

Applying Petroleum Exploration Data to Identify Geothermal Targets in the North Perth Basin, Australia*

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Abstract

Hot Sedimentary Aquifer (HSA) geothermal systems share many characteristics with petroleum systems, and similar data and work flows are used to define them. The North Perth basin (NPB) in Western Australia provides all the geological ingredients for an HSA geothermal system, leading to an exploration campaign over the period from 2010 to 2014 to identify and drill HSA geothermal prospects in the area (Ballesteros, 2015; Ballesteros and Oppermann, 2013). One of the biggest challenges to a successful geothermal development is accurately identifying and mitigating the sub-surface risks. Undertaking geothermal exploration where sub-surface data such as wells and seismic surveys (2D and 3D) have been acquired for petroleum exploration offers a cost-effective way to address these sub-surface risks. Petroleum exploration has been carried out in the NPB since the 1960s, resulting in a substantial database of wells and seismic data (2D and 3D) in the public domain. Although accurately predicting the temperature in the sub-surface is a critical element in defining a geothermal prospect, identifying a reservoir with adequate permeability to sustain the high flow rates required for a commercially viable geothermal project is arguably the most critical element (Cooper & Beardsmore, 2008). In most cases, degradation of matrix porosity and permeability with depth because of compaction and diagenesis means it can be difficult to achieve the necessary combination of temperature and flow rate. In contrast, naturally occurring open fracture systems can offer a viable alternative reservoir target (e.g. Lushen, et. al, 2011; Schindler et al., 2010). In the NPB, a thermal model highlighting areas of high heat flow was created using temperature data available from existing petroleum wells. However, this data also suggests that matrix permeability at the 150°C isotherm is unlikely to be adequate to sustain the necessary flow rates. Attention therefore turned to the identification of natural fracture

systems that could provide a viable alternative reservoir (Ballesteros and Oppermann, 2013). Borehole image logs were used to identify the location and orientation of naturally occurring fracture systems and distinguish open from closed fractures. The regional stress field and fracture orientations most likely to remain open were predicted using the available geomechanical data, which was then correlated with the results of the borehole image log interpretations. Existing 3D seismic surveys were interpreted and integrated with the bore hole image log results. An automated fault extraction algorithm was applied to identify the density and orientation of faults and fractures in the seismic data. Taken together, these results highlighted areas with higher probabilities of both open fracture systems and adequate temperatures needed for a viable geothermal prospect. The final stages of this effort were carried out in partnership with one of the leading petroleum operating companies in the area. The company farmed into the geothermal project with the intention of undertaking a drilling program with complementary geothermal and petroleum objectives. Unfortunately, due to non-technical reasons, the company withdrew at a late stage and the project subsequently had to be abandoned before drilling a well. These highlight both the potential synergies of petroleum and geothermal exploration as well as the challenges inherent in attempting any significant variation to established practice.

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- Lushen, E., M. Dussel, R. Thomas, and R. Schultz, 2011, 3D seismic survey for geothermal exploration at Unterhaching, Munich, Germany: First Break 29, 45–54.
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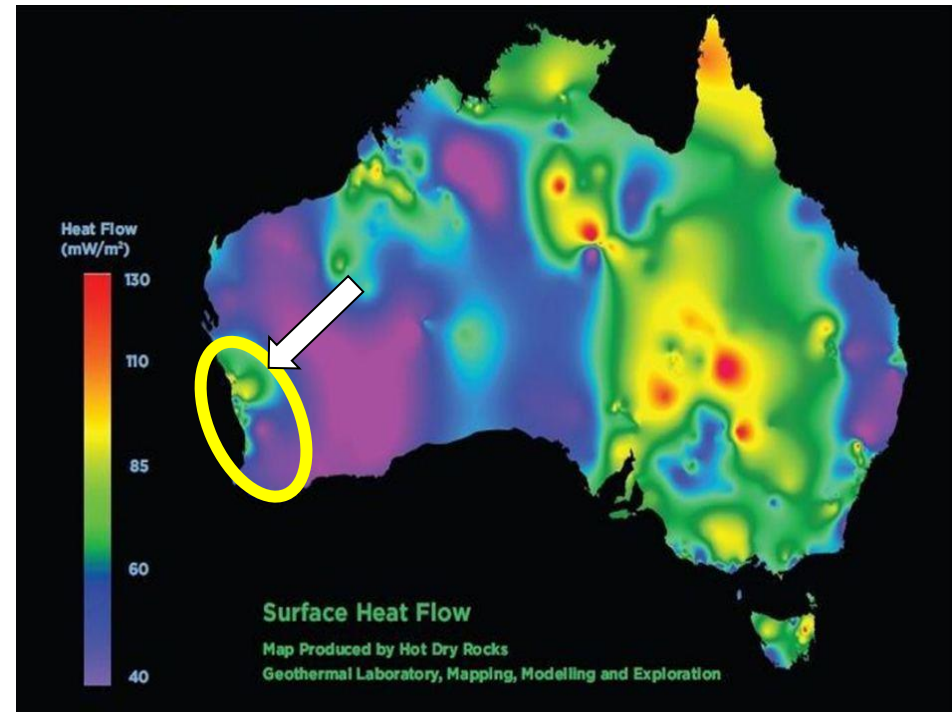
Aspects of Petroleum-Geothermal Synergy



- Data (seismic and well) for sub-surface control
- Cost sharing for dual objective exploration well
- *Produced fluid for potential low temperature ORC power generation*

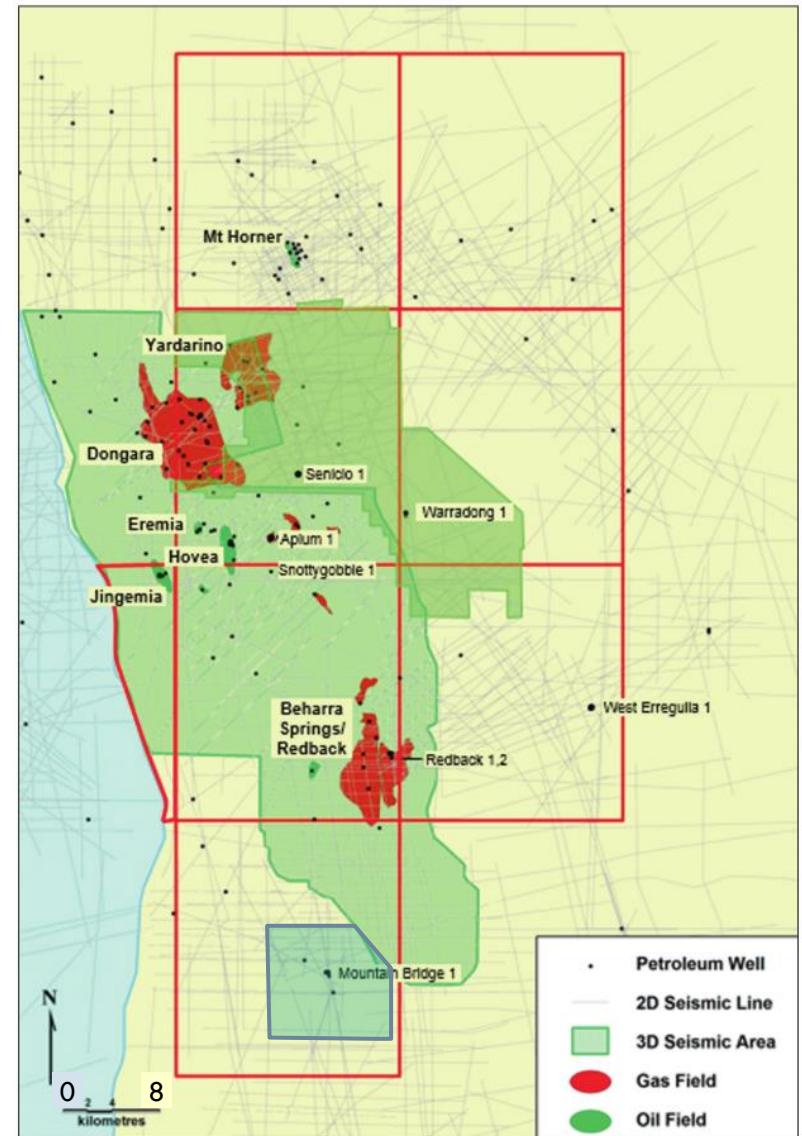
Perth Basin, Western Australia

- Located in SE corner of Western Australia
- Established (but relatively minor) petroleum producing area since 1960s
- High heat flow in northern part of basin
- Petroleum data enters public domain 2-3 years after acquired.
- Petroleum and geothermal permitting systems are separate but administered by same government agency



Available Data

- **132 wells** with temperature logs including:
 - 39 wells where at least 150°C is expected in sediments at depths less than 3,500m
 - 13 wells – where 150°C is expected in sediments at depths 3,500m to 4,000m
- **32 water bores** T logged
 - maximum depth 500m
 - 4,455 metres of T logs recorded
- 154°C at 3416m depth (Mountain Bridge-1)
- Approximately **24,000 km of 2D seismic** data
- Over **1,000 km² of 3D seismic** data (now >1600km²)

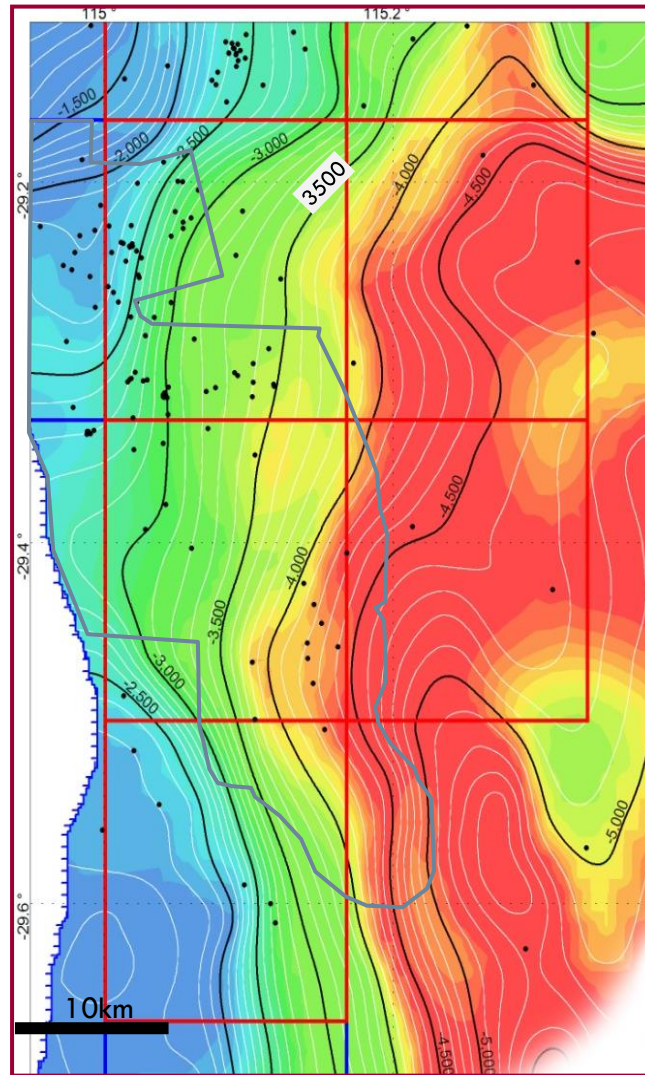


Summary of Geothermal System

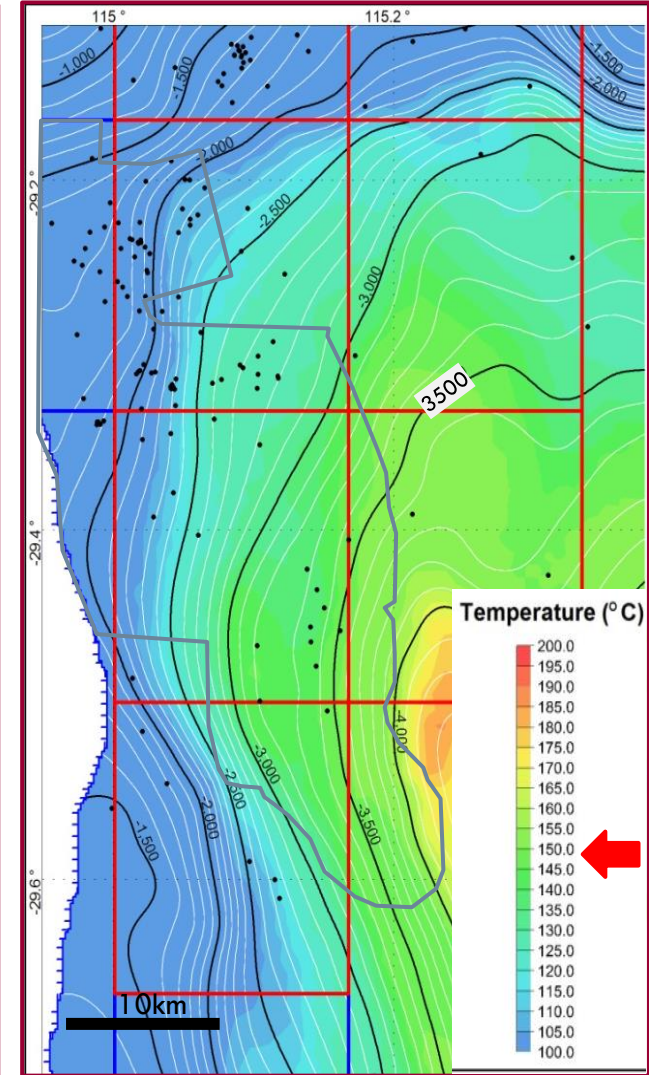
- Available data demonstrates the presence of a viable hot sedimentary aquifer (HSA) geothermal system in the North Perth Basin.
- Geothermal fluids at 150+°C accessible at ~3500m.
- Moderate water temperatures mean high flow rates (75+ l/s or 40,000+ bpd) required to produce commercially viable amounts of thermal energy for ORC electricity generation.
- Biggest challenge is finding sufficient permeability to sustain these flow rates.
- Commercially successful HSA geothermal projects in Rhine Graben (Germany) exclusively target permeability associated with natural open fracture systems.
- Similar open fractures evident in study area in data from multiple wells.

Regional Structure and Temperature

- These maps show temperature at top Permian and basement levels.
- Top Permian was primary petroleum objective and considered the best HSA target for matrix permeability.
- Porosities >10% not uncommon at target depths.
- Temperatures of ~150°C (green) occur at depths of <3500m in a number of areas.
- However, thin reservoir and limited permeability forced conclusion that formation matrix would not provide adequate geothermal reservoir.



Basement



Top Permian (Wagina Fm)

(After Morey & lasky, 1996)

Natural Fracture Permeability

- Interpretation of image log data from wells reveals numerous fractures are present in the study area (King, et al, 2008 & 2011).
- Some fractures are electrically resistive = filled or cemented by resistive material, and hence impermeable.
- Other fractures are electrically conductive = water-filled and therefore permeable, (although possibly filled with conductive minerals).
- At least some of the conductive fractures have associated mud losses, suggesting they are permeable.
- Determining a relationship between the orientation of conductive vs. resistive fractures should help determine the most favourable locations & orientations to target.

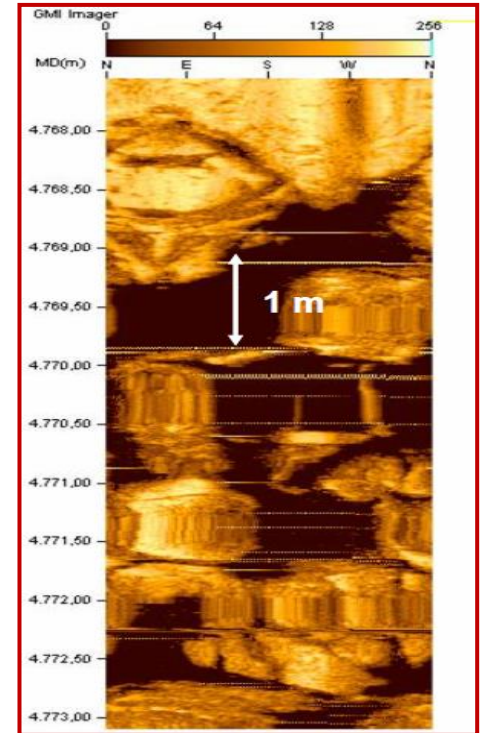
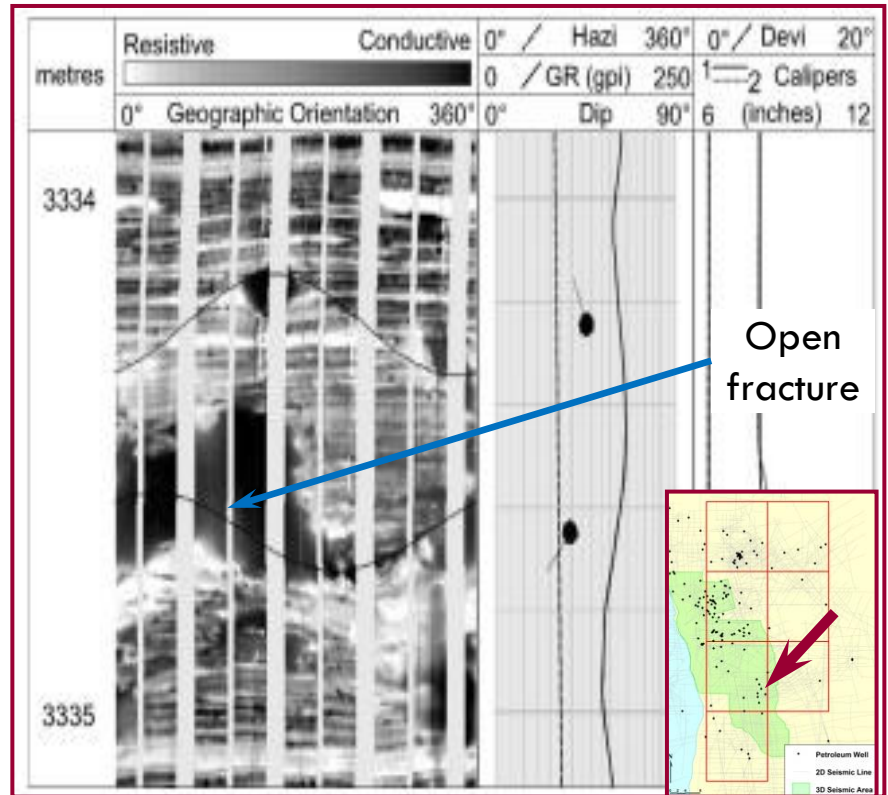


Image log from the Soultz EGS project in the Upper Rhine Graben shows 1 meter wide open fracture at 4700+ m in granitic basement.

Open Natural Fractures: Redback-1

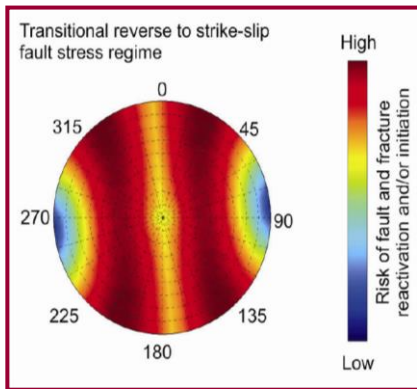
- The Redback-1 well provides direct evidence for naturally occurring open fractures in the permit area.
- The image shows a 25 cm wide open fracture at 3334 m oriented roughly E-W.
- Additional studies show open fractures also occur in N-S and NW-SE-trending faults in the area.
- Favourably oriented fractures also evident in other areas.
- Geothermal fluid production in Rhine Graben is exclusively from similar open fractures.



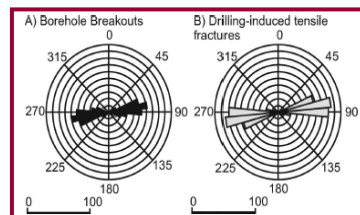
FMI log Image from Redback 1 (King et al, 2008)

Conductive Fracture Orientation

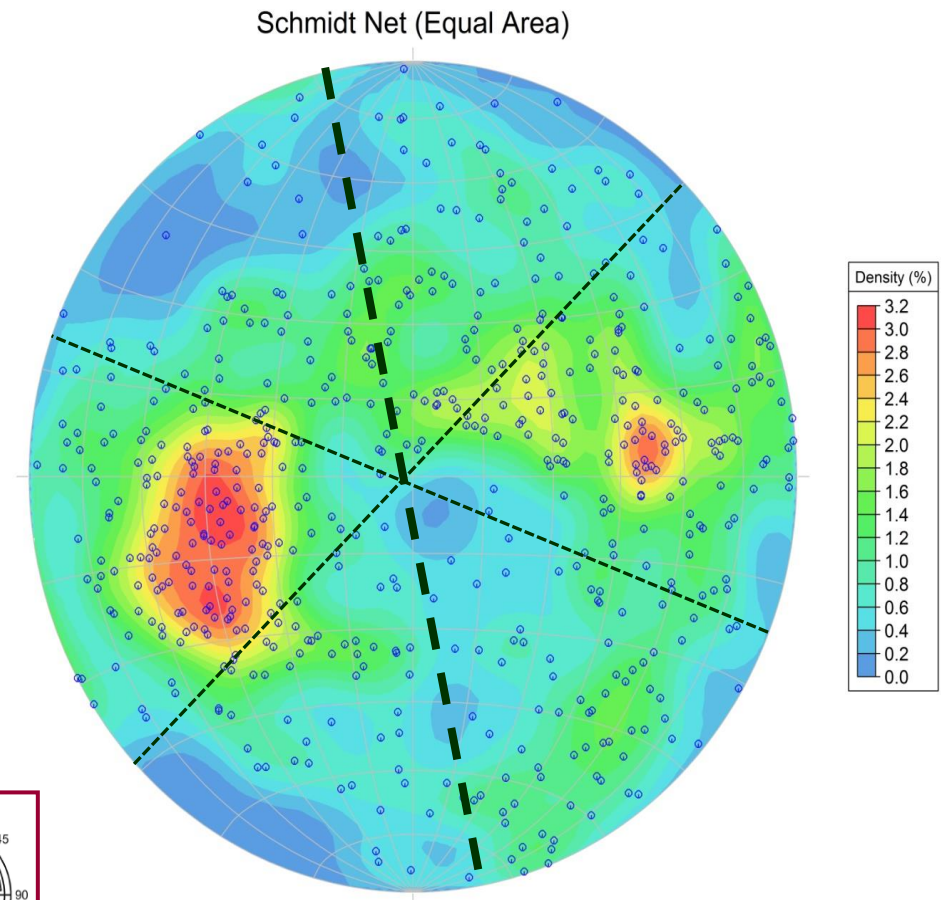
- This stereo net projection illustrates the orientation of all the conductive fractures interpreted from image log data in the permit area.
- Fractures are represented as poles to plane.
- Data show the most common orientation for conductive fractures is \sim N15°W dipping at an angle of 30° to 60°.
- Conductive fractures oriented NE dipping 60°-80° are also reasonably common.
- Another cluster occurs for WNW trending fractures dipping 60° to 70°.



Theoretical Chance
of Reactivation



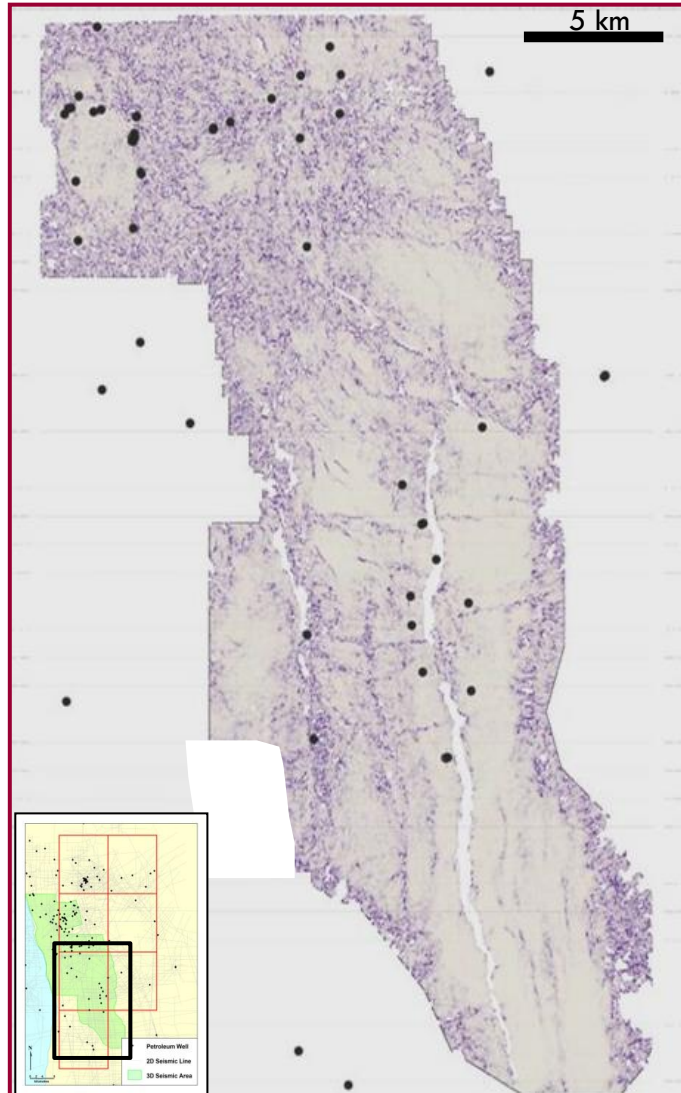
Maximum
Horizontal Stress



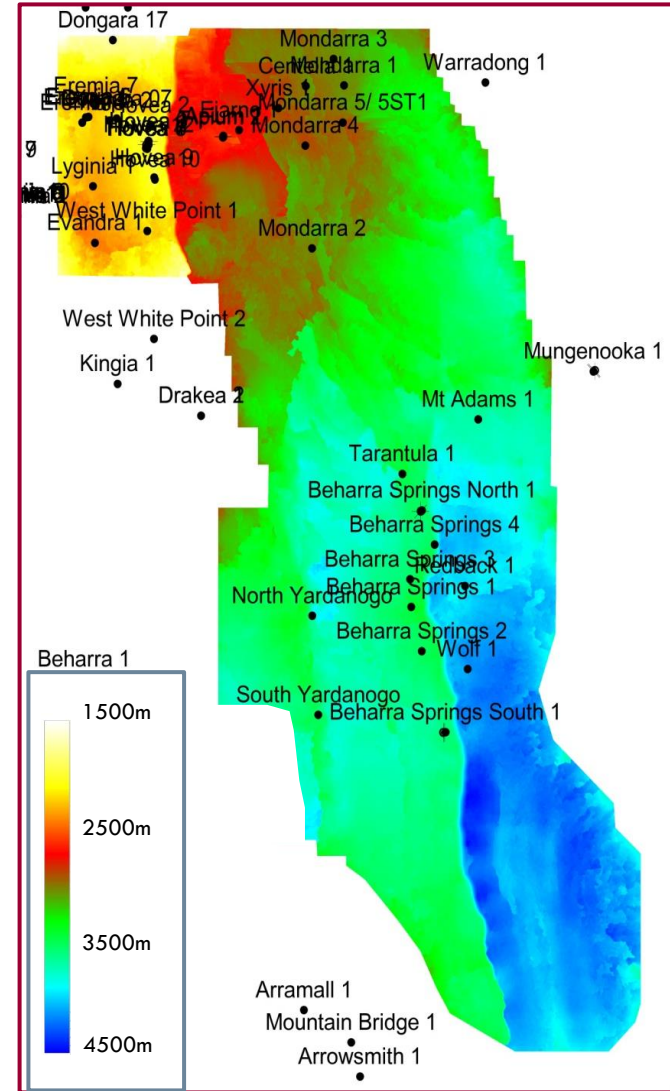
Observed
Conductive Fracture
Orientation

Top Permian Depth Structure and Coherency

Coherency processing helps to highlight discontinuities in the seismic data, such as faults and fractures, providing a much clearer illustration of fault orientation.



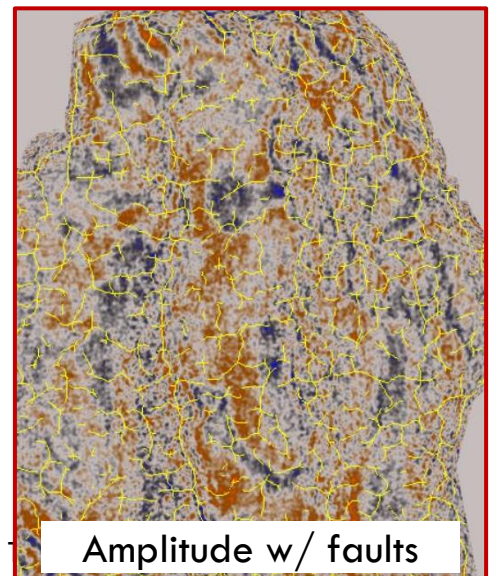
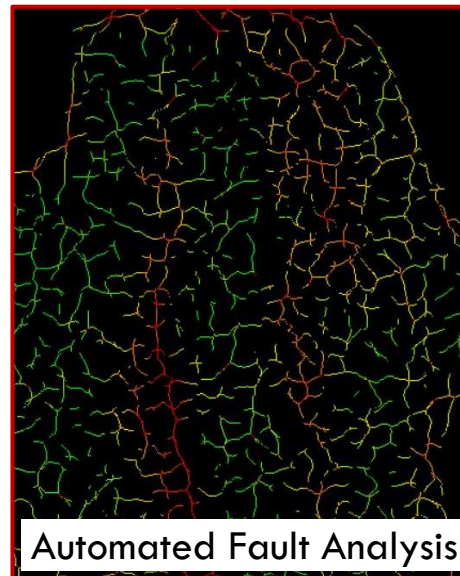
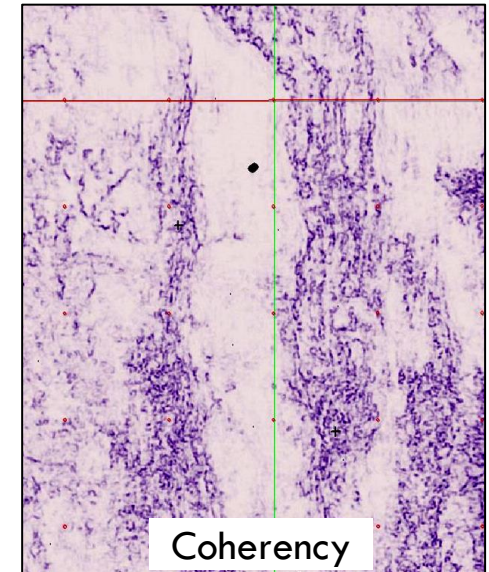
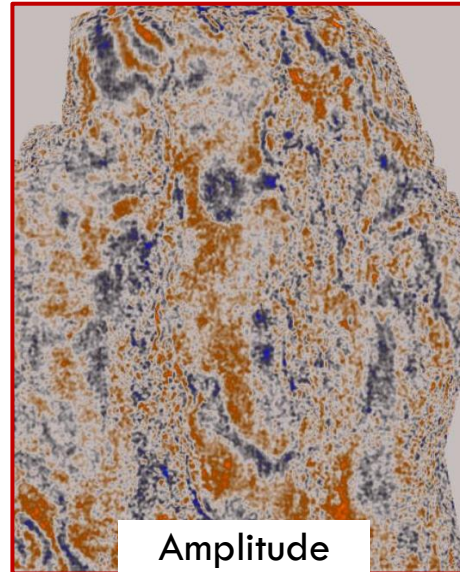
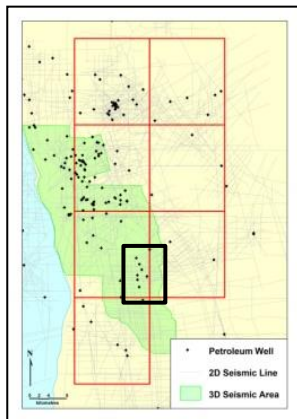
Coherency at Top Permian

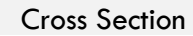
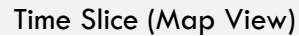
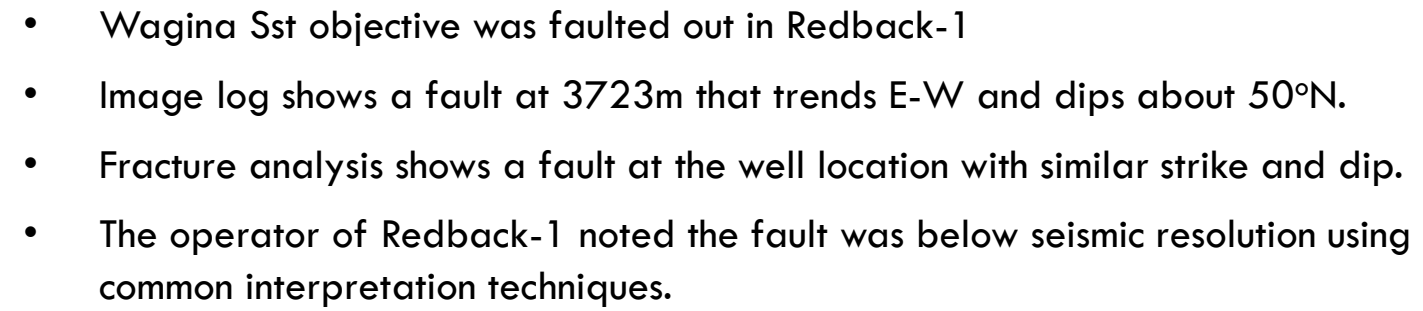


Top Permian Depth Structure

High Resolution Fault Detection

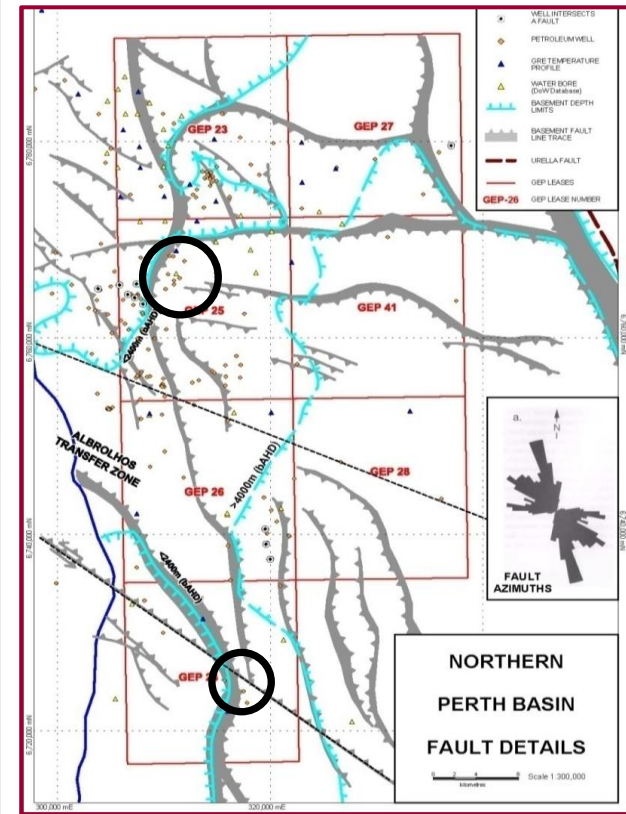
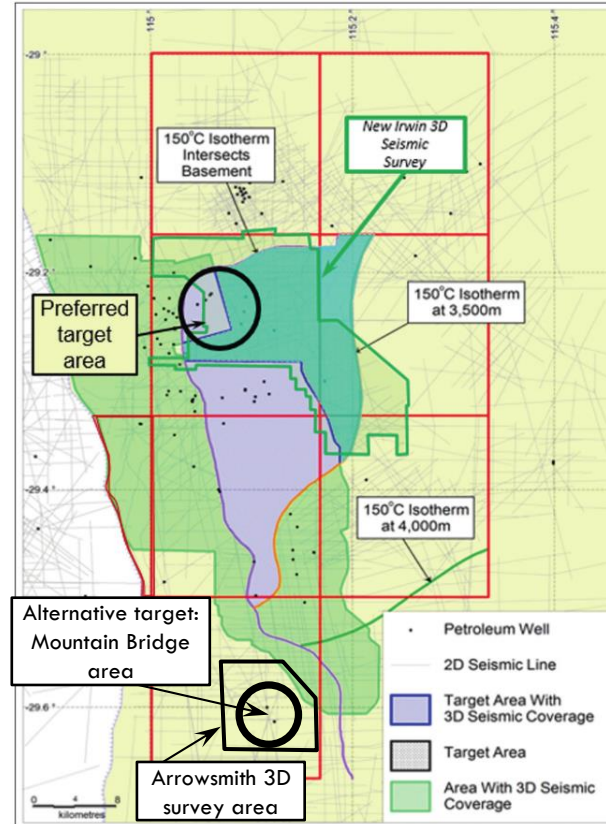
- General trends are well imaged in the coherency data.
- Detailed information about fault segments and smaller scale features is only visible in the fault extraction processing.
- This example is a time slice at 1150ms (in the Jurassic).





Drilling Phase

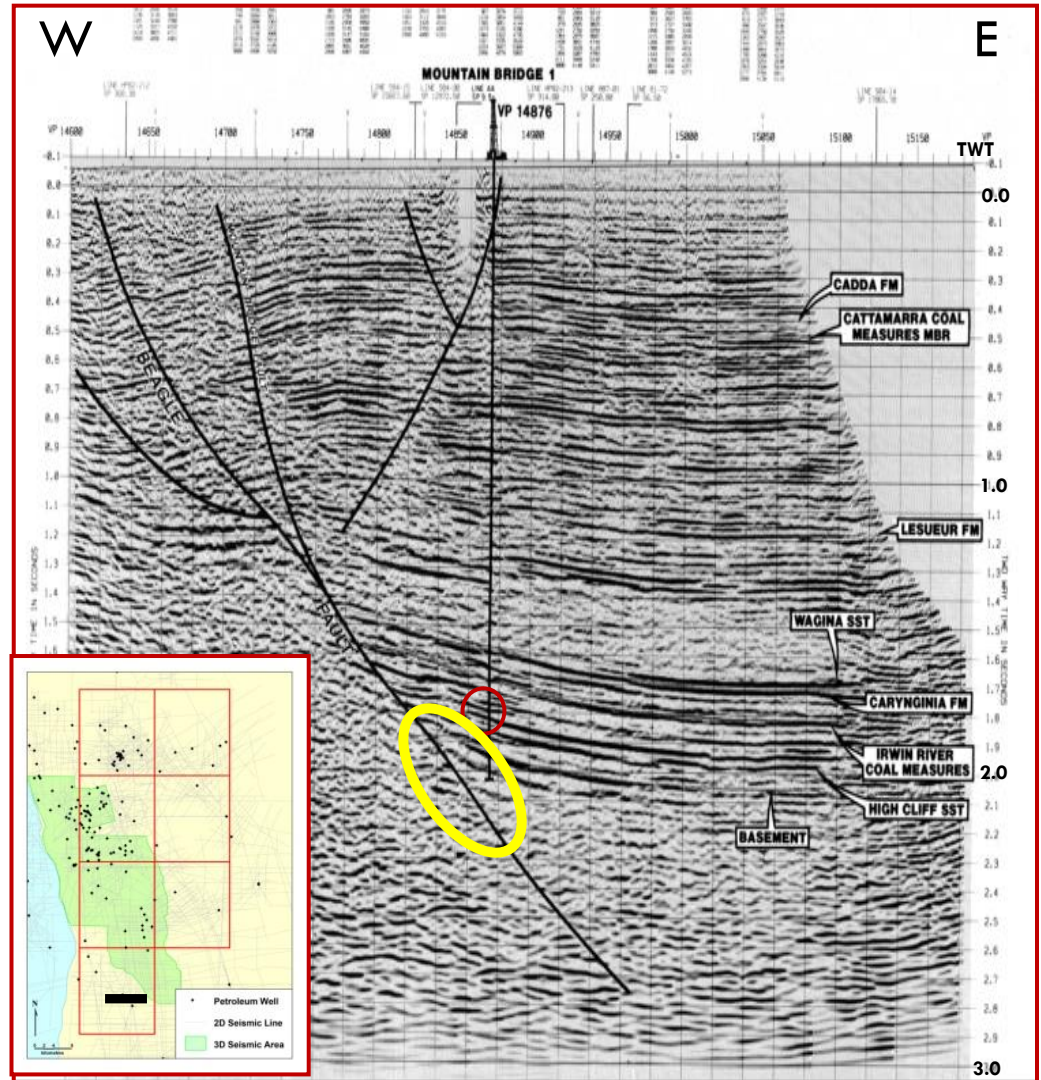
- Government funding obtained (A\$17MM)
- Oil company farmed in
- Preferred target area identified where
 1. fault orientation favourable for open conductive fractures
 2. In 3D data coverage
- Problems arose in permitting process that prevented access to proposed location.



- New location identified in Mountain Bridge area
- Outside of existing 3D coverage, but 3D survey planned (additional potential synergy!)
- Survey designed to evaluate recent unconventional oil and gas discovery
- Petroleum appraisal well planned

Mountain Bridge-1 Geothermal Prospect

- DST-2a (3185-3235m) in High Cliff Sst.
- **Flowed 146°C water** at 2000-3000 BPD (5 l/s) w/ 0.25 mmcf/d gas.
- **Producing from fractures**
- Core shows open fractures with very low matrix permeability.
- **Geothermal prospect testing fractures in main fault zone**

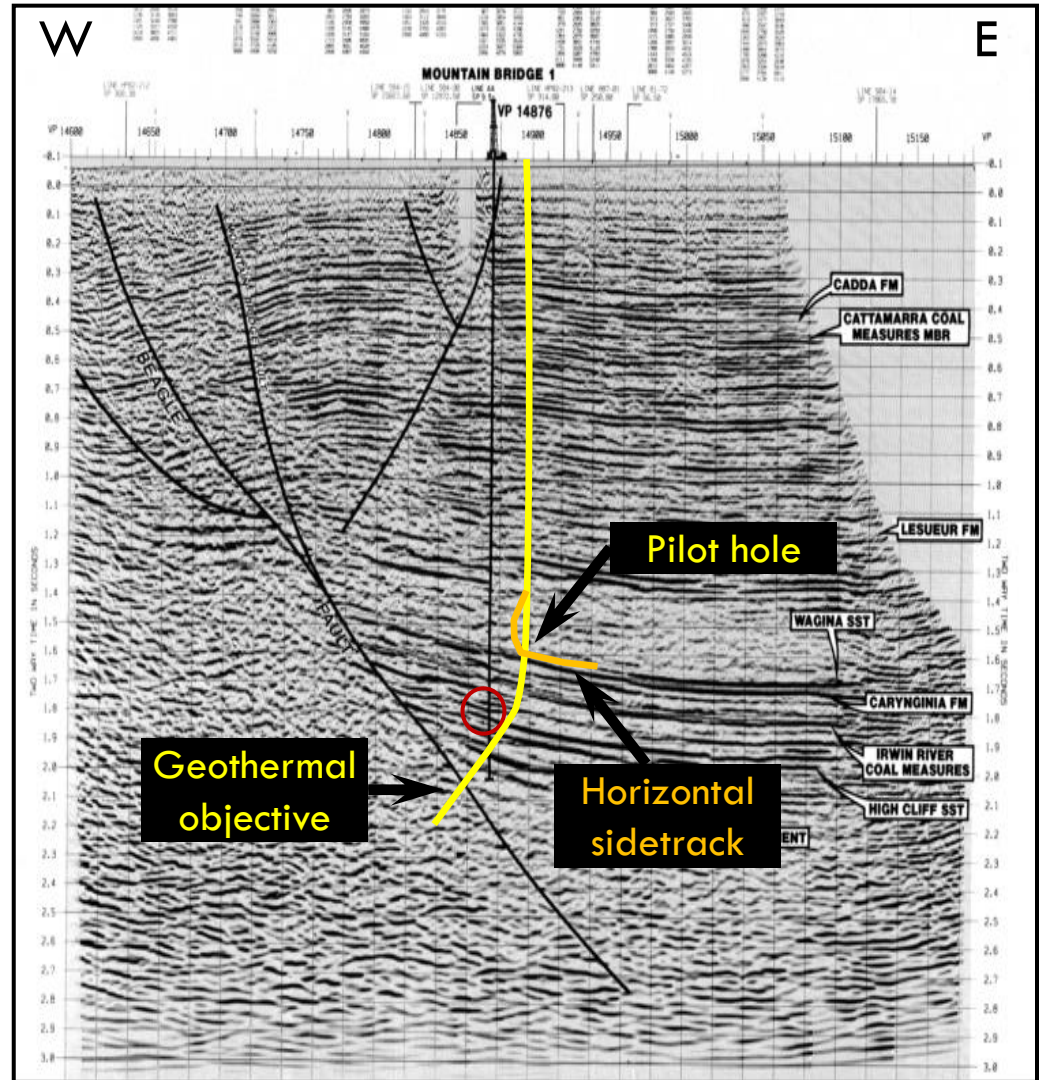


Mountain Bridge-1 Petroleum Prospect

- Nearby well (Arrowsmith-2) successfully tested oil and gas from multiple zones after hydraulic stimulation.
- 3D seismic survey acquired to target appraisal wells
- Company planned to drill, frac and test horizontal well
- Pilot well required

OPPORTUNITIES:

- Acquire passive seismic data as part of 3D survey (Tomographic Fracture Imaging) to identify permeable fracture systems
- drill pilot well as geothermal test into fault zone



Conclusions

- Public-domain petroleum exploration data demonstrates the presence of a viable hot sedimentary aquifer geothermal system in the North Perth Basin with geothermal fluids at 150+°C accessible at ~3500m.
- Permeability associated with natural open fracture systems offers the best chance to achieve the required flow rates for a commercially viable ORC development. Matrix permeability too low.
- Analysis of available borehole image logs allows orientation of conductive and resistive fractures to be defined and distinguished.
- Automated high resolution fracture extraction methods of 3D seismic data can identify orientation and density of small-medium scale faulting.
- Correlation of borehole image data and high resolution fracture analysis of seismic data allows identification of drilling location and well design that maximize chance of encountering high permeability zones.

Conclusions (2)

- Petroleum and geothermal exploration programs can be complementary.
- Similar analyses of fracture systems can be used to identify and assess geothermal and petroleum (conventional and unconventional) prospects
- Potential synergy of dual objective well (geothermal and petroleum) can reduce risks and increase chance of commercial success
- Close cooperation and open minds are essential as standard practice for drilling differs significantly in the two industries

Acknowledgements



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THANK YOU

