SHAPE-UK

Challenge 3 – Impact of hydraulic fracturing in the overburden of shale resource plays: Process-based evaluation

NERC ESRC Unconventional Hydrocarbons in the UK Energy System Annual (Virtual) Conference, 17 Sept, 2020

Challenge 3: SHAPE-UK

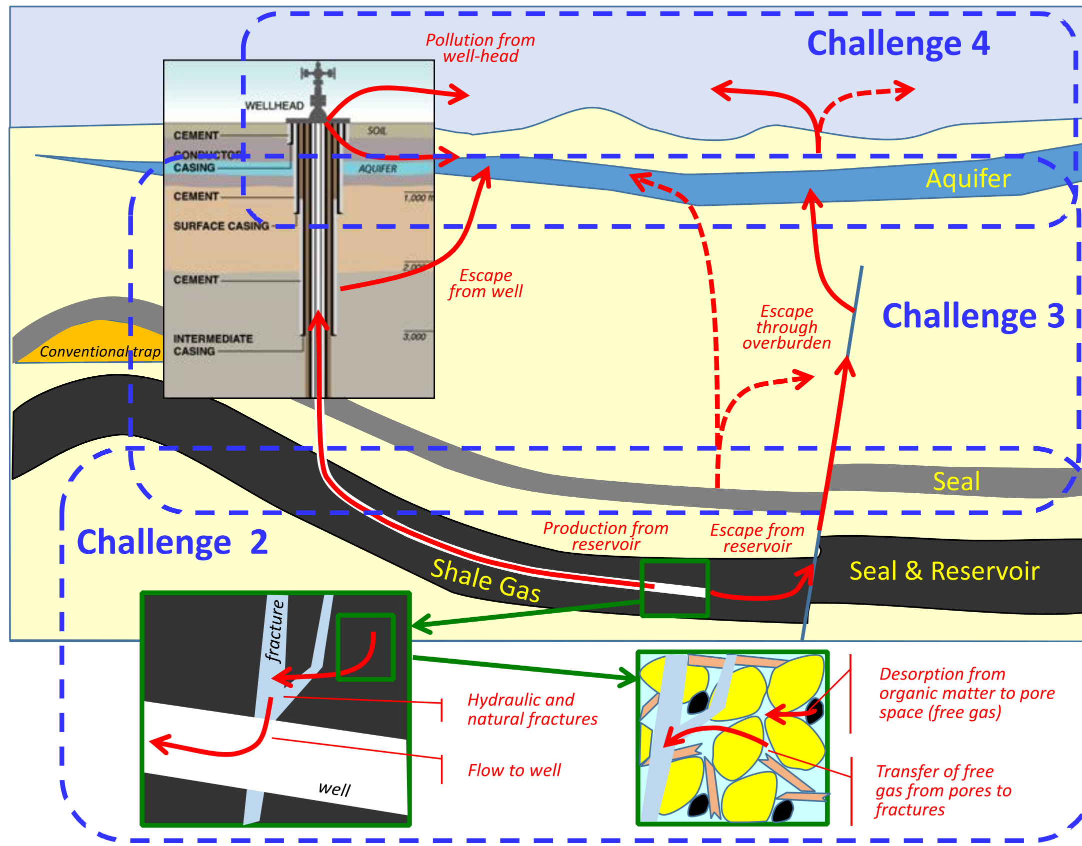
Connections between the reservoir and the surface

Project aims, to better understand:

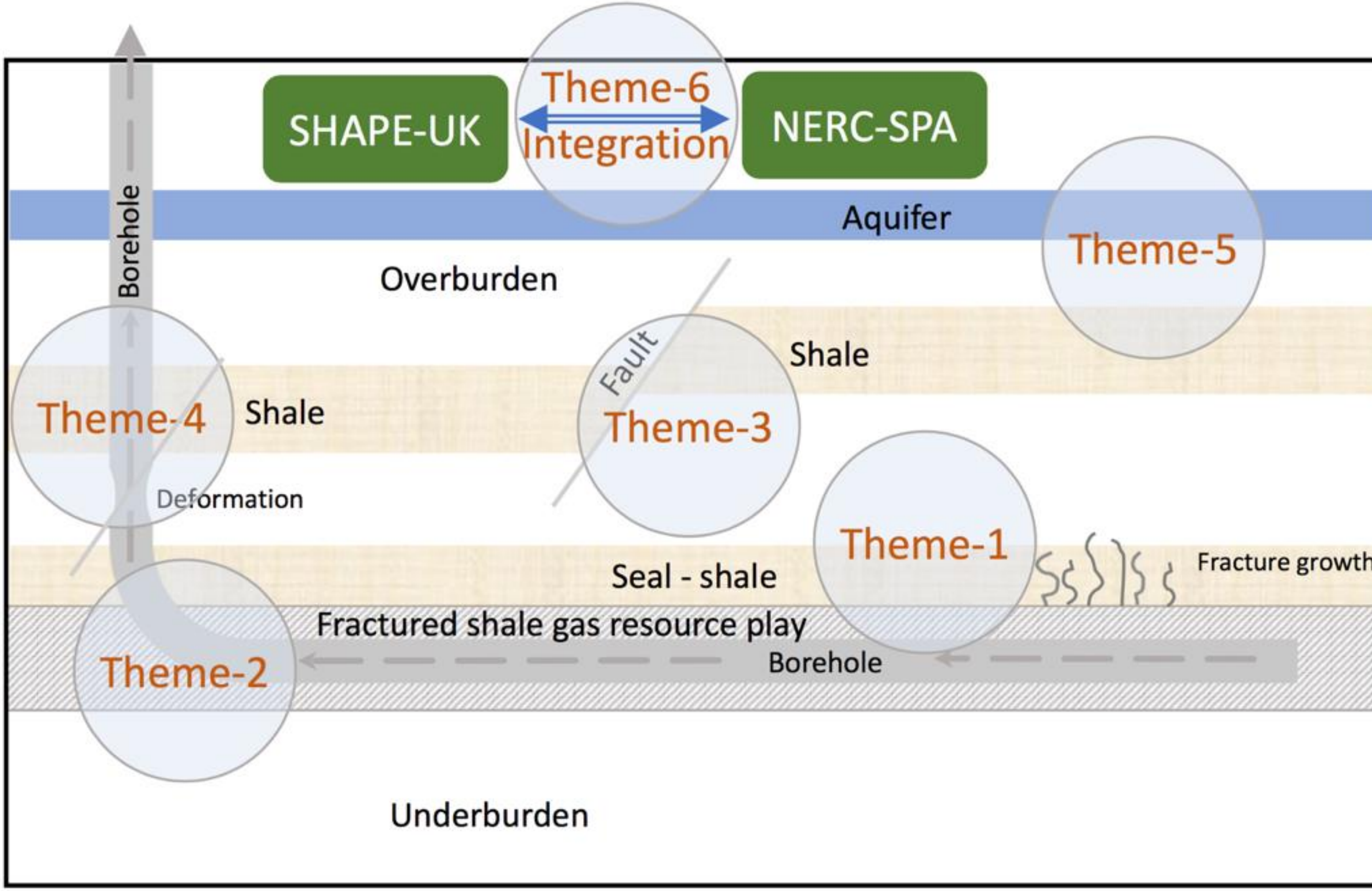
- Leakage mechanisms
- Impact on geochemistry and microbes
- Induced seismicity

Develop: Strategies to monitor and mitigate effects

Implications for shale gas, CO2 storage, enhanced geothermal, waste disposal, ….



Project integrates 6 **themes** and delivered through 6 **work packages:** petrophysics, rock mechanics, geochemistry and environmental impact, geologic and stress models, geomechanics, geophysics

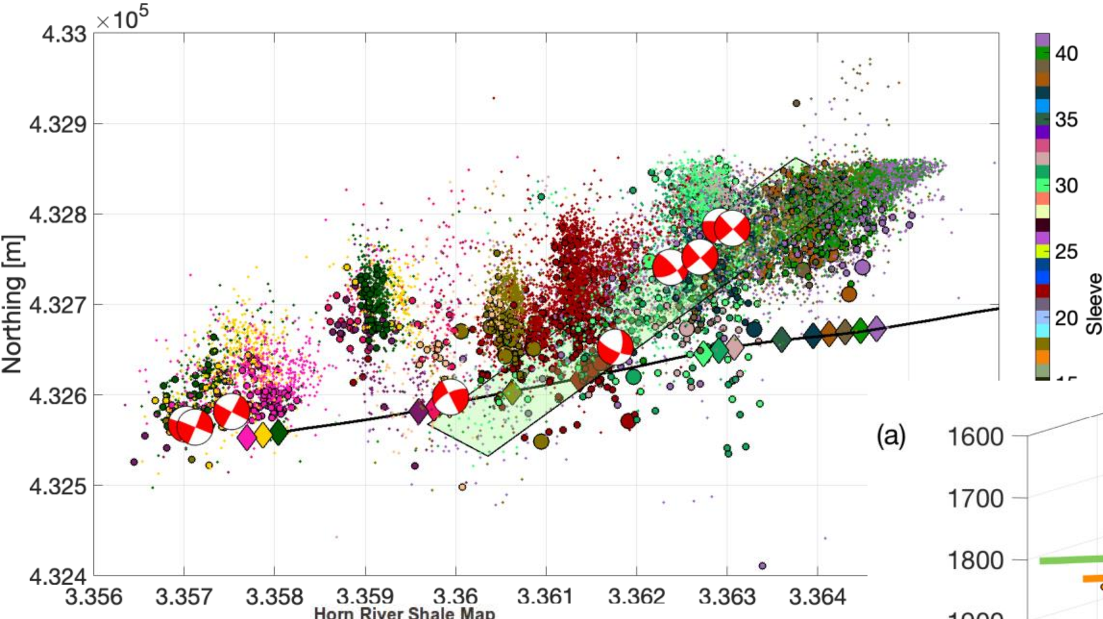


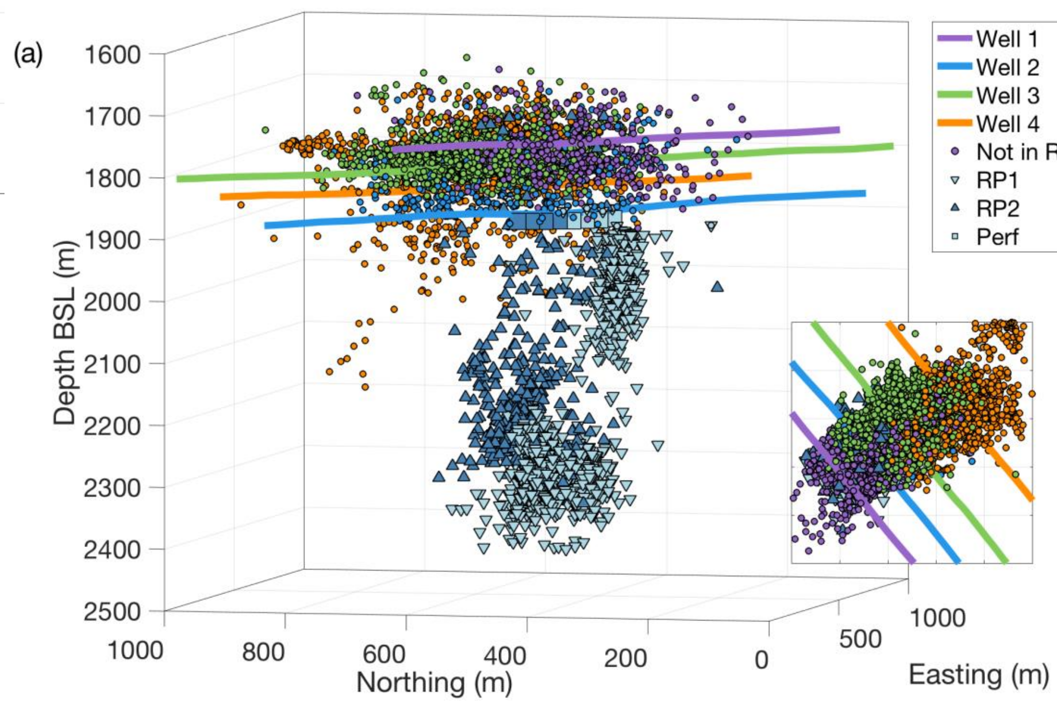
Motivation

- Leakage mechanisms
- Impact on geochemistry and microbial impact
- Induced felt seismicity
- A *key risk* in hydraulic fracturing is the triggering of ***fault slip***, ***earthquakes***, and possible ***along-fault fluid flow***

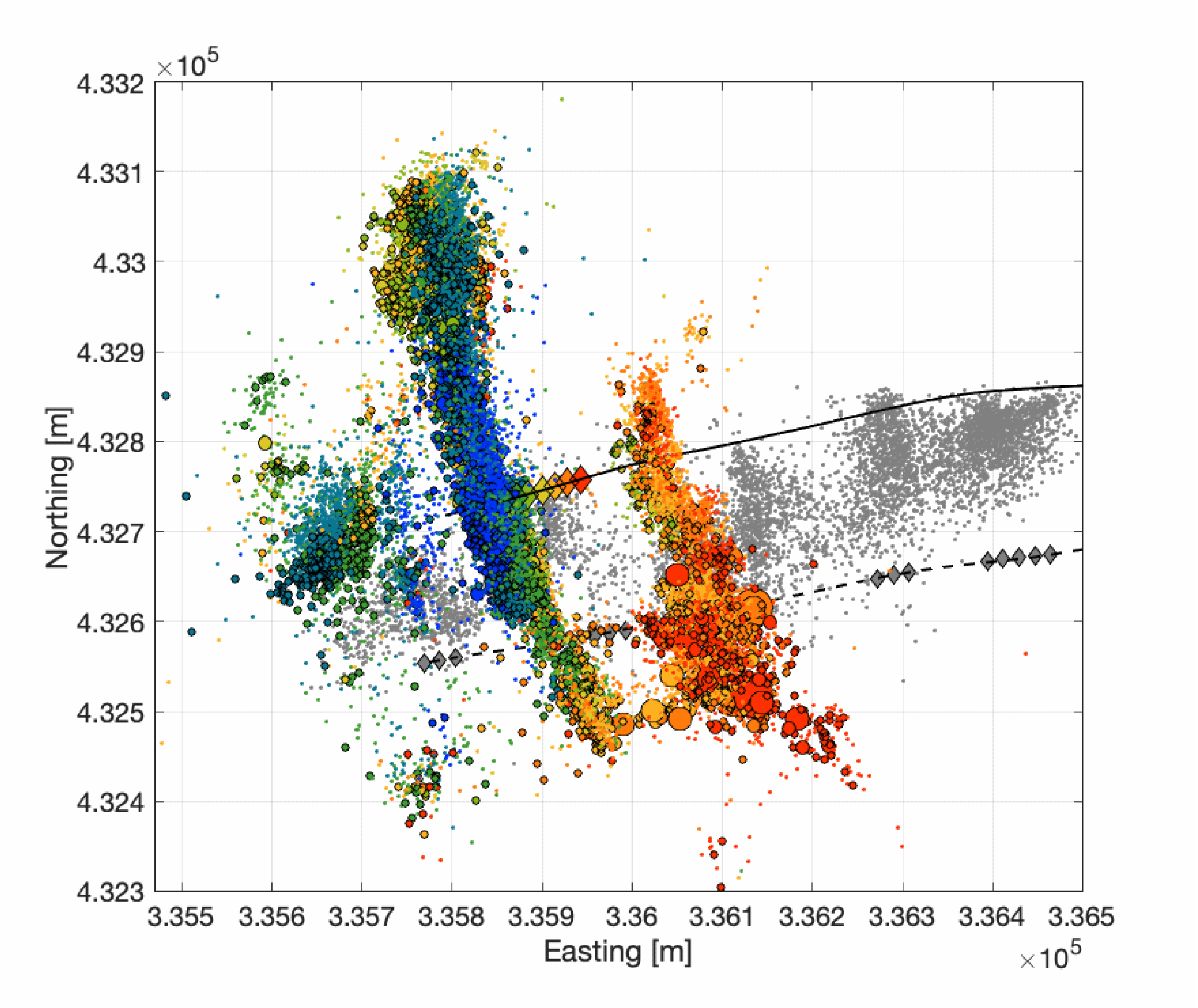
Focus on two examples where induced seismicity is a problem (Horn River and Preston New Road)

Compare two fields: Horn River (Canada) and Preston New Road (UK)





Preston New Road -2 seismicity



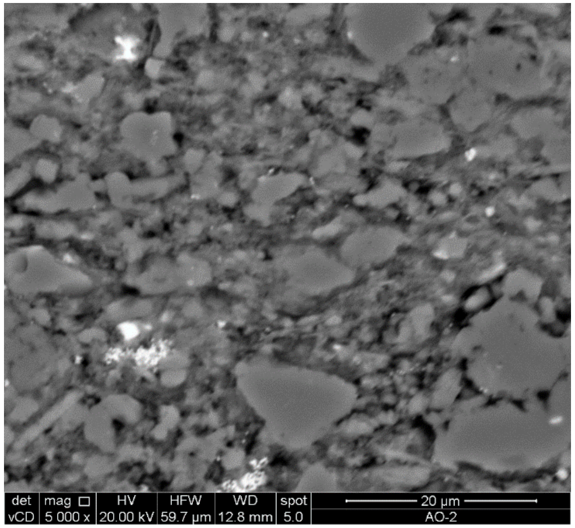
WP1 - Petrophysical characterisation (Leeds)

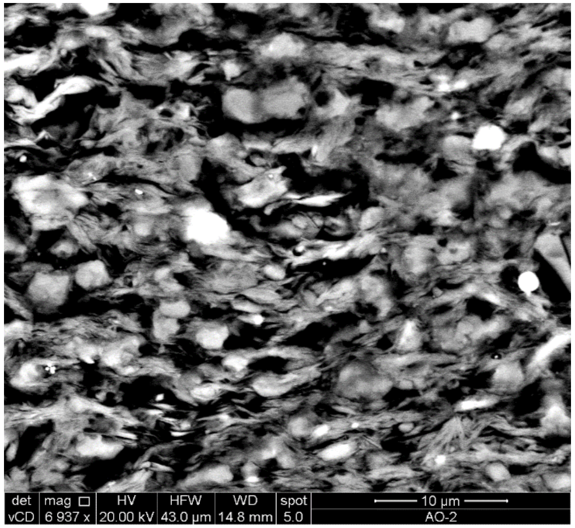
Key task of WP1 (Leeds) component is to conduct basic characterization of samples on which geomechanical tests are being conducted

- Horn River sample
- Elsmere Port samples

Analaysed using (i) microstructural analysis using BSEM, (ii) QXRD, (iii) mercury injection capillary pressure; (iv) nano-indentation; (v) triaxial deformation experiments, (vi) friction experiments and (vii) X-ray goniometry.

Phyllosilicates and rock ductility are key to elastic properties, induced seismicity, sealing properties, ….

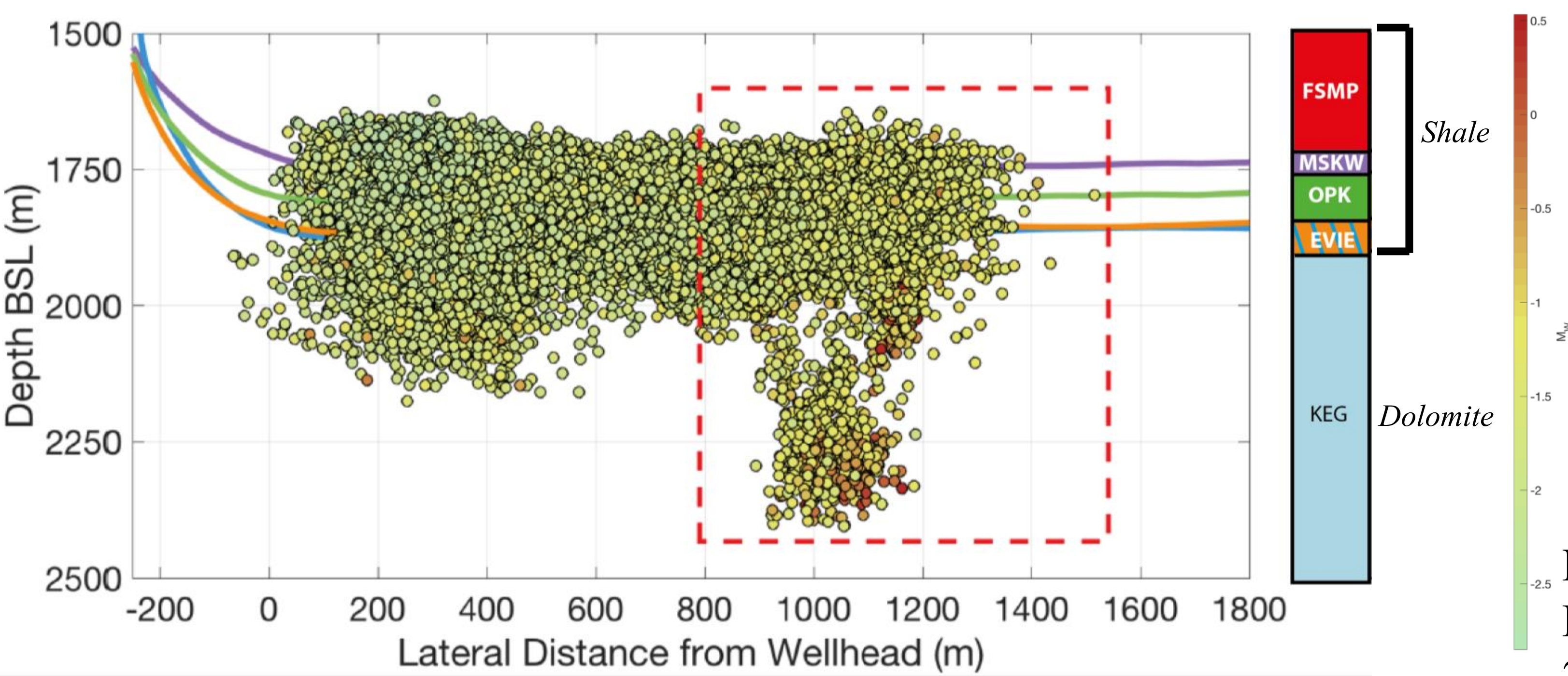




WP2: Rock mechanics (Liverpool, Durham and Newcastle)

Horn River Basin: Relating lab experiments to observed microseismicity

- Microseismicity analysed by WP6 - Oxford/Bristol, reported in Kettlety et al., 2019.
- Induced seismicity within the reservoir and underburden units and with *greater magnitude* in the *underburden*.



Modified after Kettlety et al., 2019

Allen and Faulkner - Liverpool

UNIVERSITY OF LIVERPOOL

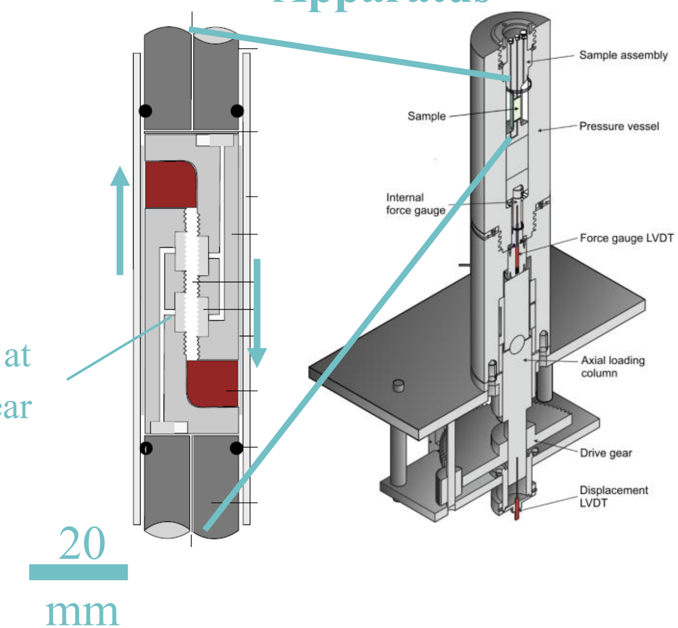
Rock Deformation Laboratory Liverpool

WP2: Rock mechanics

Do variations in the material properties across distinct lithological horizons influence the rate and magnitude of microseismicity during hydraulic fracturing?

Triaxial Deformation Apparatus

Powdered rock sample sheared at insitu conditions to recreate shear on faults and fractures



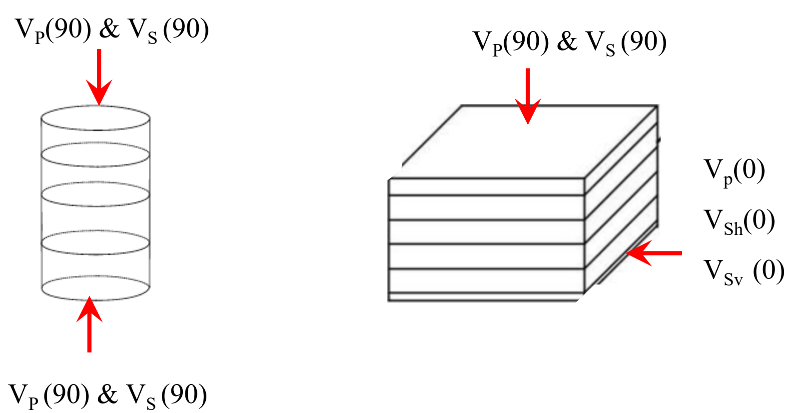
Allen and Faulkner - Liverpool

WP2: Rock mechanics

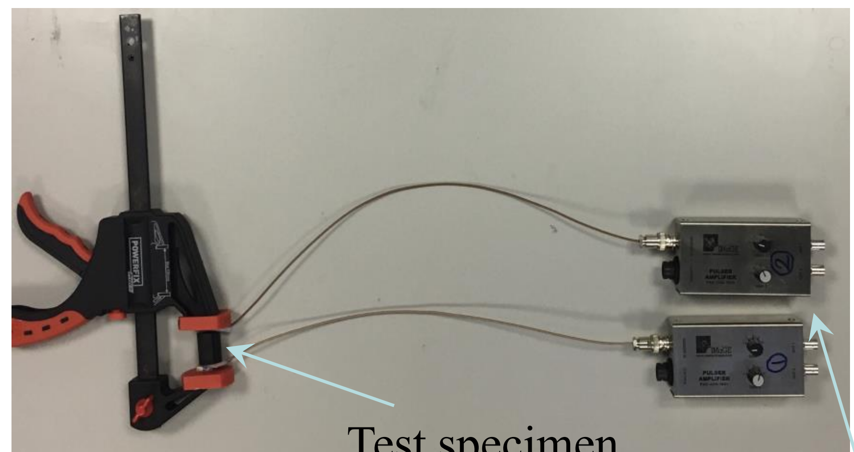
Triaxial Loading experiments – Rock physical properties

Elastic wave speed (V_P and V_S) measurement protocol

a) Measurements orientation



b) Measurements set up

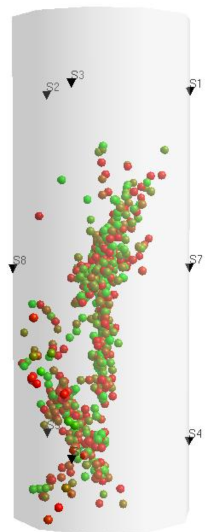


De Paola, Aplin and Dawood - Durham

WP2: Rock mechanics

Triaxial Loading experiments – Rock physical properties

Acoustic emission (AE) and laboratory earthquakes



On-going research and Main aims :

- Obtain scaling relationships between measured seismic parameters of laboratory earthquakes (e.g., amount of slip, rupture size, magnitude, stress drop, b-value);

- Upscale laboratory earthquakes to field observations (e.g., Preston New Road microseismic datasets).

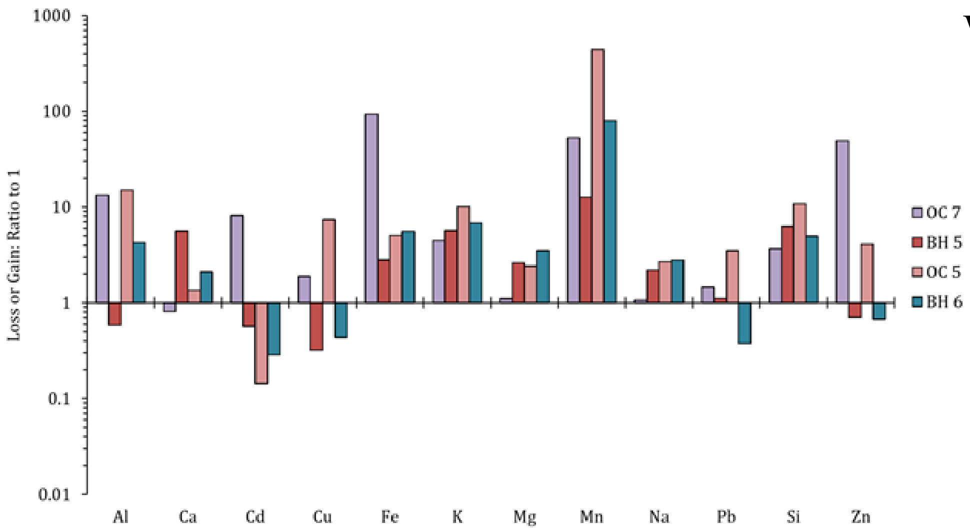
De Paola, Aplin and Dawood - Durham

WP3 – Geochemistry and environmental impact

What is the chemical composition of produced water and its impact on the environment?

Fate of additives – polyacrylamide PAM

- PAM is highly adsorptive on shale lithologies
- PAM acts as a colloid to facilitate metal movement
  - But does not matter as shale is too adsorptive
- The amount of shale surface available means PAM will stay at depth



What happens at depth?

- Shale lithologies from Bowland Shale
- Mixed with synthetic deep groundwater and reacted with synthetic fracking fluid
- Pressures up to 7 MPa and 80°C
  - Some metals consistently enhanced in reacted fluids (e.g. Mn)
  - Some metals consistently removed (e.g. Cd)

Worral, Hsu and Ward - Durham

WP3 – Geochemistry and environmental impact

Geomicrobiology

Overarching question: to what extent do changes in subsurface microbiology in both fracking and geothermal contexts cause contamination and problems with infrastructure (e.g. biocorrosion)

- Work currently underway:
  - Extracting microbial DNA from core samples, supplied from UKGEOS Glasgow site, with the aim of identifying microbial communities present.
  - Microcosm experiments have been set up using Glasgow core samples as inoculum in a range of media to enrich different types of microorganism:
    - Methanogens
    - Sulfate reducers
    - Iron reducers
    - Fermenters
  - The aim is to grow native subsurface microorganisms for further testing in conditions relevant to fracking and geothermal energy.

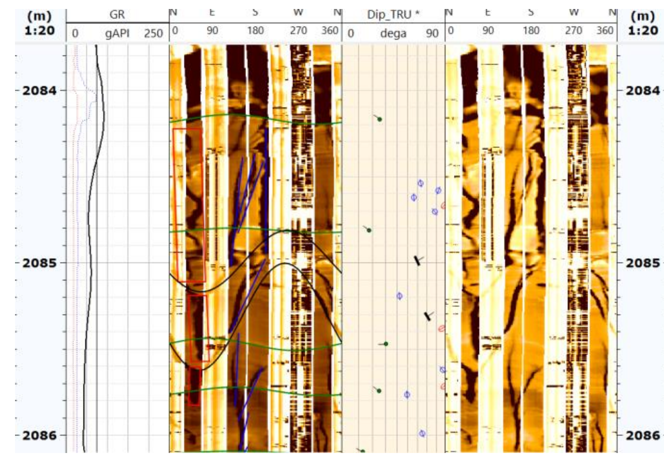
Edwards and Buss - Bristol

WP4: Geologic and stress models

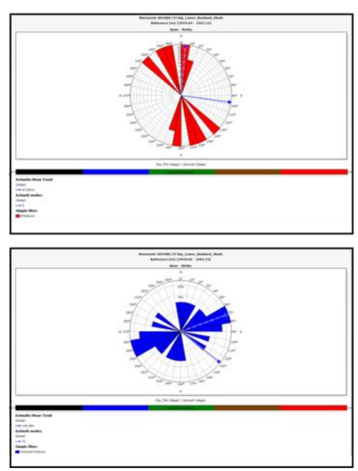
Stress and Fracturing

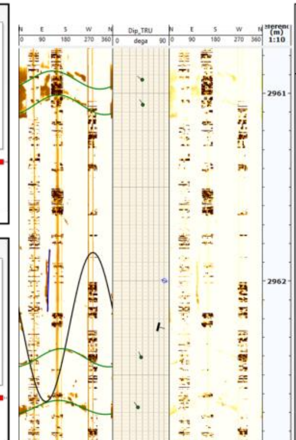
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

- Initial interpretation of all borehole imaging & petrophysics data completed
  - Borehole breakouts / Drilling Induced Tensile Fractures
  - Fracture/fault orientation and widths
- Completed new in-situ stress orientation for Lancashire & Cheshire shale gas prospects
- Now interpreting complex fracture patterns, inc. flower structures & critically stressed fractures



Kingdon et al. - BGS





STRATIGRAPHIC UNIT	MODAL STRIKE	
	BREAKOUTS	INDUCED FRACTURES
Roeburndale Fm	-	053 NE
Brennand Grit	-	066 NE
Pendle Grit	146 SE	058 NE
Upper Bowland Shale	074 ENE	070 ENE
Lower Bowland Shale	005 N	070 ENE

WP5: Linked geomechanical, fluid flow and seismic modelling

Purpose: Linking nano/microscale geomechanical properties (elastic, strength, creep) measured from shale cuttings to macroscale properties for reservoir modelling.

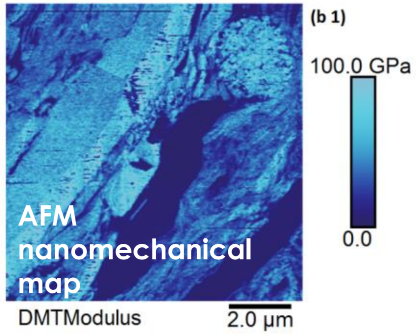
Research successes

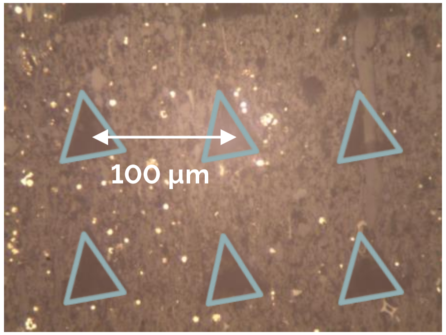
- Inverse analysis of nanoindentation test (FEM)
- Analysis of micromechanical experiments on Posidonia shale including creep behaviour
- Implementation of microcracks in multiscale model for upscaling elastic properties

Future

- Developing visoelastic constitutive model
- Effect of fluids on micromechanical properties
- Link to 3D PNR model

Micromechanical experiments (Posidonia shale, Germany)





Nanoindentation grid

Rouainia, Charlton, Aplin – Newcastle, Durham

WP5 – Linked geomechanical, fluid flow and seismic modelling

ParaGeo

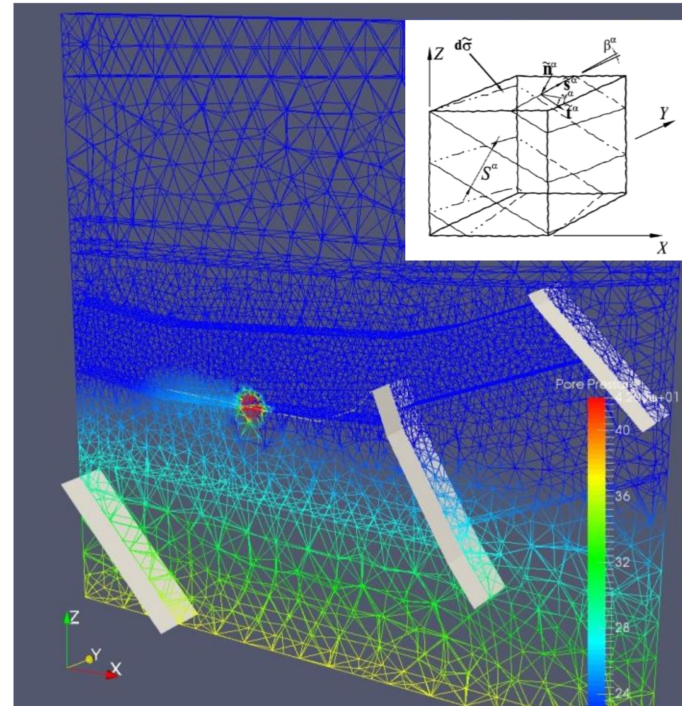
UNIVERSITY OF LEEDS

Objective: Field-scale simulation of Preston New Road 1z well

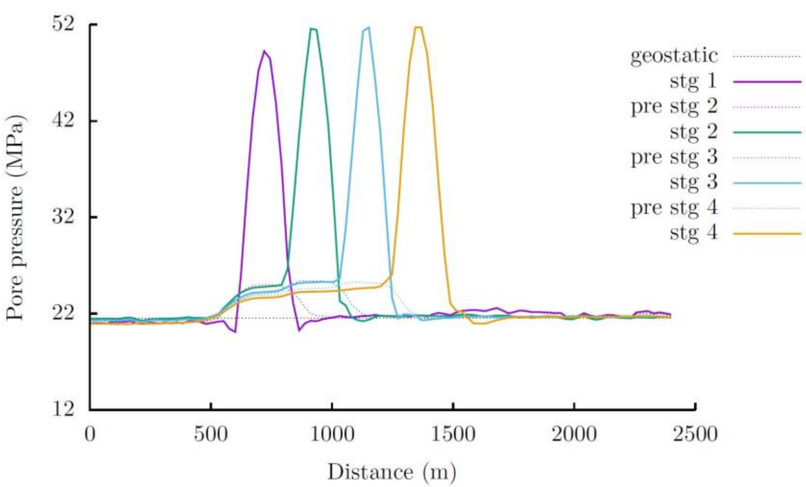
Highlights:

- Combined geo-mechanical/flow model
- Discrete and embedded fault/fracture definitions
- Pore pressure dependent fracture properties

Status: Preliminary simulation performed, awaiting detailed topology and material properties to become available for a refined model.



Pore pressure distribution at the end of stage 4



Pore pressure distribution at well depth for various stages with trailing residual pressure.

Methodology:

- Fracture sets at sub (up-scaled) and super element levels
- Inverse analysis to find fracture properties that generate the best match

WP6 – Geophysical imaging of unconventional reservoirs

- Seismic reflection – mapping faults, facture properties, seismic anisotropy, …
- Passive seismic monitoring – image faults and their reactivation; stimulation volumes; spatio-temporal variations in fracture-induced anisotropy
- Draw on other WPs to predict seismic properties
- Inform seismic regulatory framework; seismic hazard assessment, …

Kettlety, Verdon, Butcher, Kendall, Luckett, Baptie – Bristol, Oxford, BGS

Mechanism controlling seismicity?

What is the physical process governing the way a fault zone activates?

- Fluid volumes and rates; fluid composition
- Stress state and fault orientation
- Pre-existing fractures
- Fluid pressure increase (diffusion)
- Poroelastic stress transfer
- Elastic stress transfer

Not all faults are equal ….

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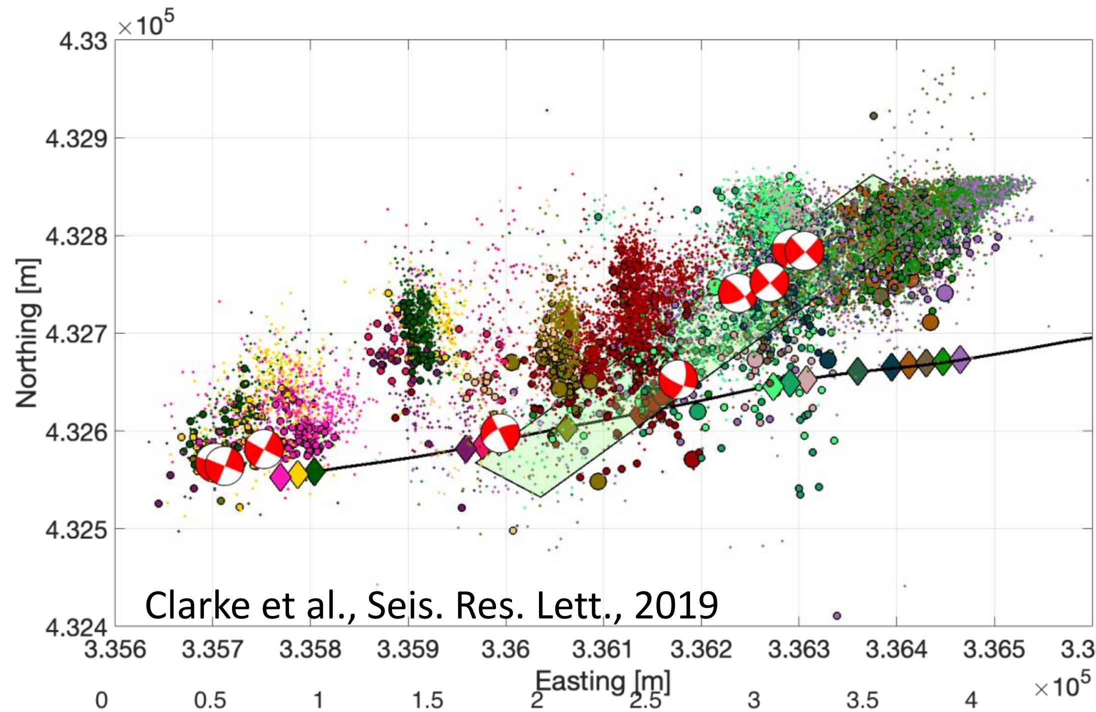
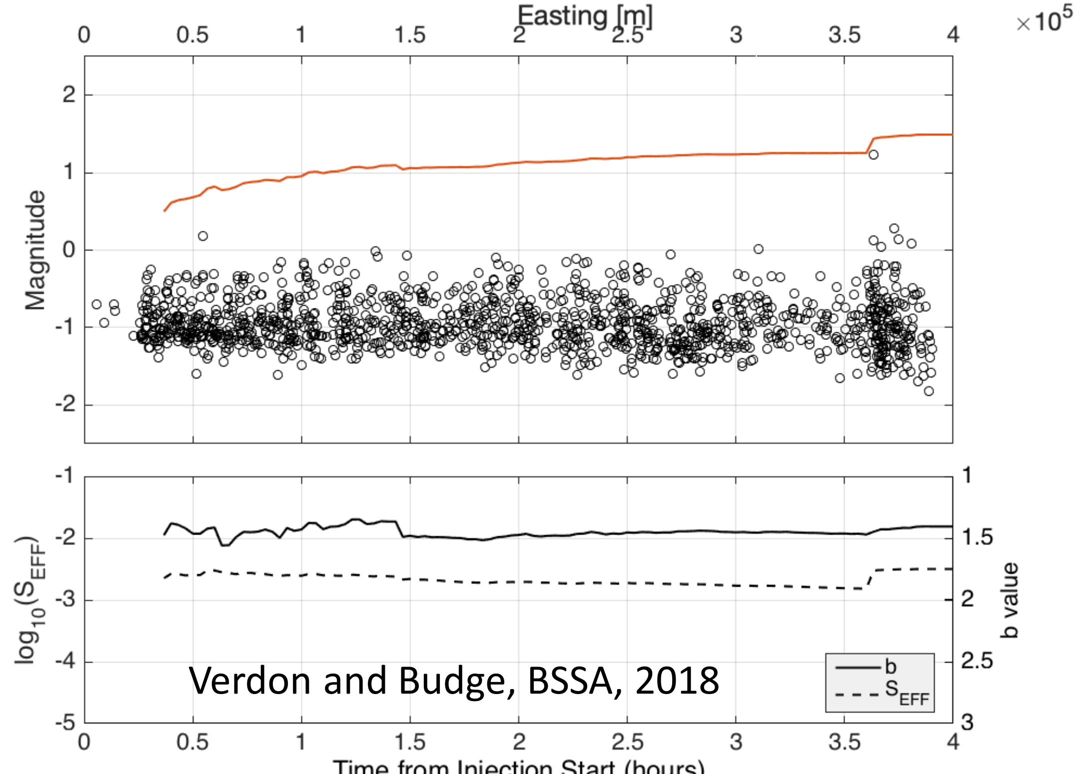
PNR – stress transfer; favourably oriented faults, high stress anisotropy

Horn River – diffusion through hydraulic pathways (faults)

Preston New Road – phase 1

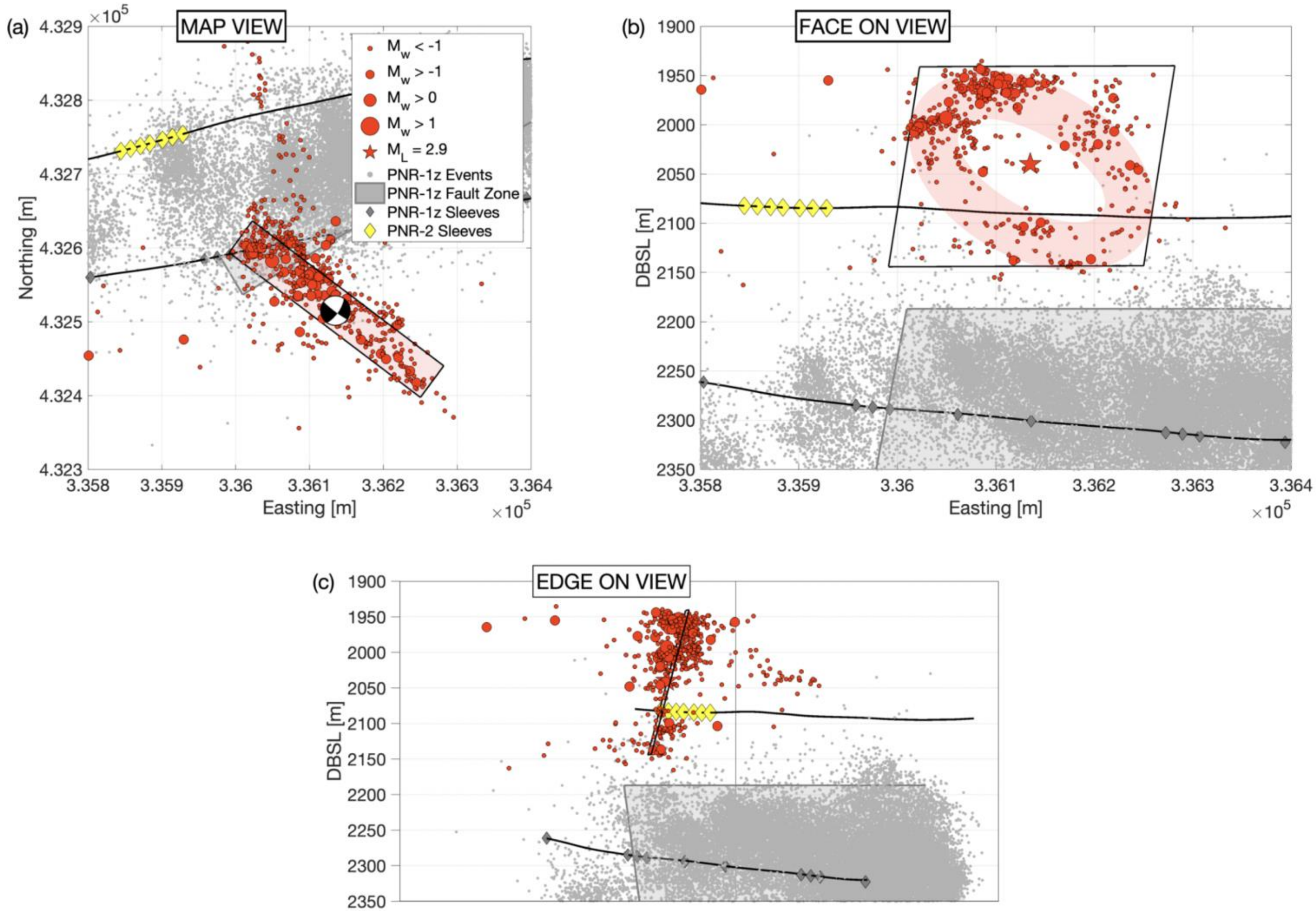
- Microseismicity indicated a fault/fracture zone running obliquely to the well (previously unmapped)
- No mapped faults reactivated
- Shale gas site where operational decisions were made during injection; use statistical framework to forecast the expected maximum event magnitude
- Microseismic observations revealed the intersection between hydraulic fracturing and a pre-existing fault or fracture network that became seismically active
- Failure is a stress effect (in contrast to Horn River) (Kettlety et al., 2019; Kettlety et al., 2020)





PNR2: M_L 2.9 event – fault and dimensions

- Fault plane well resolved by locations of microseismic aftershocks.
- Area of aftershock ellipse is around 330×250 m = 6.5×10^4 m².
- Rupture area for M_L 2.9 (M_w 2.9) event is $\sim 1 \times 10^5$ m², assuming typical stress drop.
- Little-to-no overlap between PNR-1z fault and PNR-2 seismicity.



Kettlety et al., 2020

Seismicity natural or induced?
Proposed Framework Requirements

A framework for assessing potential induced seismicity must:

1. Provide a result that makes sense to non-expert stakeholders
2. Weight different sources and types of evidence according to their significance
3. Be capable of incorporating pieces of evidence that have different levels of uncertainty
4. Characterise the quality and availability of evidence used to reach an answer
5. Be flexible, such that new questions can be easily added as our understanding of induced seismicity improves

Verdon, Baptie and Bommer, Seis Res Lett, 2019

Replaces *Frohlich et al., 2016*

Take home messages

- Not all fields/faults are the same
- Orientation of faults w.r.t. stress field is important
- Different mechanisms in different circumstances (stress transfer versus fluid connectivity)
- Fault properties (e.g., permeability, architecture, mineralogy, …) important
- Real time monitoring (and mitigation, to an extent) a possibility
- Clear framework for assessing induced versus natural seismicity
- Not unique to shale gas – CCS, geothermal, … natural settings
- Working with operators and regulators (state-of-the-art datasets