Natural Environment Research Council

Economic and Social Research Council

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, 09 Sept, 2021

University of Liverpool

ParaGeo

University of Oxford

Newcastle University

University of Leeds

Durham University

British Geological Survey
Natural Environment Research Council

University of Bristol

Challenge 3: SHAPE-UK

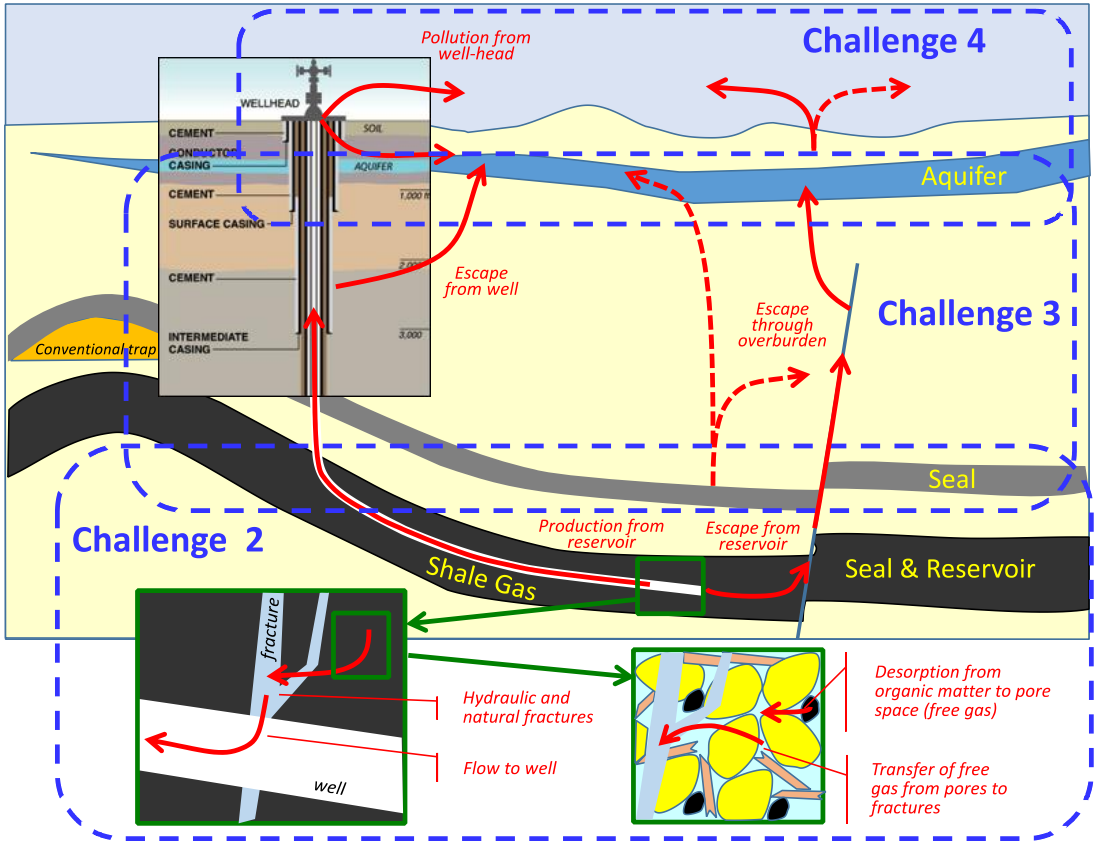
Connections between the reservoir and the surface

Project aims, to better understand:

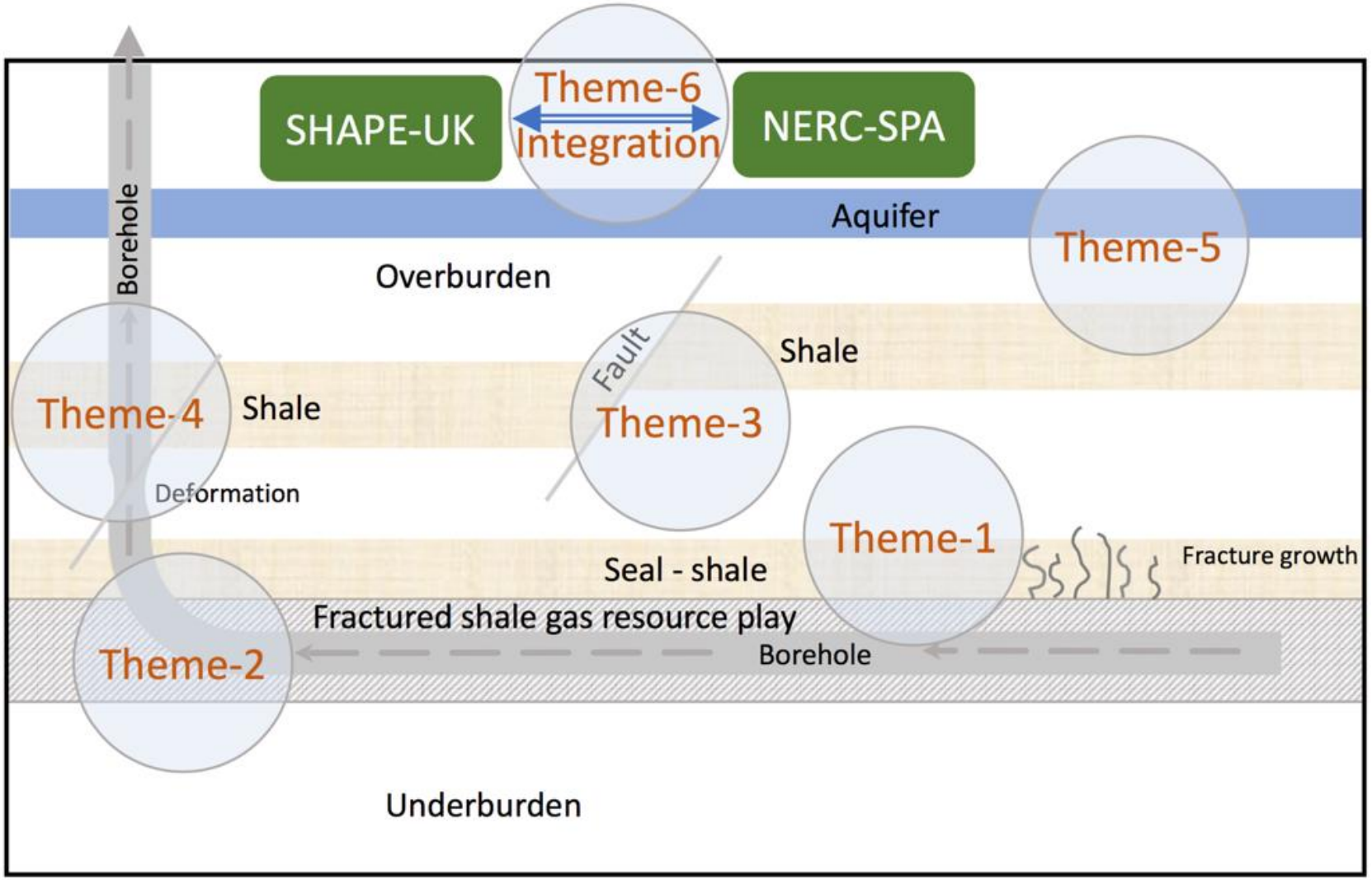
- Leakage mechanisms
- Impact on geochemistry and microbes
- Induced seismicity

Develop: Strategies to monitor and mitigate effects

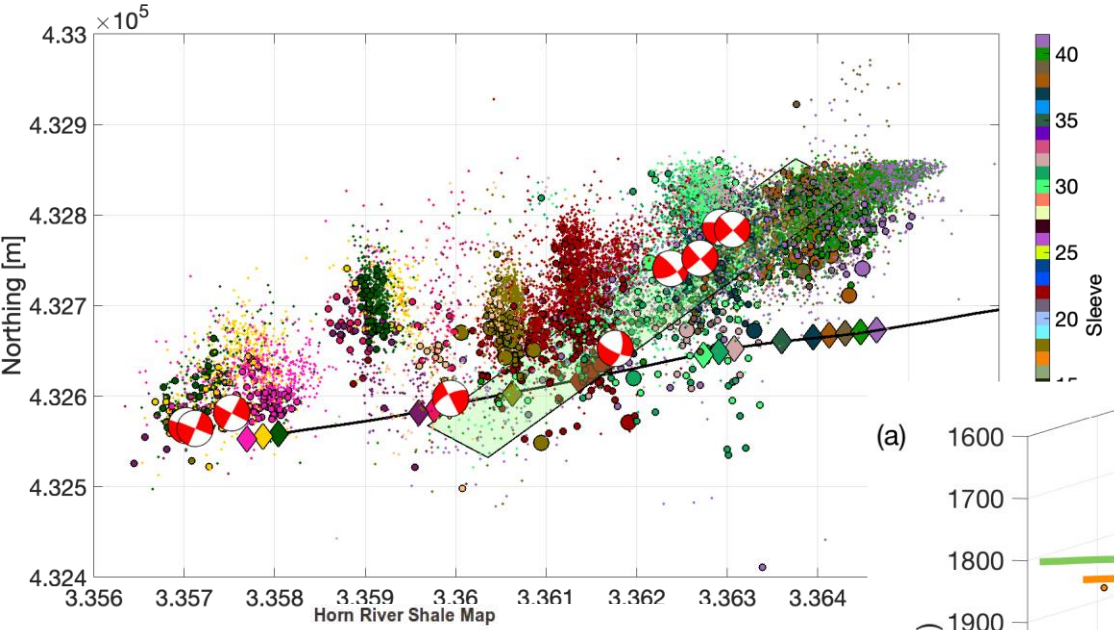
Implications for shale gas, CO_2 storage, enhanced geothermal, waste disposal, ….

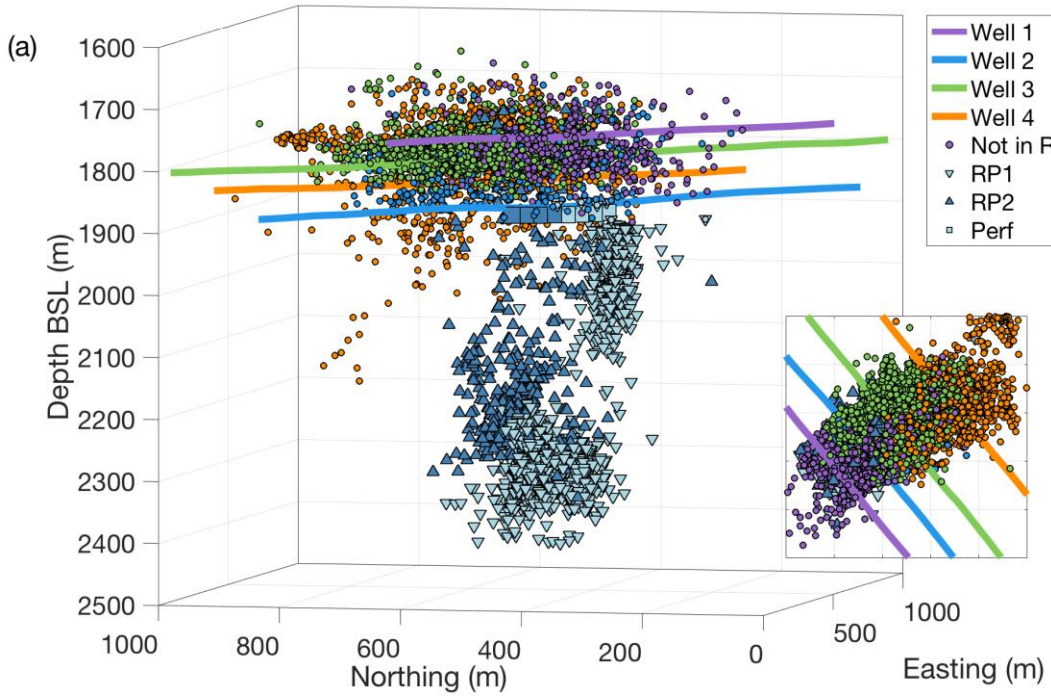


Project integrates 6 **themes** and delivered through 6 **work packages:** petrophysics, rock mechanics, geochemistry and environmental impact, geologic and stress models, geomechanics, geophysics



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





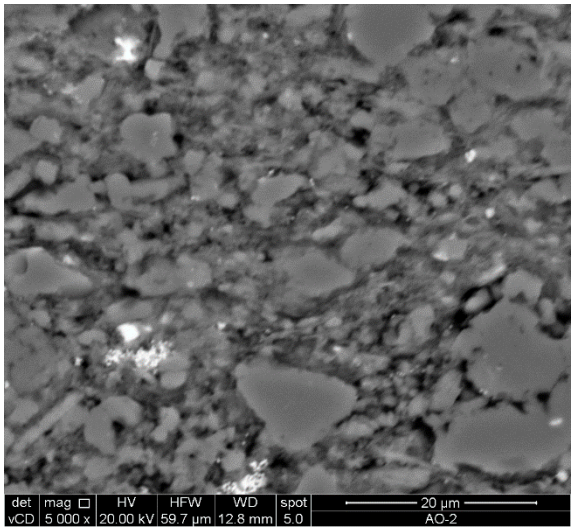
WP1 - Petrophysical characterisation (Leeds)

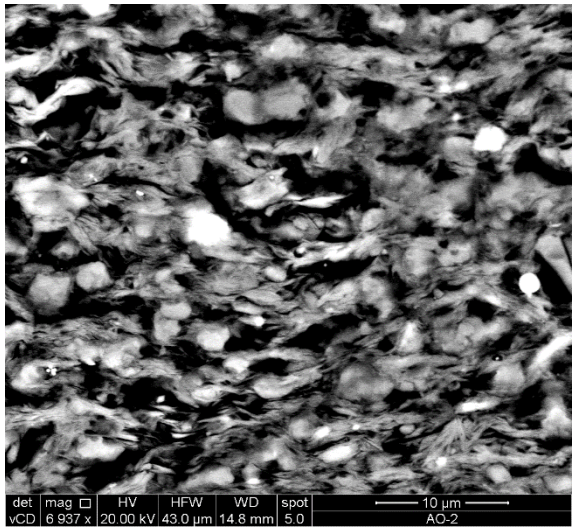
Key task of WP1 (Leeds) component is to conduct basic characterization of samples on which geomechanical tests are being conducted

- 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, ….





Fisher - Leeds

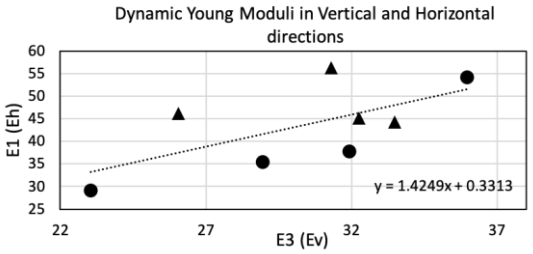
WP2: Rock mechanics (Liverpool, Durham and Newcastle)

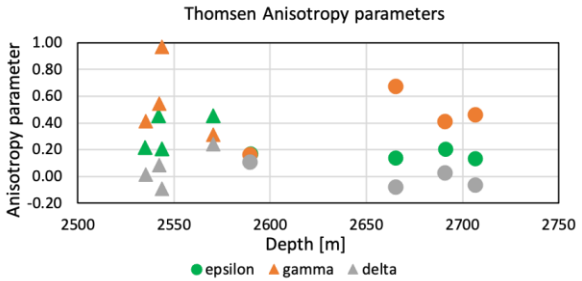
F. Dawood, N. De Paola, S. Nielsen & A. Aplin

Rock Mechanics Laboratory

Physical parameters of shale rocks and their anisotropy

These results are critical to the correct depth conversion of seismic profiles and to the accurate localization of laboratory and field seismic events.



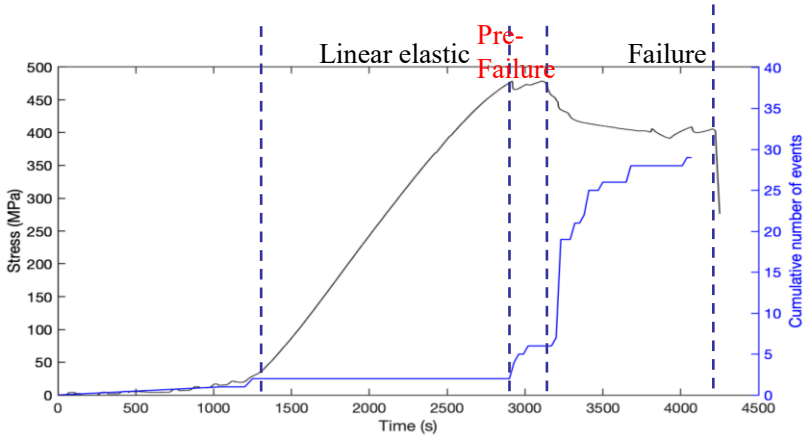


Dawood et al., In Prep.

Dawood et al., In Prep.

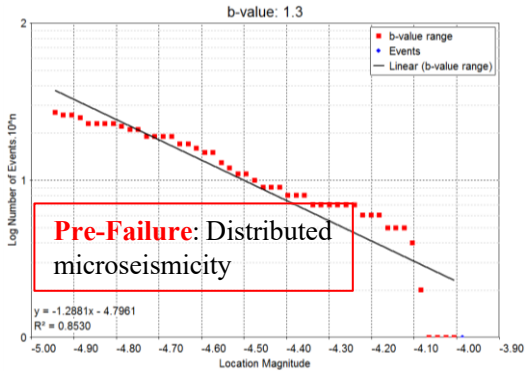
Evolution of rate of seismicity and seismic parameters in fractured shale rocks (Laboratory earthquakes)

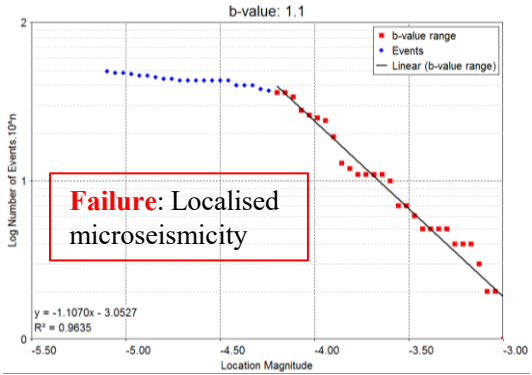
Temporal and spatial evolution of fault patterns link to variations of seismic parameters (b-value) prior to large induced events.



Rate of microseismicity starts increasing during the *pre-failure stages* leading to failure.

Seismic paramaters evolution

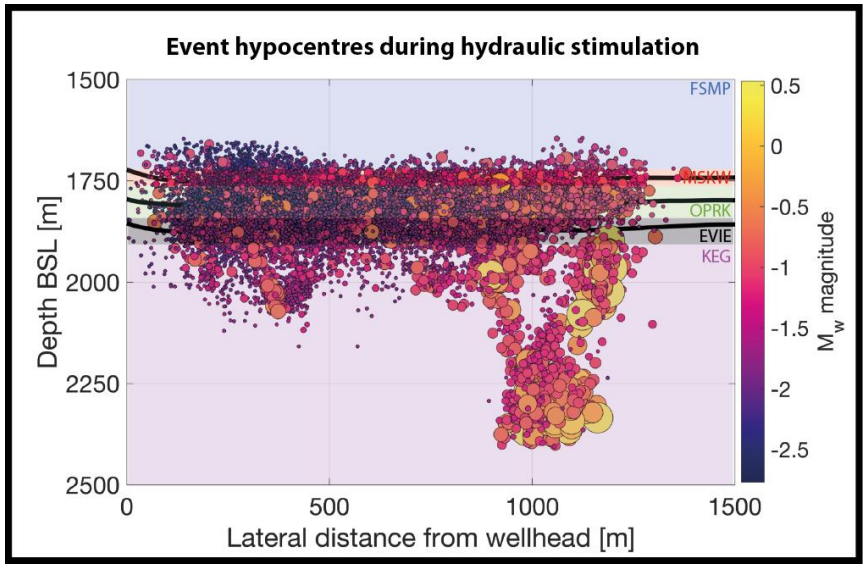




Variations of *b-values* occur at the transition from *distributed microseismicity (contained within the stimulated reservoir volume) to localised larger fault ruptures (able to grow beyond the stimulated reservoir volume).*

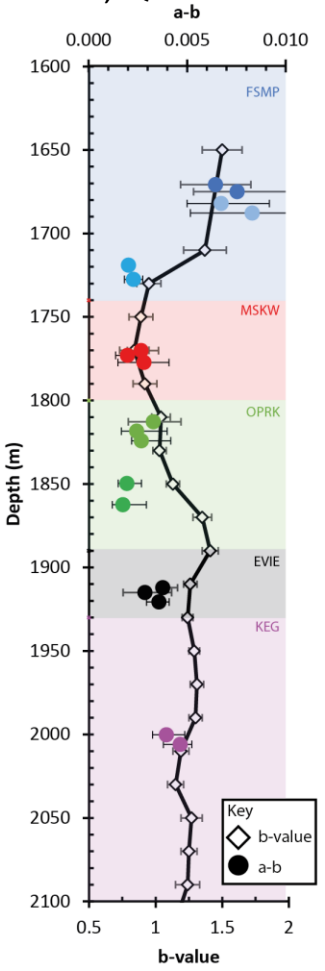
WP2 - Fault friction and induced seismicity: The relationship between earthquake size distributions and laboratory measured frictional stability parameters from induced seismicity on faults during fluid injection

Michael J. Allen*; Tom Kettlety; Daniel R. Faulkner; J. Michael Kendall; Nicola De Paola; Quentin Fisher; James Verdon



Summary

Laboratory measured frictional stabilities (a-b) relate closely to induced earthquake-size distributions (b-values) in a shale gas play within the Horn River Basin (British Columbia, Canada). Fluid injection promotes seismicity along faults that cut lithologically distinct horizons, each with characteristic frictional behaviours and earthquake-size distributions that we are able to compare. Results suggest that material properties may play a key role in earthquake-size distributions, contrasting with the view that they are solely controlled by stress on the fault.



Lithologies

FSMP (Fort Simpson)
Overburden Clay-rich shale

MSKW (Muskwa)
Reservoir qtz/carbonate-rich shale

OPRK (Otter Park)
Reservoir qtz/carbonate-rich shale

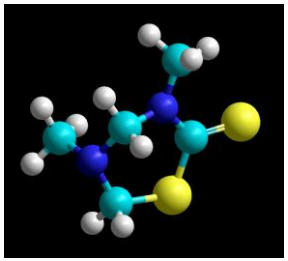
EVIE (Evie)
Reservoir qtz-rich Shale

KEG (Keg River)
Underburden Dolomite

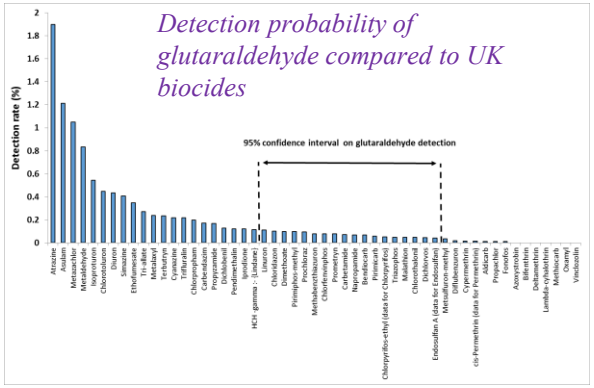
See Mike Allen's poster

WP3 - What is the chemical composition of produced water and its impact on the environment?

- Predicting deep groundwater composition
  - Bayesian analysis of the geotherm
  - Bayesian of the salinity gradient
  - Not really enough data
- Fate of biocides
  - Molecular modelling
    - Includes fracking biocides and UK pesticides
  - Model occurrence in English groundwater
    - Models compare fracking biocides to current pesticides

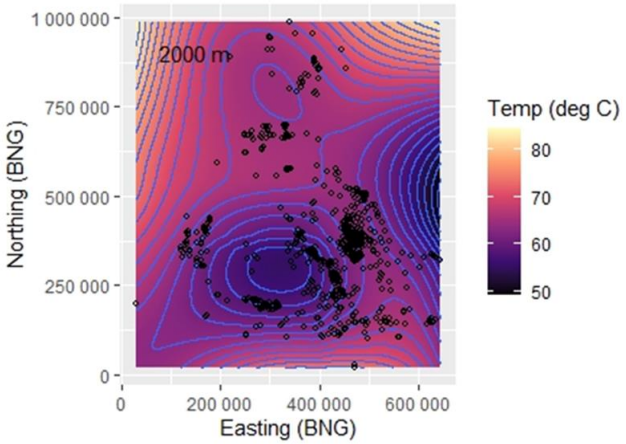


Molecular model of dazomet

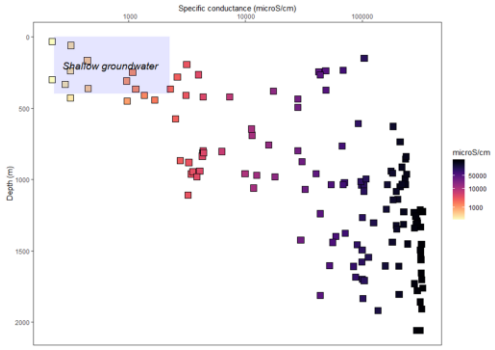


Detection probability of glutaraldehyde compared to UK biocides

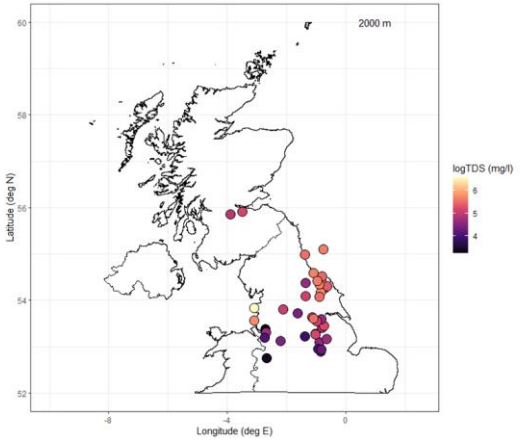
Bayesian analysis of geotherm



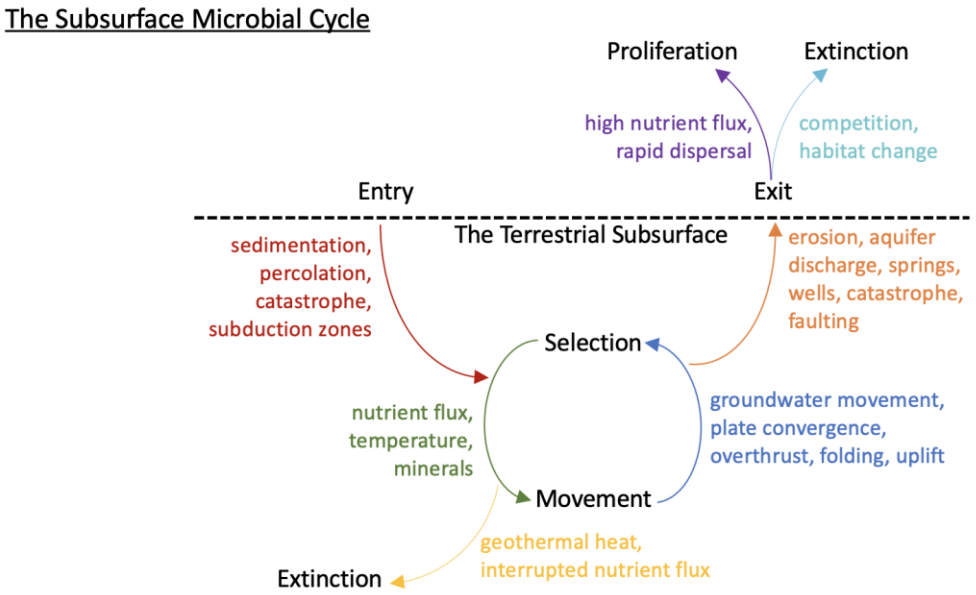
Apply same analysis to groundwater composition



Not really enough data to get a map of the deep groundwater composition



WP3: Impacts of subsurface energy extraction on terrestrial subsurface microbiology



- Core samples preserved for geomicrobiology were obtained from UKGEOS Glasgow, from 4 depths and varying lithologies.
- DNA extraction methods were developed with the aim of sequencing the extracted DNA and identifying the microorganisms present. Despite optimising the method and carrying out PCR to amplify the DNA, no microbial DNA was detected any of the samples.
- To try and cultivate subsurface microbes, cores from the UKGEOS site was enriched in multiple nutrient medias that selected for different types of microorganism and synthetic groundwater. After 6 months of incubation no microbial growth was seen.

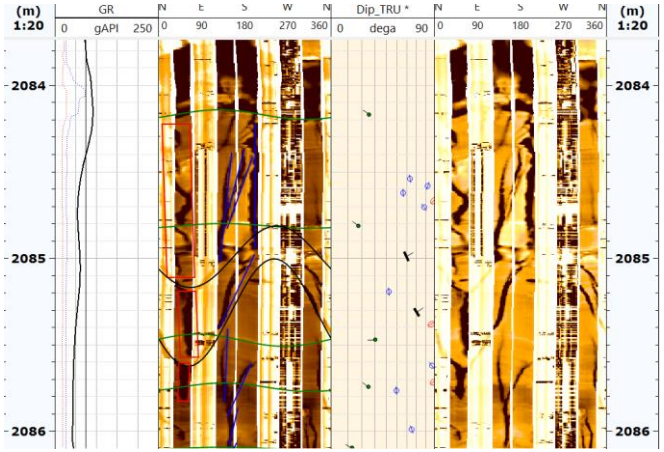
Future Work: Glutaraldehyde is the most used biocide in fracking in the US. It has also been approved for use in fracking in the UK but is common in many industries. While there is evidence that glutaraldehyde is readily biodegraded, plan is to research the impact of conditions common to fracking and geothermal on the biodegradation of glutaraldehyde, e.g. salinity, temperature, pH.

See Katie Edward's poster

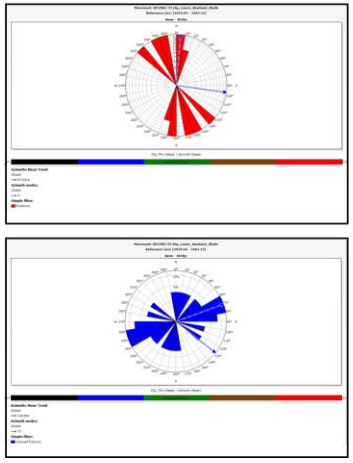
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

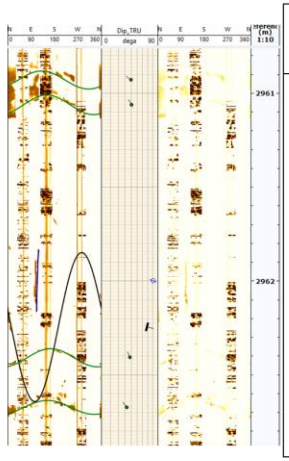
WP4: Geologic and stress models
Stress and Fracturing

- 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





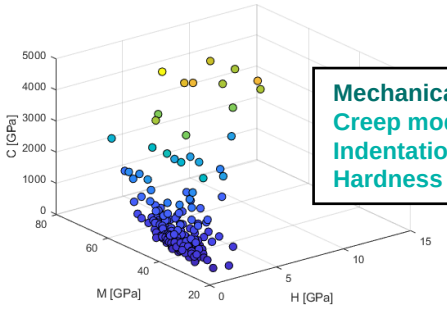
STRATIGRAPHIC UNIT	MODAL STRIKE	
	BREAKOUTS	INDUCED FRACTURES
Roeburndale Fm	-	053 NE
Brennand Grit	-	066 NE
Pendle Grit	146 SE	058 NE
Upper Bowland Shale	074 ENE	070 ENE
Lower Bowland Shale	005 N	070 ENE

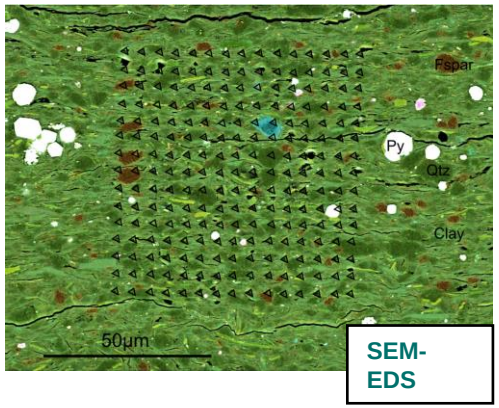
WP5: Micro to macro

Linking microscale geomechanical properties of shale to macroscale

- **Nanoindentation**
  - **Micromechanical experiments** on Horn River shales
  - Low-load grids 15 x 15 → big data
  - Parallel and normal directions to bedding → **anisotropy**
- **Chemo-mechanics**
  - **SEM-EDS analysis** of indentation grid
  - Coupled chemo-mechanical **statistical deconvolution** to identify phases
- **Homogenisation**
  - Microstructure-based **upscaling** of mechanical properties
  - Input from nanoindentation results on **material phases** (clay matrix, silt inclusions)
  - Link to microseismic anisotropy (field scale)

Nanoindentation grid on Fort Simpson overburden



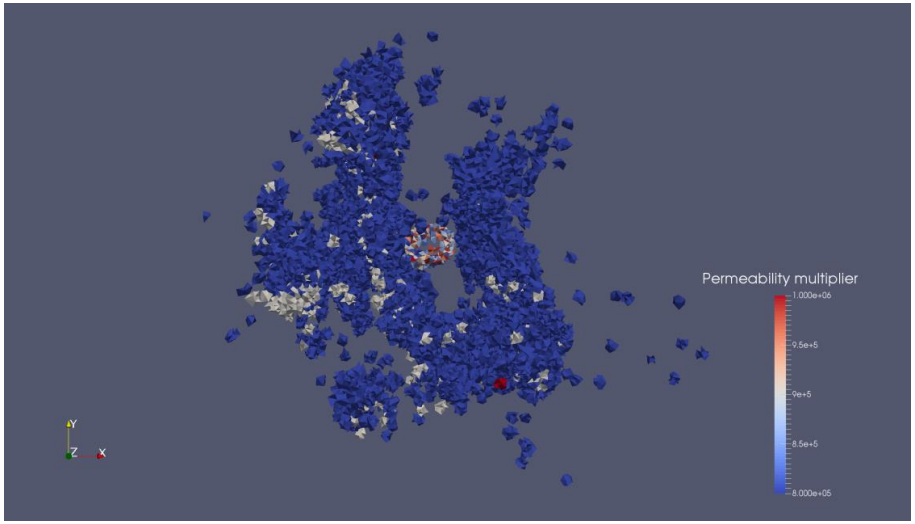


WP5 – Linked geo-mechanical, fluid flow and seismic modelling PNR2 Model

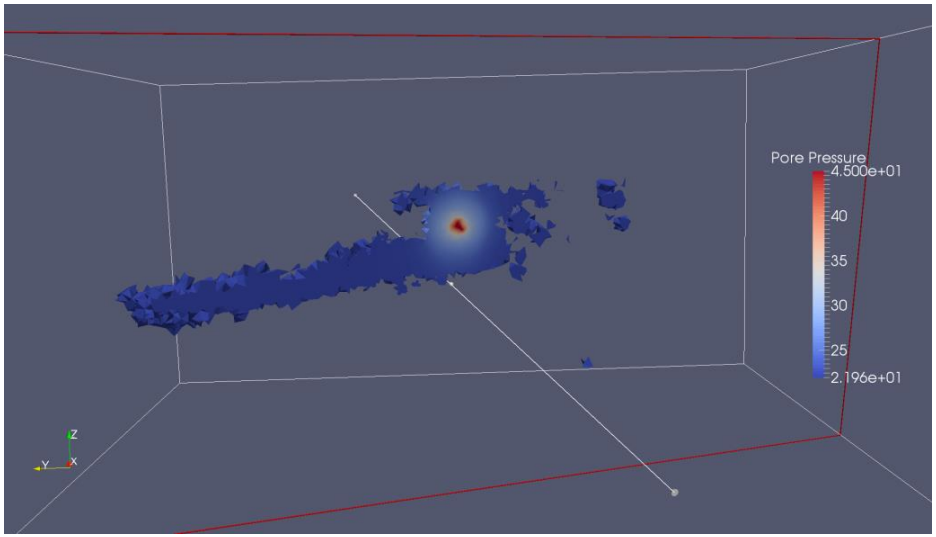
Objective: Field-scale simulation of Preston New Road 2 well. Link the high resolution micro-seismic data to geo-mechanical simulation to identify triggering mechanisms for seismicity

Methodology:

- Combined geo-mechanical/flow model
- Use sleeve locations to impose pore pressure boundary conditions and local permeability enhancement
- Define pre-existing/fracking induced damage at micro-seismic event locations



Permeability multipliers associated with micro-seismic event locations/moment magnitudes



Pore pressure distribution on the NS HF zone after Stage 2.

Status:

- Micro-seismic data projected onto mesh, initial simulations performed.
- First results support diffusion of increased fluid pressure as seismicity trigger

To do:

- New enhanced permeability field along well path
- Moment magnitude dependent effective damage area

WP6 – Geophysical imaging of unconventional reservoirs

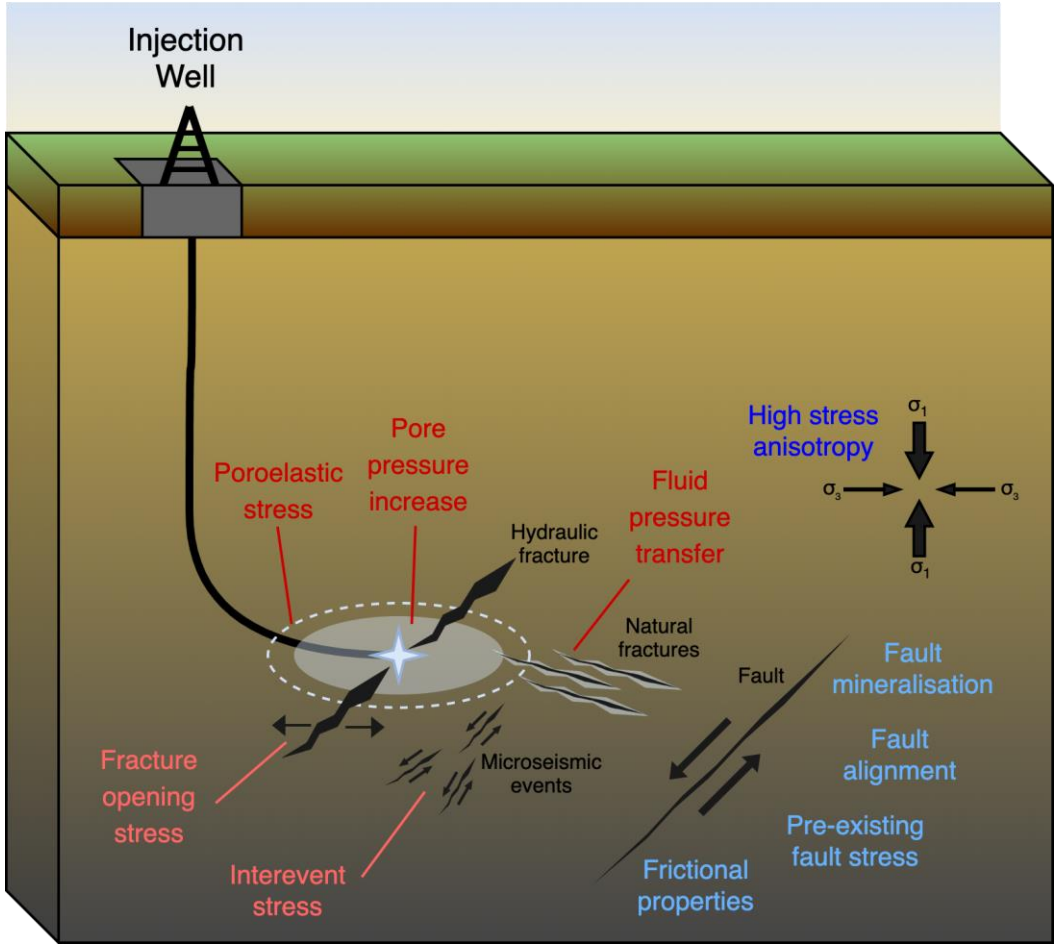
- **Output:** inform seismic regulatory framework (e.g., TLS); seismic hazard assessment, accurate estimates of seismic magnitudes through…
- *Passive seismic monitoring & geomechanical modelling:* new paper published in Frontiers on physical mechanisms underpinning fault activation during PNR-2 (**poster: Tom Kettlety**)
- *Passive seismic monitoring:* feed PNR-2 microseismic data into WP2 and Horn River Basin data in WP5 (**poster: Michael Allen**)
- *Fracture modelling* (collaboration with C2): combined with PNR microseismic data to develop injection scenarios to mitigate induced seismicity (**poster: Robin Thomas**)
- *Seismic reflection* (collaboration with C2): study of PNR fault identification, improving understanding of fault mapping for hazard analysis (**poster: Germán Rodríguez-Pradilla**)

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 ….



Going forward

- Continue with work on induced seismicity
- New threads in geomicrobiology
- More integration between WPs and other Challenges
- Results equally applicable to CO2/H2 storage, geothermal, rad waste, etc.