GeoNetZero Centre for Doctoral Training (CDT): Geoscience and its Role in the Low Carbon Energy Transition

(2022 start)

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

Host institution: Keele University

Supervisor 1: S.E. Egan (Keele)

Supervisor 2: A. G. Leslie (BGS) and S. M. Clarke (Keele)

Project description (250 words max.):

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.

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 are sparse.

Stated link to the overarching theme of the CDT i.e. The Role of Geoscience in the Energy Transition and the challenge to meet the net zero emission targets (NOTE: In order to qualify for NEO Energy CDT funding, there must be an explicit link to the Energy Transition with a clear application to the UK's Continental Shelf (UKCS). For projects supported by 100% matched funding from your University, links to the broader Energy Transition remit are sufficient):

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. In addition, the proposed project is fully compatible with the overarching theme of the GNZ CDT, particularly *'Geothermal opportunities'* and *'Extending the Life of Mature Basins to address the Energy Transition'.*

Details of mapping/fieldwork locations/data to be used by the project and confirmation of access to key data being secured (please attach map as an appendix if relevant):
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 include 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).

Outline of planned work schedule for the 4-year research period:

Year 1:

October 2022 - March 2023:
Project start-up and formal planning; start review of literature; student familiarisation with MATLAB programming environment as well as finite difference and finite element-based algorithms for modelling the thermal behaviour of the crust; student 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; Attend relevant conferences/meetings (e.g. TSG);

April 2023 – September 2023:
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; University progression & year 1 review, including presentation to collaborators; CDT training and annual conference.

Year 2:

October 2023 - March 2024:
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, with refinement of model algorithms to include finite element-based algorithms, as well as including validation of model results; plan/begin writing papers; attend and present at relevant conferences/meetings (e.g. EGU).

April 2024 – September 2024:
Further develop thermal modelling programme to work in 3D and apply to geological model of the North Pennine Basin, including validation of model results; attend relevant training courses; attend and present at relevant conferences/meetings; submission of first paper for publication; University progression & year 2 review, including presentation to collaborators; CDT training and annual conference.

Year 3:

October 2024 – March 2025:
Collect and interpret subsurface data to construct a 3D geological model of another study area (TBC); planning 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.

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April 2025 – September 2025:
Apply 3D thermal model of the crust to second study area to assess the geothermal potential of the region; begin writing thesis; continue writing/completion of papers; University progression & year 3 review, including presentation to collaborators; CDT optional training and annual conference.

Year 4:
October 2022 – September 2026:
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; CDT annual conference.

Any Additional Research Costs (NOTE: Each CDT studentship includes an individual Research Training and Support Grant (RTSG) budget of £20k for the full 4-year study period)
NA

Supervisory arrangements and involvement of external partners (NOTE: Please indicate the area(s) of expertise covered by each supervisor. External collaboration is encouraged, but if proposed partner is not currently providing support to the CDT, please outline the extent of the partner's involvement with the project.)
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 (Howell, 2021) 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 proposed PhD 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).

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

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.