

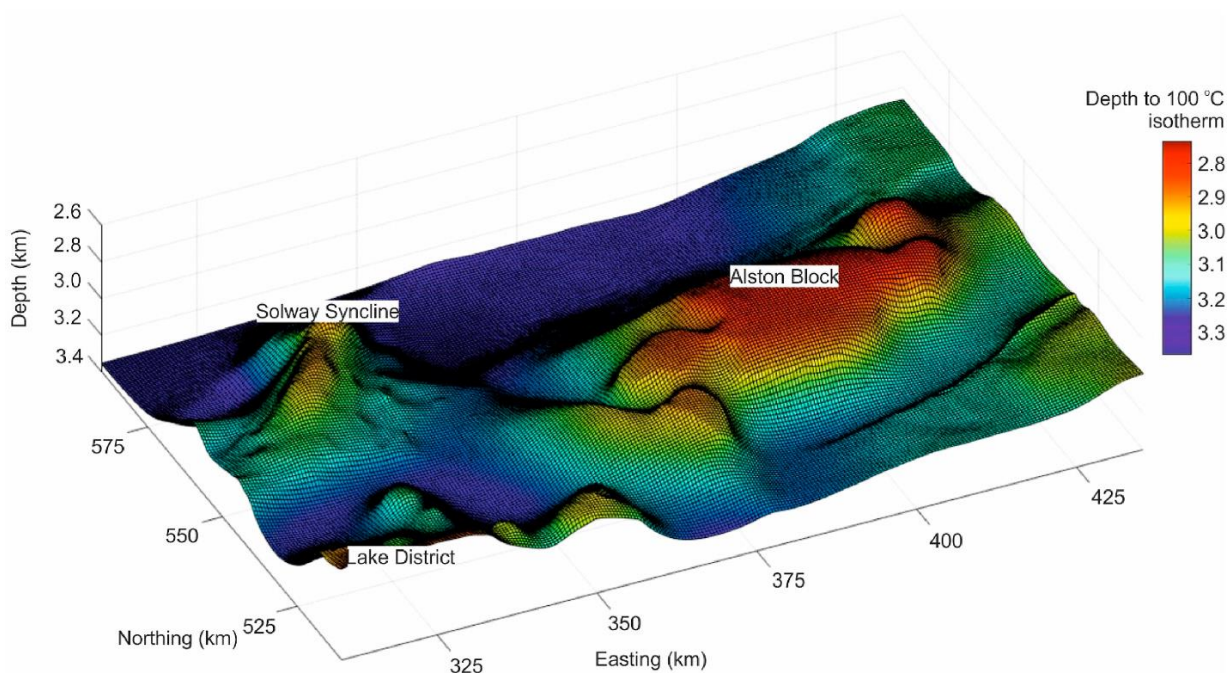
3D regional thermal modelling of the crust: application to the geothermal potential of the Carboniferous 'Blocks and Basins' of northern England.

Keele University in collaboration with the British Geological Survey

Supervisors: Dr Stuart Egan (Keele), Dr Graham Leslie (BGS) and Dr Stuart Clarke (Keele)

In the aftermath of the Paris Climate Agreement (2016), reducing the consumption of hydrocarbons has been framed as a long-term solution to carbon neutrality. However, with an ever-increasing energy demand, this places a significant burden on finding alternative energy resources. Geothermal energy, even in areas with relatively modest geothermal potential, can help bridge the energy gap left behind by hydrocarbons. This project will make a significant contribution to this long-term solution, particularly during the preliminary stages of geothermal exploration when it is imperative to understand the thermal structure of the crust, identifying the temperature of target reservoirs and regional thermal barriers.

The thermal structure of the crust in the UK is currently represented by a series of regional-scale resource maps, which have all been constructed by contouring around separate temperature measurements that are widely spaced and, therefore, susceptible to influence from localised structures as opposed to more regional trends. In order to address these weaknesses, the main aim of this project will be to develop a 3D numerical crustal-scale temperature model. The modelling approach will utilise both finite difference and finite element solutions of the steady-state heat equation and will include geological and geodynamic processes to enable lateral and temporal variations in temperature to be quantified in response to tectonic regime. The model will be applied to the North Pennine Basin, northern England, which is an area of ongoing geothermal exploration. Structural, lithological and rock property information derived from seismic and borehole data from the area, as well as radiogenic heat production values from concealed granite bodies will be integrated into a 3D model to help predict lateral and vertical temperature variations. The model will also be applied to other case studies to provide insights into their potential for geothermal exploration.



Modelled depth to the 100°C isotherm for northern England (Howell, et al., 2021).

Overall, the proposed research will provide an increased understanding of the integration, in 3D, between thermal, structural and geodynamic processes which will have far reaching implications for constructing more precise and reliable regional geothermal resource maps of the UK, particularly where data is sparse.

Work Plan:

This project is based largely on the interpretation of existing subsurface data along with the further development of numerical/computer modelling software. Model development will be carried out using the MATLAB programming platform. The data required to carry out the project includes regional heat flow data of the UK and regional onshore seismic lines and borehole data which are either published or accessible from UK Onshore Geophysical Library (UKOGL) and the British Geological Survey (BGS).

- **Year 1 (2022/23):** Project start-up and formal planning; begin review of literature; familiarisation with MATLAB programming environment as well as finite difference and finite element-based algorithms for modelling the thermal behaviour of the crust; familiarisation with software required for the interpretation, analysis and visualisation of project data sets (e.g. ArcGIS, Petrel, etc); begin collection and interpretation of seismic, borehole and geothermal data from the North Pennine Basin, northern England; construction of regional cross-sections of the North Pennine Basin, including structural, thermal, lithological and rock property information derived from seismic and borehole data from the area; commencement of the modelling component of the project in 2D based on input parameters obtained from subsurface data analysis (existing model algorithms will be progressively refined and new ones will be developed to incorporate input parameters and processes that are relevant to the study area); completion of literature review and progression report to satisfy Keele University's progression procedures; attend relevant conferences/meetings and CDT training courses.
- **Year 2 (2023/24):** Build a 3D geological model of the North Pennine Basin, based on regional cross-sections; continuation of thermal modelling of North Pennine Basin in 2D and 3D, with refinement of model algorithms to include finite element-based algorithms, as well as including validation of model results; plan/begin writing papers with submission of a manuscript for publication by the end of the year; attend relevant training courses; attend and present at relevant conferences/meetings (e.g. EGU).
- **Year 3 (2024/25):** Collect and interpret subsurface data to construct a 3D geological model of another study area (e.g. Cheshire basin); apply 3D thermal model of the crust to second study area to assess the geothermal potential of the region; planning and begin writing of thesis and continuation of writing publications; attend and present at relevant conferences/meetings; continue writing of papers with submission of at least one other publication.
- **Year 4 (2025/26):** Assess the broader implications of the thermal model to assess the geothermal potential of the UK; completion of writing of thesis; continue writing/completion of papers; attend and present at relevant conferences/meetings.

Likely graduate career routes:

Energy exploration or academia, with specialisms in basin analysis and modelling, structural geology and tectonics, and numerical and computer modelling of geological and geodynamic processes. In addition, the project will provide training in a variety of software applications including MATLAB for model development, Petrel for seismic interpretation and GIS for spatial data integration.

Further information on supervisors and potential collaboration:

The main supervisor, **Dr Stuart Egan (Keele)**, has extensive experience in the development two- and three-dimensional numerical models, which include a number of geological and geodynamic processes, to simulate the evolution of basin structures within a variety of tectonic regimes. More recently, he has been applying structural, thermal and geodynamic modelling techniques to geothermal exploration. The supervisory team also consists of **Dr Graham Leslie (BGS)** who will bring his expertise in structural geology and 3D visualisation to the project. In addition, **Dr Stuart Clarke (Keele)** is a continental sedimentologist and sequence stratigrapher with extensive knowledge of the Carboniferous geology of the Northumberland Trough and Aston Block in Northern England.

This project links to past and existing PhD projects within the [Basin Dynamics Research Group](#) at Keele that are underpinned by expertise in basin analysis, geodynamic modelling, sedimentology/sequence stratigraphy, structural geology and geothermal exploration. In particular, this project builds upon a recently completed PhD project entitled 'Structural, stratigraphic and geodynamic controls on the evolution of the Carboniferous succession of northern England and southern Scotland' supervised by S. Egan (Keele), G. Leslie (BGS) and S. Clarke (Keele). In addition, the project is cognate to, but not reliant on, another GeoNetZero CDT project, 'Mapping geothermal potential of hot water in Carboniferous sandstone aquifers using legacy coal and oil exploration data' (supervised by I. Stimpson, B. Besly and G. Leslie).

Funding:

This project is offered for competitive scholarship funding through the GeoNetZero Centre for Doctoral Training (CDT): Geoscience and its Role in the Low Carbon 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 first degree in geology, geoscience or a related discipline, and a keen interest in basin analysis and geodynamics.

For further information on this project please feel free to contact the lead supervisor Dr Stuart Egan at Keele University by email (s.s.egan@keele.ac.uk) or by phone (+44 1782 733174).

For further information on the Basin Dynamics Research Group please see:

<https://www.keele.ac.uk/bdrg/>

For further information on applying for postgraduate research opportunities at Keele please see:

<https://www.keele.ac.uk/study/postgraduateresearch/apply/>

Formal applications for the PhD study at Keele are handled centrally through Keele University's central admissions system at:

<https://www.keele.ac.uk/study/postgraduateresearch/researchareas/geologygeoscience/>

Relevant publications by project supervisors:

- Howell, L.P., **Egan, S.S.**, **Leslie, G.** and **Clarke, S.M.** 2019. Structural and geodynamic modelling of the influence of granite bodies during lithospheric extension: application to the Carboniferous basins of northern England. *Tectonophysics*, 755, pp. 47-63. <https://doi.org/10.1016/j.tecto.2019.02.008>
- Howell, L., Brown, C.S. and **Egan, S.S.** 2021. Deep geothermal energy in northern England: insights from 3D finite difference temperature modelling. *Computers and Geosciences*, 147. <https://doi.org/10.1016/j.cageo.2020.104661>
- Brown, C.S., Cassidy, N.J. **Egan, S.S.** and Griffiths, D. 2021. Numerical modelling of deep coaxial borehole heat exchangers in the Cheshire Basin, UK. *Computers and Geosciences*, 152. <https://doi.org/10.1016/j.cageo.2021.104752>