

## Induced seismicity hazard of minewater geothermal projects - linking coal-measure sedimentology to fracture properties: Implications for the UK's geothermal prospectivity.

Keele University in collaboration with Plymouth University

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Coal mining in the UK was associated with significant levels of induced seismicity due to destabilisation of the ground. On abandonment, changes in fluid pressures on flooding of the workings induced further earthquakes up to magnitude 3, but that activity has now ceased as the stresses stabilised. The use of flooded abandoned coal mines as an aquifer for low enthalpy, carbon-free, geothermal energy has the potential provide the UK with upwards of 1,500MW of geothermal heat from shallow workings alone, but fluid pressure changes caused by geothermal

pumping operations have the potential to further destabilise pre-existing fracture networks, induce failure, and generate subsidence and seismicity. There is potential to easily exceed the M0.5 earthquake threshold currently set for cessation of reservoir stimulation operations in the onshore UK.

Following a review of mining engineering and induced seismicity literature on UK coal-fields, and analysis of mining-induced seismicity using data available on the EPOS platform, this work will utilise a combination of outcrop localities and subsurface data from northern England, southwest Wales and the Midland Valley of Scotland, together with underground access to the Aurora Mine at Apedale, Staffordshire, to develop a statistical approach to linking deformation to Carboniferous delta-top sedimentology and stratigraphy at a variety of scales, and to compare theoretical modelling with in situ structural observations.

The project will have implications for the understanding of the destabilisation of fracture networks and induced seismicity potential adjacent to geothermal mine-water systems and may be able to provide mitigation strategies in mine-water geothermal operations.

### Rationale

In November 2020, the UK Government announced an ambitious ten-point plan to kick-start a green industrial revolution and achieve their pledge of becoming carbon neutral by 2050 (Gov.uk, 2020). A major barrier to achieving this aim is industrial and domestic heating and cooling, which currently contribute to nearly a third of the UK's greenhouse gas emissions. Plans for 360 geothermal plants by 2050 could provide 15,000GWh of annual heat and carbon savings of around three megatonnes annually.

However, research into heat recovery and storage in the UK's coal mines is still embryonic, and a whilst a bespoke underground observatory is being constructed in Glasgow as part of the UKGEOS programme to characterise the hydrogeology of abandoned mineworkings, little work other than seismic monitoring is being conducted on the structural stability of coal workings during geothermal operations. When the mineworkings of Stoke-on-Trent were abandoned in the 1990s hydrological changes triggered a series of earthquakes beneath the city up to M3 (Lovell et al., 1997), that died away once hydrological conditions stabilised. Shale gas reservoir stimulation operations are currently restricted in the UK to a seismic threshold of only M0.5.

Geothermal energy currently has a good public acceptance in the UK, but if geothermal operations start inducing significant tremors again beneath Britain's cities, that acceptance could be lost very quickly. Identification of, and mitigation against, induced seismicity hazards caused by minewater geothermal operations could prove critical to the take-up of a major UK carbon neutral energy source.

## **Project Details:**

The Cullercoats region of northern England, exposing Carboniferous Coal Measure strata, will be the main area of study for the project. The 4 km long, almost continuous exposure provides an excellent opportunity for geothermal system-scale study. Photogrammetric and a large amount of fracture data are already collected. This site will be coupled with Spireslack, a dominantly Namurian deltaic succession, in the southern part of the Midland Valley. Again, some fracture data are already available, but further constraint on the sedimentology is required across the area. The Apedale Mining Heritage Centre near Keele provides access to underground pillar and stall coal mine workings where fractures can be mapped in the very conditions likely to be encountered by minewater geothermal operations. This will be supplemented by available UK onshore hydrocarbon exploration data from Northern England / Southern Scotland and data available from the Coal Authority. Finally, the student will study the Amroth-Saundersfoot and Broadhaven sections in the Pembrokeshire Coalfield of South Wales to determine the validity of their results in a new locality without previously collected data and contrast results with an area that has undergone greater deformation before, during and after the Variscan Orogeny. Seismic data and core scans available from the UKGEOS Glasgow Geoenery Observatory will be analysed in order to make potential links between the field scale fracture networks mapped and any microseismicity / microfracturing observed in the Glasgow minewater geothermal operations. Induced seismicity data from various coal mining operations in UK and wider Europe are freely available from the EPOS TCS AH platform.

### **Work Package 1**

To conduct a literature review of discrete fracture network measurement, fractures, deformation and seismicity around active coal mining operations, and sedimentology of delta top successions and to become familiar with data already collected and analysis software.

### **Work Package 2**

To determine statistical relationships between fracture characteristics and delta-top sediments at the facies scale.

### **Work Package 3**

To determine statistical relationships between fracture characteristics and delta-top sediments at the architectural scale.

### **Work Package 4**

To analyse any microseismicity and microfracture at the Glasgow UKGEOS and determine linkages with fracture characterisation.

### **Work Package 5**

Thesis write-up and to draw implications from WP 2, 3 & 4 to mine water geothermal operations.

## **Work Plan:**

- **Year 1 (2022/23):** Literature review into minewater geothermal operations, fracture mechanics, fracture mapping, active coal mining deformation and seismicity, delta top sedimentology, geology of field sites, and induced coal mining related seismicity on the EPOS platform (WP1); familiarity with data already collected, identify data further data to be collected in field seasons 1 and 2. (WP2); Familiarisation with data analysis, interpretation and visualisation software; field season 1 – Sedimentology of Cullercoats and Spireslack (WP2); basic interpretation of the field data from the Cullercoats and Spireslack (WP2); analysis of Glasgow UK GEOS microfracture networks from borehole scans and any microseismicity recorded to that date (WP4); attend relevant conferences; University progression & year 1 review, including presentation to collaborators; CDT training and annual conference.
- **Year 2 (2023/24):** Detailed interpretation of the sedimentology in Cullercoats and Spireslack, using field and previously collected data (WP2); draw comparison between previously collected fracture data and newly developed sedimentological models (WP1&2); main field season – tidying up season 1 data collection and main fracture data collection for Cullercoats and Spireslack (WP2&3); in-situ fracture mapping underground at the Aurora Mine, Apedale and integration with other studies; paper

1 / Conference attendance – “Statistical link between fracture properties and facies scale sedimentology” (WP2); University progression & year 2 review, including presentation to collaborators; CDT training and annual conference.

- **Year 3 (2024/25):** Comparison between stratigraphical/architectural scale depositional elements and gross fracture geometry (WP 3); field season 3 – Pembrokeshire – Fracture and sedimentology of Carboniferous strata (WP2&3); analysis of field season 3 data (WP 3); paper 2 / Conference attendance – “Statistical link between fracture properties and depositional environment scale sedimentology” (WP 3); planning and start writing thesis. (WP5); University progression & year 3 review, including presentation to collaborators; optional CDT training and annual conference.
- **Year 4 (2025/26)** Further analysis of field season 3 (WP 3); apply findings to model the coal-mining induced seismicity available on the EPOS platform including re-evaluation of earthquake source mechanism characteristics (WP1); revisit Glasgow UKGEOS for new data since analysis in Year 1 (WP4); paper 3 / Conference attendance – “How sedimentology drives geothermal induced seismicity risk” (WP 5); thesis write-up (WP 5); CDT annual conference.

### **Funding**

This project is offered for competitive studentship funding through the CDT in ‘Geoscience for the Energy Transition’. Funding covers UK/EU Home fees, student stipend to RCUK levels, and a 5k pa Research Travel and Subsistence Grant (RTSG) to support fieldwork, conference attendance and training.

Start Date: September 2022

### **Application**

This position would suit an applicant with a 2:1 or higher bachelor’s degree in geology, geoscience or a related discipline, and a keen interest in structural geology, sedimentology & induced seismicity. An enjoyment of fieldwork is important. Some existing experience or background in Coal Measures sedimentology and structural geology is useful but not essential.

For further information on this project please feel free to contact the lead supervisor Dr Ian Stimpson at Keele University by email (i.g.stimpson@keele.ac.uk).

For further information on the Basin Dynamics Research Group please see: [keele.ac.uk/bdrg/](http://keele.ac.uk/bdrg/)

For further information on studying at Keele please see: [keele.ac.uk/pgresearch/howtoapply/](http://keele.ac.uk/pgresearch/howtoapply/)

Formal applications for the PhD study at Keele are handled centrally through Keele University's central admissions system: [keele.ac.uk/researchsubjects/geologygeoscience/](http://keele.ac.uk/researchsubjects/geologygeoscience/)