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

(2022 start)

Project Title: Mapping geothermal potential of Carboniferous sandstone aquifers using legacy coal and oil exploration data.

Host institution: Keele University

Supervisor 1: I. G. Stimpson (Keele University)

Supervisor 2: B. Besly (Independent), A. G. Leslie (BGS), S. D. Burley (Keele)

Project description (250 words max.):

Carboniferous sandstone aquifers have been identified as a potential source of hot water for low enthalpy heating schemes in the UK, but there has been no systematic mapping of locations where this might be feasible. There are several difficulties: a) aquifers are distributed over a large area; b) different stratigraphical intervals in the very thick succession have widely varying sandstone content; c) provenance and burial history differences lead to large contrasts in porosity distribution and porosity/permeability transform; d) studies in the Southern North Sea suggest significant enhancement in poroperm in a weathering zone beneath the Variscan Unconformity. In addition, the topology, connectivity and fill history of Variscan and younger fracture networks may enhance or degrade aquifer potential.

The aim of this project is to map the distribution of sand-body aquifers in the Carboniferous strata that have temperature and poroperm characteristics that might enable a sustainable geothermal yield and are in locations accessible to low enthalpy geothermal developments. This will involve: a) systematic mapping of areas in which heat flow suggests availability of sufficient hot water; b) identification of petrographic and diagenetic patterns, and abundance of sandstone bodies in various stratigraphic intervals in the Carboniferous succession; c) petrophysical analysis of borehole wireline logs and core data (BGS, British Coal and hydrocarbon exploration) to characterise stratigraphical zones having sufficient permeability. Fracture network characterisation will focus on the third of these datasets and will include targeted study of faults and fracture networks in seismic images and surface exposures.

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):

Two studies have hitherto been made of the geothermal potential in Carboniferous sandstones (Hirst *et al.,* 2015; Younger *et al.,* 2016). These have both been focussed on specific sites. The first demonstrates the viability of the method; the second highlights the problem potentially caused by the presence of an unsuitable low-permeability aquifer in a site with good thermal characteristics. This study will generate a methodology to high-grade other potential geothermal target areas using the Play Fairway Analysis techniques employed in the hydrocarbon exploration industry and employing existing data sources (particularly the British Coal borehole database) that have hitherto been neglected. As such it makes a direct contribution to the following CDT themes: *'Re-purposed exploration to meet the needs of society'* and *'Geothermal opportunities (of both hot rocks and low enthalpy ground sources)'*

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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): The project will be restricted to northern and central England. Mapping and analysis will be conducted at two scales: a) regional (heat flow, Carboniferous subcrop and gross sand distribution); and b) targeted on basis of results of a) and on data availability. The targeted areas will be those in which there is sufficient well and other data to carry out a meaningful analysis. These areas will probably be focussed on (but not restricted to): North Yorkshire and Teesside; parts of the Yorkshire Coalfield and its sub-Mesozoic extension; parts of the Lancashire and North Wales Coalfield; parts of the Cumbrian Coalfield. These are areas in which there are sufficient penetrations of pre-Westphalian rocks to allow the project to address a significant proportion of the Carboniferous succession rather than being solely focussed on the Coal Measures.

Seismic data will be obtained via UKOGL, with whom one of the supervisors has a close working relationship. British Coal and BGS borehole data will be obtained from BGS. A significant set of hydrocarbon well data is already held at Keele. Further well data will be reviewed at BGS, or obtained from operators or via the OGA data repository (onshore data scheduled for availability in 2022 – but if this is delayed onshore well data will be purchased from data release agent IHS under their academic discount scheme).

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

YEAR 1 (2022/23): Extensive literature review into Carboniferous stratigraphy and sedimentology, UK heat flow studies and low enthalpy heating systems; introduction to subsurface datasets and creation of databases; familiarisation with software required for the analysis, interpretation and visualisation of project-related datasets e.g., Petrel, ArcGIS etc.; familiarisation with unique aspects of British Coal dataset and its integration with 'conventional' subsurface data sets; regional mapping of sandstone distribution, depth and relationship to Variscan Unconformity in stratigraphic slices; integration with regional heat flow maps to produce high-graded exploration target zones; attend relevant conferences; University progression & year 1 review, including presentation to collaborators; CDT training and annual conference.

YEAR 2 (2023/24): Identification of target areas for more detailed study; collection and processing of well data; interpretation of porosity distribution; mapping and modelling of sandbody dimensions; mapping and modelling of fault populations and hierarchies; fieldwork to document bedform and fault/fracture heterogeneity; attend relevant conferences; Submission of paper for publication; University progression and end year 2 review, including presentations to collaborators; CDT training and annual conference.

YEAR 3 (2024/25): Continuation of targeted case studies; mapping of enhanced porosity distribution related to sub-Permian weathering; review of existing petrographic and diagenetic studies; targeted additional petrography and mineralogy work to fully understand: a) linkages between burial history and Variscan telogenesis; and b) diagenetic history in sandstones of differing provenance and resulting control on permeability; attend relevant conferences and training courses; planning and start of thesis writing. Submission of paper for publication. End year 3 review, including presentations to collaborators; CDT training and annual conference.

YEAR 4 (2025/26): Generation of regional models of Carboniferous aquifer distribution and potential geothermal exploitation areas; Thesis production and completion; final presentation to collaborators; 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)

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N/A

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.)

Primary supervisor: Dr I. Stimpson - project design and administration; mathematical and physical aspects of thermal mapping and modelling; seismic interpretation; structural geology.

Secondary supervisors: Dr B. Besly (stratigraphy and sedimentology; processing and interpretation of borehole data); Dr G. Leslie (structural & Carboniferous geology; liaison with BGS); Prof. S. Burley (petrography, diagenesis, burial history analysis)

Advisory team: Dr S. Egan (lithospheric scale geothermal & numerical modelling)

The proposed project is supported and underpinned by the current interests of members of the research group in which it would reside (Basin Dynamics Research Group – Keele University). The project links directly to the temperature field modelling of northern England contained within the recently completed PhD thesis of Dr L. Howell (Howell, 2021, Howell *et al.,* 2021) and is cognate to, but not reliant on, another proposed PhD project ("3D regional thermal modelling of the crust: application to the geothermal potential of the Carboniferous 'Blocks and Basins' of northern England"; supervised by Dr S. Egan). Recent publications of the Group include a wide-ranging review of Carboniferous petroleum geology in the onshore and Southern North Sea areas (Besly, 2018). Other members of the Group (Professor G. Kelling, Dr S. Clarke) have wide experience in Carboniferous regional geology.

Citations:

Besly, B.M. 2018 Exploration and development in the Carboniferous of the Southern North Sea: a 30-year retrospective. *In:* Monaghan, A. A., Underhill, J. R., Hewett, A. J.& Marshall, J. E. A. (eds), *Palaeozoic Plays of NW Europe.* Geological Society, London, Special Publications, **471**, 17–64 https://doi.org/10.1144/SP471.10

Hirst, C.M., Gluyas, J.C. & Mathias, S.A. 2015. The late field life of the East Midlands Petroleum Province: a new geothermal prospect? Quarterly Journal of Engineering Geology and Hydrogeology, **48**, 104-114 https://doi.org/10.1144/qjegh2014-072

Howell, L. 2021. Structural, stratigraphical and geodynamic controls on the evolution of the Carboniferous succession of northern England and southern Scotland. PhD Thesis (Keele University).

Howell L, Brown CS, Egan SS. 2021. Deep geothermal energy in northern England: Insights from 3D finite difference temperature modelling. Computers & Geosciences, Article ARTN 104661, **147**. http://dx.doi.org/10.1144/sjg2020-007

Younger, P.L., Manning, D.A.C., Millward, D., Busby, J.P., Jones, C.R. & Gluyas, J. 2016. Geothermal exploration in the Fell Sandstone Formation (Mississippian) beneath the city centre of Newcastle upon Tyne, UK: the Newcastle Science Central Deep Geothermal Borehole. Quarterly Journal of Engineering Geology and Hydrogeology, **49**, 350-363 https://doi.org/10.1144/qjegh2016-053

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Likely graduate career routes:
Exploration or development geologist (geothermal industry, conventional hydrocarbons or CCS); Sedimentologist; Stratigrapher; Petrophysicist; Data scientist; Academic and governmental careers.