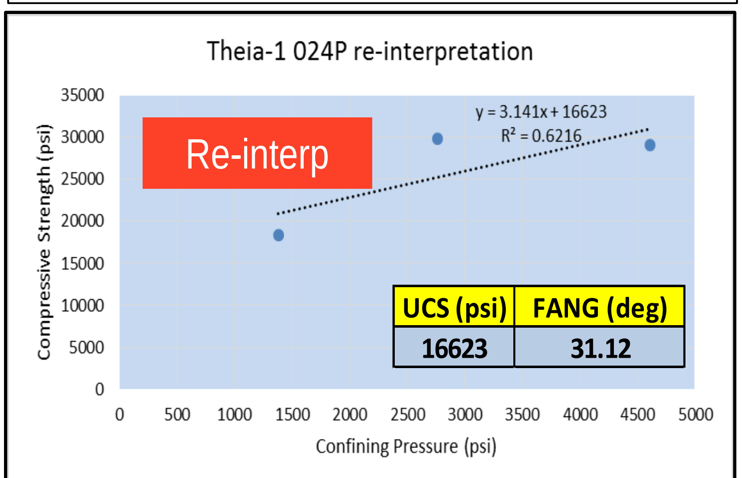



# Rock Mechanics Tests - UCS and FANG Re-Interpretation (2)

- UCS and FANG were recalculated for core 004P, 018P, 024P and 050P by fitting the line to 3 confining pressure and excluding zero confining pressure from Mohr-Coulomb failure envelope.
- Plots below shows UCS and FANG re-interpretation for core 024P and core 050P.

## Core 024P




## Core 050P