

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

Keele University in collaboration with the British Geological Survey

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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 stratigraphic 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 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 stratigraphic 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.

Rationale

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 technique employed in the hydrocarbon exploration industry and employing existing data sources (particularly the British Coal borehole database) that have hitherto been neglected.

Project Details:

The project will be studying the Carboniferous sandstones of 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).

Work Plan:

- **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 and training courses; University progression & year 1 review, including presentation to sponsors.
- **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 and training courses; Submission of paper for publication; University progression and end year 2 review, including presentations to sponsors.
- **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 sponsors.
- **Year 4 (2025/26)** Generation of regional models of Carboniferous aquifer distribution and potential geothermal exploitation areas; Thesis production and completion; final presentation to sponsors.

The proposed project is supported and underpinned by the current interests of members of the Basin Dynamics Research Group. The project links directly to the temperature field modelling of Northern England contained within the recently completed PhD thesis of Dr. L. Howell (Howell *et al.*, 2021) and is cognate to, but not reliant on, another proposed CDT PhD project for 2022 start ("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.

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 sedimentology. Some existing experience or background in Carboniferous sedimentology 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/

For further information on studying at Keele please see: 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/

Cited references (members of the supervisory team in bold):

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, 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>