Australian Experiences in EGS Permeability Enhancement: A Review of 3 Case Studies

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Presentation Outline

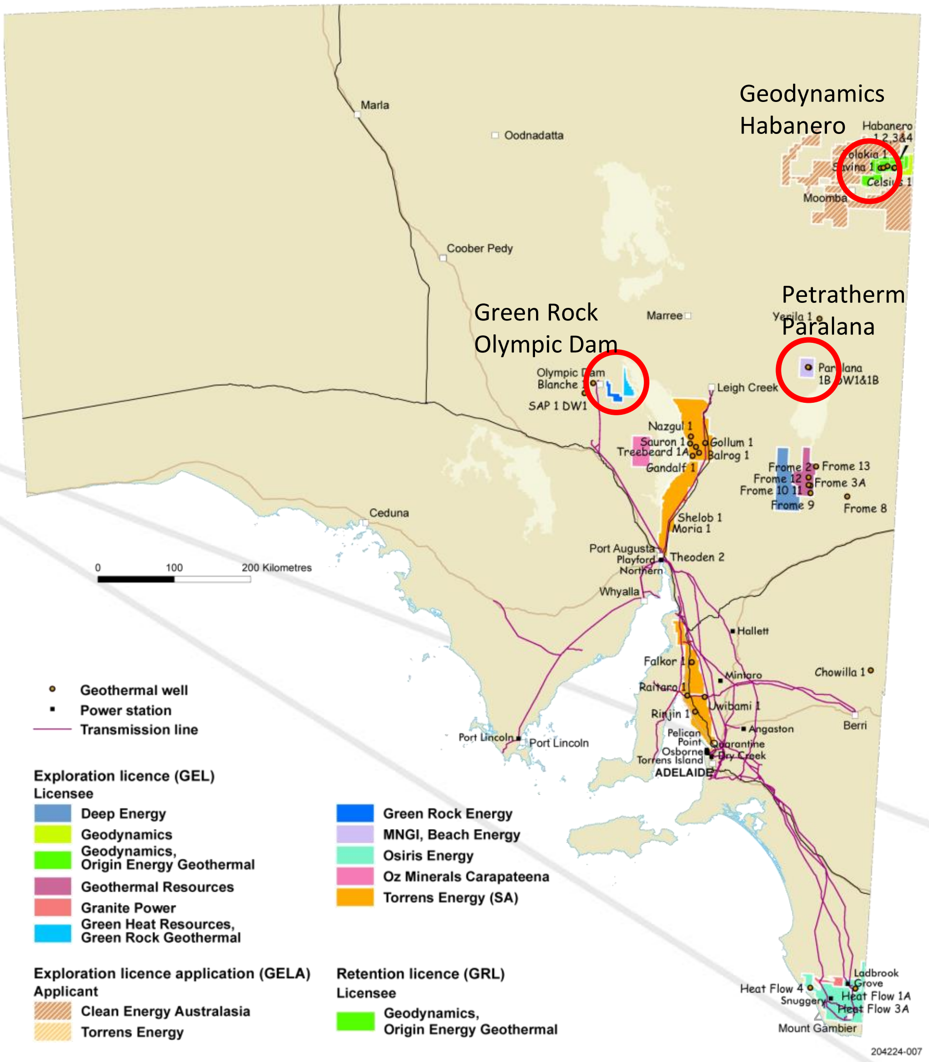
- Overview
- 3 Case Studies
  - Green Rock Energy’s Olympic Dam Project
  - Petratherm’s Paralana Project
  - Geodynamics’ Habanero Project
- Lessons learned

Acknowledgements

- Geodynamics Limited - Robert Hogarth, Heinz Holl, Andrew McMahon.
- Green Rock Energy Limited – Adrian Larking.
- Petratherm Limited – Peter Reid.

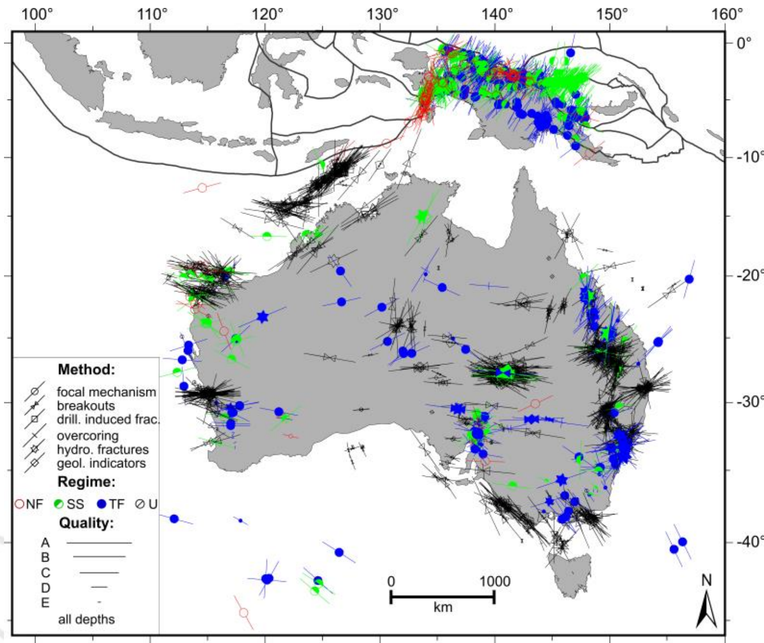
Overview

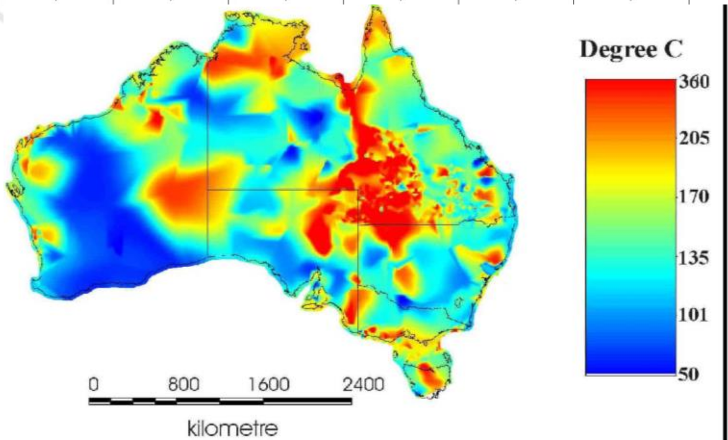
- Review of 3 case studies
- All located in SA
- 3 different geological terrains
- Different exploration, well design and stimulation strategies used.
- Green Rock Energy – Olympic Dam:- in Mesoproterozoic granites of Gawler Craton.
- Petratherm – Paralana:- in Mesoproterozoic metasediments and granites, Flinders Ranges.
- Geodynamics – Habanero:- in Carboniferous granites below Permian Cooper Basin, petroleum province.



Overview

- Some commonalities between the projects are unique features of the Australian Crust.
- Indo-Australian plate converging with Indonesia – compressional to strike slip in situ stress field promotes horizontal fracturing (data from World Stress Map).
- Extensive high heat producing (radiogenic) basement as potential heat sources (Geoscience Australia Oztemp Map – estimated temperature at 5km depth)



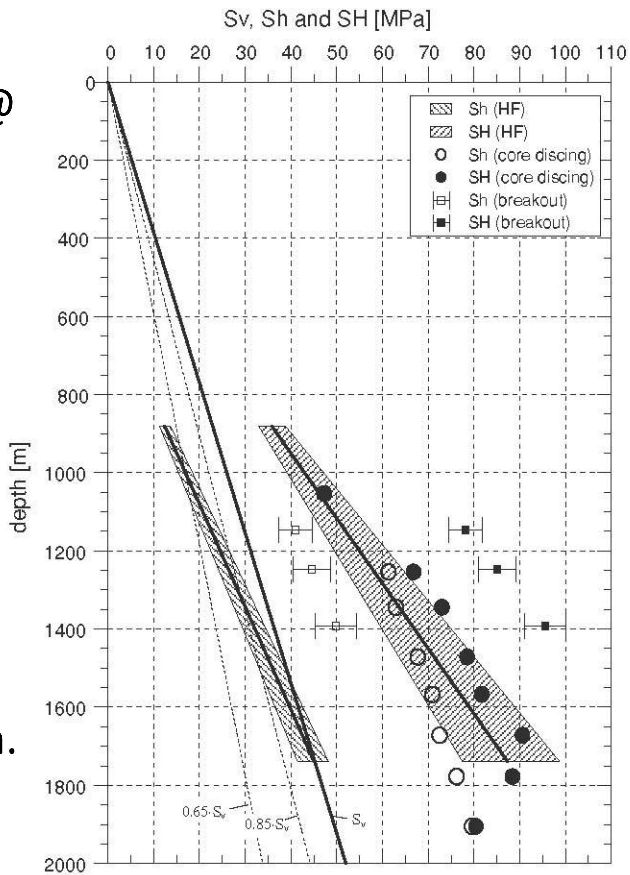


Green Rock Energy – Olympic Dam

- 2005 Blanche 1 TD 1954m in Burgoyne Batholith.
- Constrain heat flow (~94 mW/m^2), temperature (85.3^{o}C @ 1934.2m), drilling and stress conditions.
- Core disc, borehole breakout, 12 DFITs (881–1739m).
- SHmax to N97^o; magnitude (~34 – 96 MPa).
- Change in stress regime: <1340m = strike slip; >1340m = compressional
- At reservoir depth SHmax>Shmin>Sv: hydraulic fracture planes should propagating horizontally. Opening pressure ~ Sv.

Lessons

- Investigate stresses as close as possible to reservoir depth.
- Target natural fractures.



(After Klee et al, 2011)

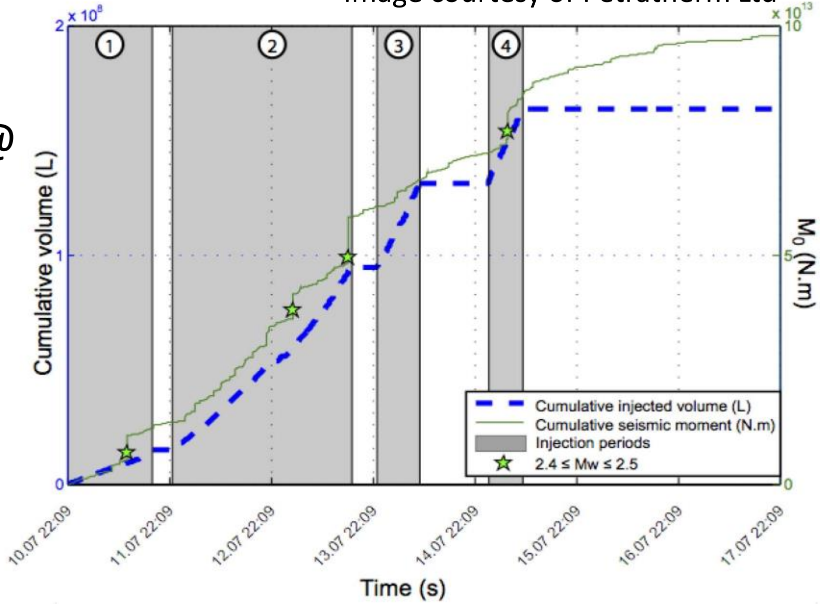
Petratherm – Paralana Project

- 2006 Paralana 1 tested heat flow (~110mW/m^2) & temperature (108.5^{o}C @1807.5m).
- 2009 Paralana 2 to 4003m. Stimulation to be conducted through perforated casing to enable multi-stage ops.
- Several zones of instability @ 3670 – 3864m, overpressured fluids and fractures intersected. Shut in pressures ~ 3300 psi; casing only deployed to 3725m.
- LWD suite run inc. low res Azimuthal Density log – in situ stress tensor and fracture susceptibility calculated.
- Fracture clusters at 2595 – 2670m & 3610 – 3730m striking NE.
- SHmax striking N97^o but SHmax Shmin magnitudes poorly constrained; strike slip or compressional regime possible.
- Susceptible fractures striking parallel SHmax +/- 50^o & steep dipping (>60^o) N or S.
- Existing fractures are critically oriented for re-activation.

Petratherm – Paralana Project

- 2011 – Casing perforated at 3679 – 3685m, i.e. 6m.
- DFIT then stimulation of Paralana 2 well to enhance fracture network.
- Injected 3.1M litres of fluid at pressures to 9,000 psi, injection rates 3 to 27 L/s
- Acid treatments allowed higher pumping rates (mud & cement).
- Late Gel /Sand slugs to maximise well connection.
- Flowed back ~ 1.3 million litres (overpressure) @ 6 L/s
- Stable WHP ~4000 psi
- 11,000 events recorded in Real Time
- ~98% < M_L 1.0; maximum M_L 2.6
- Good correlation between cumulative injected volume/seismic moment

Image courtesy of Petratherm Ltd

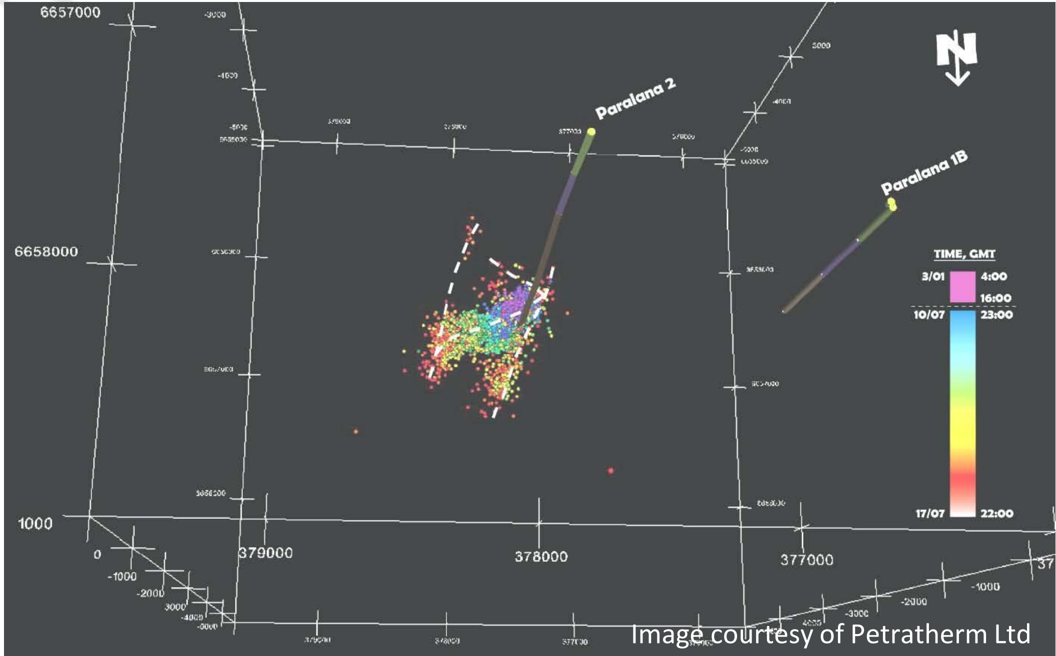


Petratherm – Paralana Project

- Fracture stimulation produced a large complex fracture cloud extending ~1,100m mainly N & NE between 3500 – 4000m depth.
- At least 4 main structures modeled.
- Focal mechanism solution shows in situ stress state compressional (thrust).

Lessons:

- Target natural fractures for max. flow.
- Critically oriented with in situ stress field.
- Acid treatments used successfully to initiate fracturing.
- Successful stimulation through perforated zone.
- Test strategy with multi-stage stimulation.



Geodynamics – Habanero Project

- 4 EGS wells > 4200m into Big Lake Suite granite, Cooper Basin.
- Multiple stimulations since 2003.
- SH_{max} azimuth is ~N82°; compressional regime.
- Pre-existing N-S striking, shallow dipping structures prone to slip with stimulation.
- Numerous fractures identified – not all critically stressed.

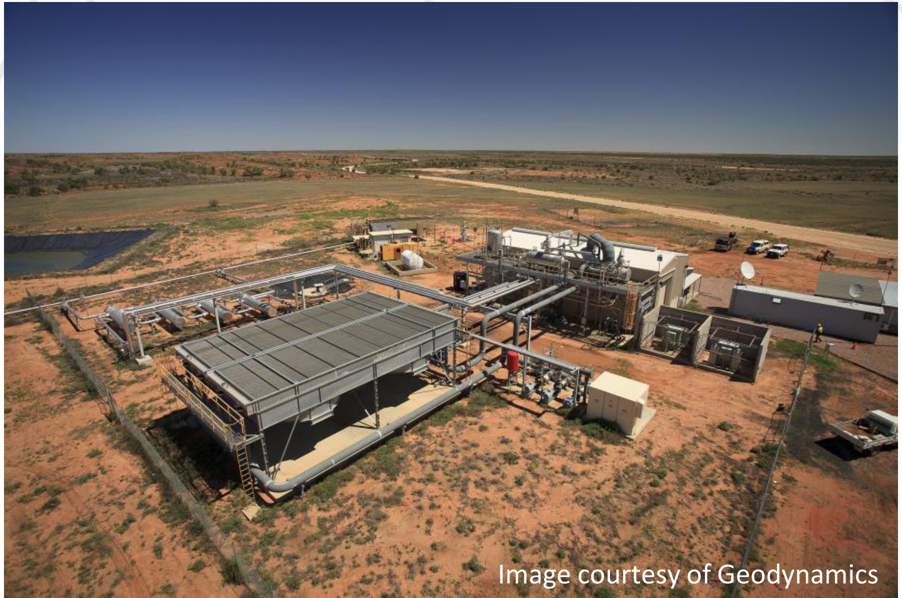


Image courtesy of Geodynamics

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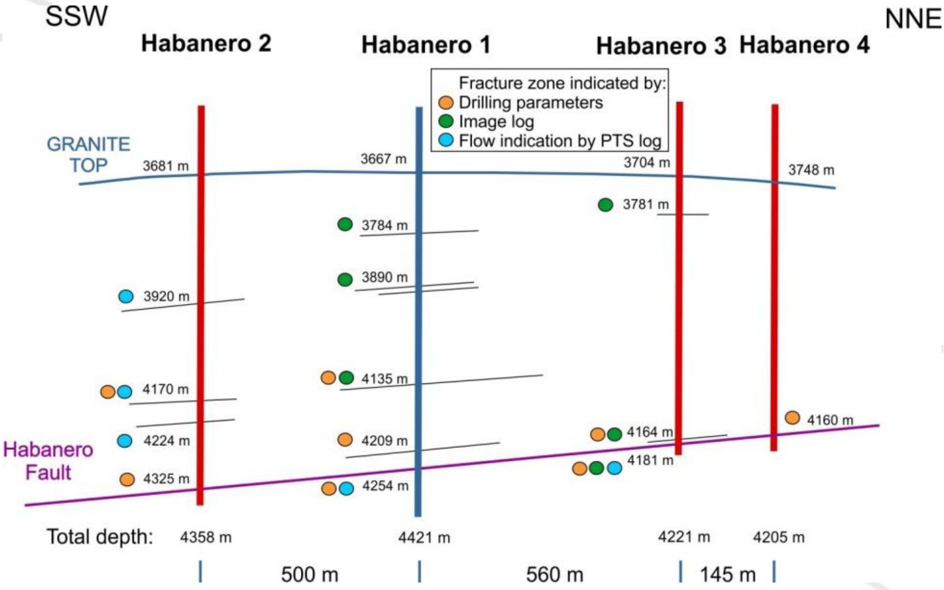
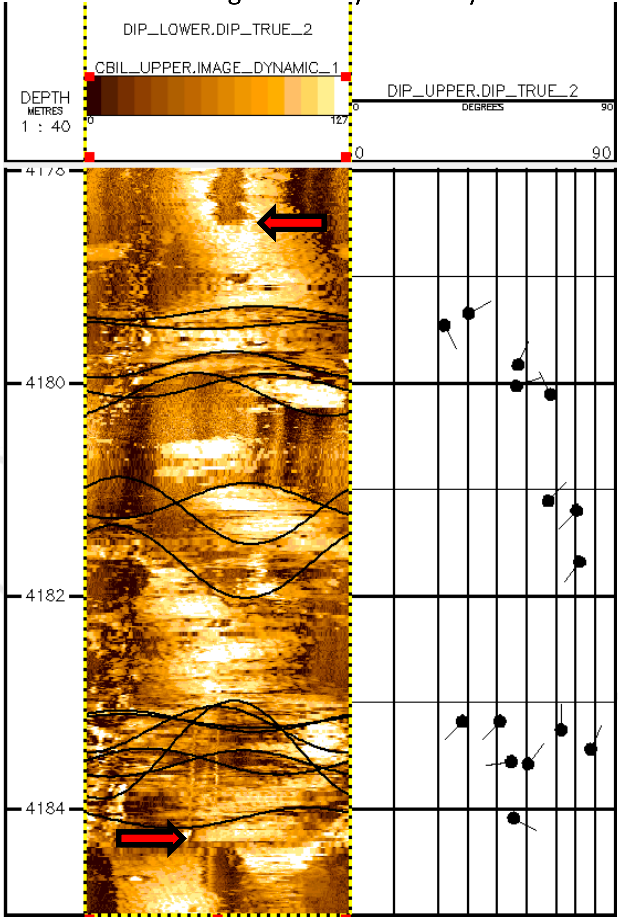


Geodynamics – Habanero Project

- Only one conductive zone contributes to fluid flow through the reservoir.
- Young thrust fault (5-10 Ma).
- “Habanero Fault” 5-6m thick active zone consisting of a ~ 1m thick zone of broken granite flanked by damage zones above and below.
- CBIL image from Hab 3 - fault zone between red arrows.
- No breakout due to stress release caused by slip.
- Active shearing along fault is maintaining “structural” permeability.

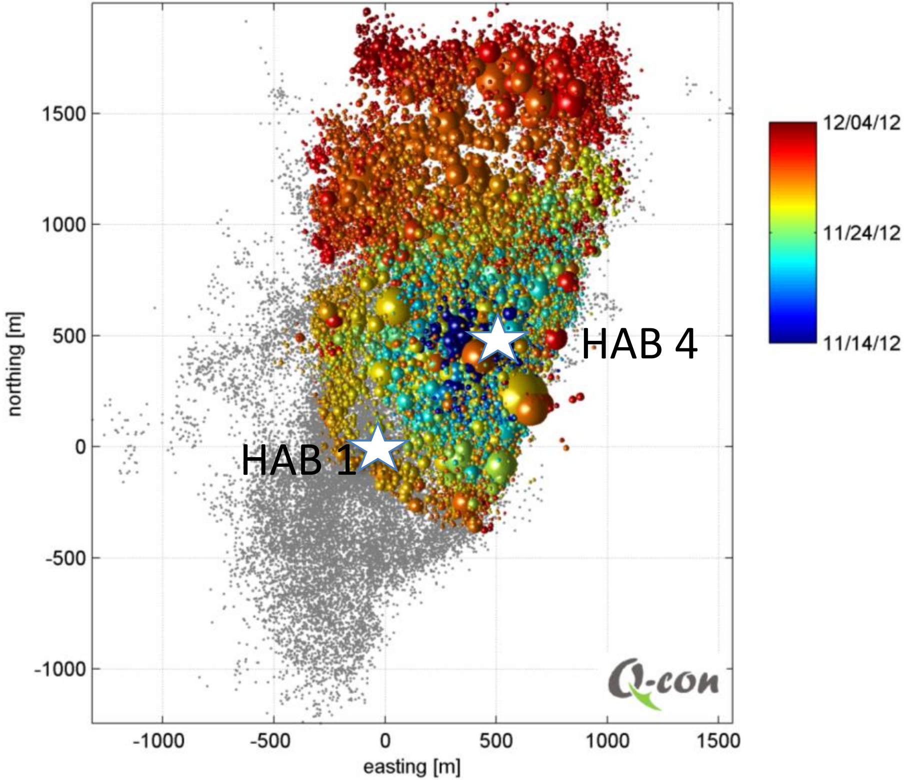
Image courtesy of Geodynamics



Geodynamics – Habanero Project

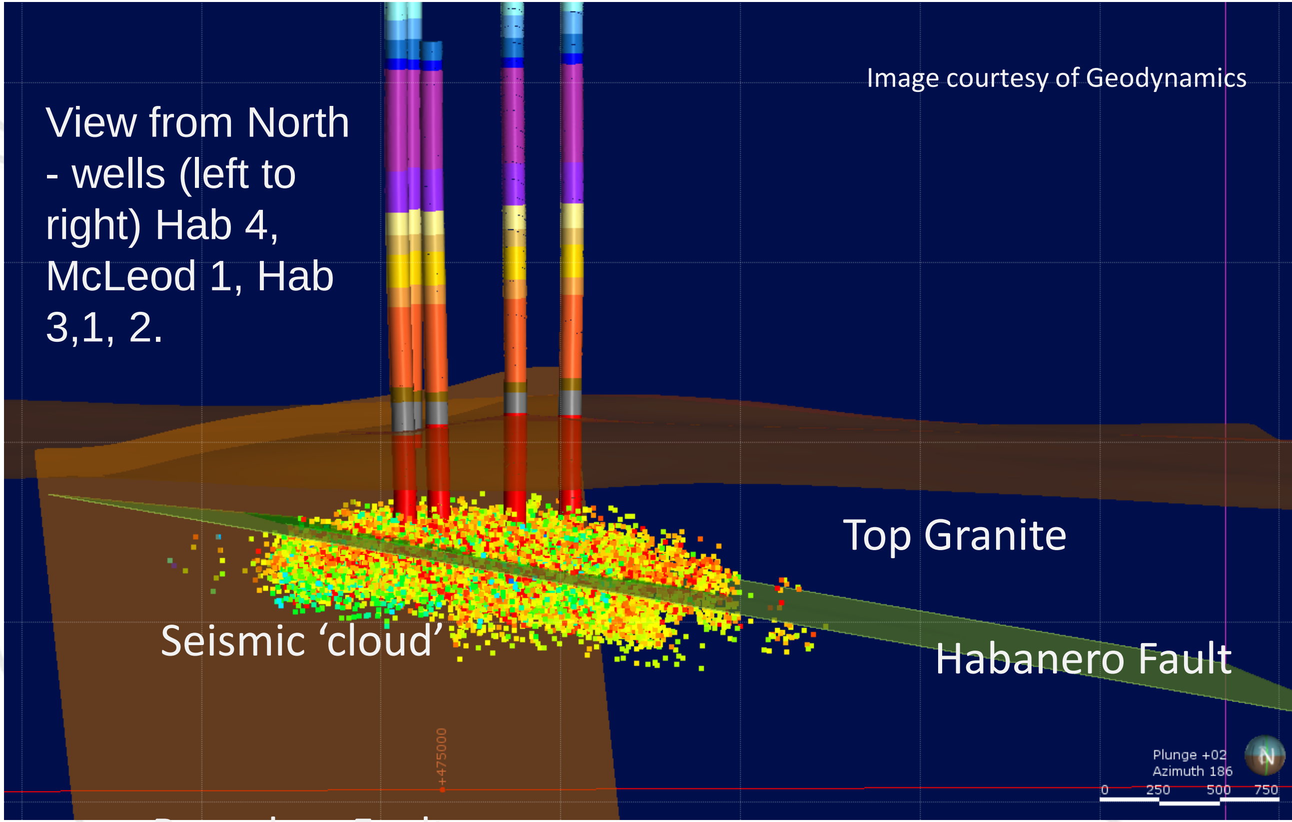
- Plan view of seismic 'cloud' with Habanero 1 and Habanero 4.
- Stimulation of HAB 4 in Nov 2012 in colour.
- 34M litres water injected over 3 weeks; initially 43.6 MPa @ 31 to 27 l/s then up to 48.5MPa @ 37l/s.
- Colour indicates time of event; grey indicates seismicity from earlier stimulations.
- Size indicates event magnitude; >27,000 events, ML -1.6 to 3.0.
- Seismicity 'grew' radially from Habanero 4 well.
- NNE – SSW ellipsoid partially overlapping existing network.

Image courtesy of Geodynamics



Geodynamics – Habanero Project

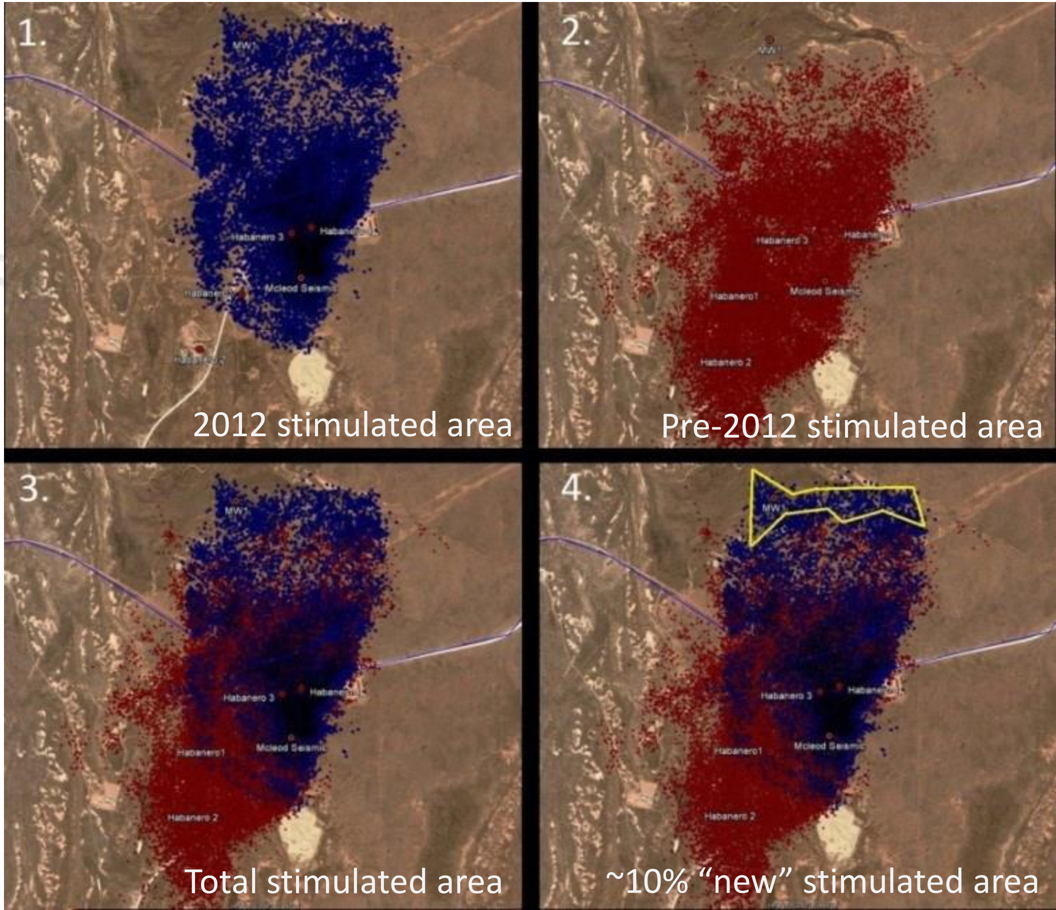
- Reservoir is a thrust fault, dipping ~10° to the west.
- Truncated to the east by a near vertical boundary fault.
- Planar fault with apparent vertical component due to location uncertainties.



Geodynamics – Habanero Project

(After McMahon & Baisch, 2015)

- Open flow test max. rate of ~39 kg/s.
- Circulated 19 kg/s
- Granite temperature of 241°C at 4,130 m depth.
- HAB 4 flowing temperature of 215°C and increasing.
- 1MW plant running brine pump, auxiliaries and camp – excess capacity.
- ~31000m^3 swept reservoir volume, 40 days fluid residence time, 6 days breakthrough.
- ~10% “new” reservoir created by 2012 ops - restricted to north of field.



Lessons learned at Habanero

- Habanero granite has numerous fractures, but most are not hydraulically conductive;
- Habanero reservoir is a single critically stressed fault, dipping 10° WSW, which is prone to slip triggered by stimulation pressure;
- Multistage stimulation techniques may enable activation of other amenable fractures;
- Mud losses into the fault system were extremely damaging and must be avoided;
- Stimulation of production wells can lead to temporary cooling of produced fluids.
- Multiple stimulations have consistently delivered significant productivity and injectivity improvements and created a seismic cloud of ~ 4 km2 total area and ~31000m3 swept reservoir volume.

Overall Lessons Learned

- Understanding the in situ stress regime helps predict and plan stimulation outcomes, well siting and design.
- The local in situ stress regime can differ from the regional.
- Movement tends to occur on amenably oriented pre-existing natural fractures, so target and exploit these.
- Hot Dry Rock can be a misnomer – all basement hosted fractures are fluid-filled and some may be overpressured.
- Massive stimulation of an EGS system is possible via perforated casing.
- Stimulation ops has been demonstrated to successfully enhance fracture permeability in a variety of crystalline basement rocks.
- Enhancement of multiple fracture zones is desirable and thus multi zone stimulation may improve well-reservoir connectivity and overall productivity.

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