UK Geoenergy Observatories: new facilities to understand the future energy challenges

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Summary:

Decarbonisation of energy supplies will require development of new technologies to store energy, heat and waste gases and to act as alternatives to batteries are required for storing renewable energy to make it available during periods of peak demand. The subsurface has the potential to deliver these new technologies through Carbon Capture and Storage (CCS), aquifer storage of heat and compressed air, and extracting geothermal energy.

The heterogeneity of the subsurface and lack of detailed knowledge of its static and dynamic properties makes modelling of the efficacy of such proposed technologies difficult. Geoscientists require new experimental facilities where subsurface properties can be studied at unprecedented detail to underpin realistic simulations.

The British Geological Survey, on behalf of the Natural Environment Research Council, is developing two new experimental facilities. The planned UK Geoenergy Observatory at Ince Marshes in Cheshire will allow a wide variety of datasets to be gathered on rocks, fluids and fluid transport, bespoke experiments to be undertaken and the properties of a volume of the rock to be understood. It will consist of four different arrays of newly-drilled and extensively-cored boreholes which will characterize the subsurface in greater detail than has previously been possible.

Theme: 5-2.1

Alternative 7-7.1

2nd Alternative : 6-1.2

New Objectives:

New experimental facilities to parameterise the subsurface

New Aspects:

New openly available digital data to aid decision making

Introduction

The subsurface has been a central component to meeting the energy requirements of the UK since the nineteenth century. Initially coal provided the principal energy source, with a transition in the 1960s to oil, natural gas and nuclear energy. More recently, the urgent need to reduce atmospheric carbon dioxide emissions (IPCC report, 2018) has stimulated interest in low carbon subsurface energy technologies, including geothermal power, the subsurface storage of heat and energy (Evans, 2018), and subsurface storage of carbon dioxide (IPCC, 2018).

The requirement to decarbonise our energy systems whilst maintaining a secure and affordable supply presents challenges for governments, regulators, industries and citizens. For subsurface energy technologies these include increased demands on subsurface space and resources, and the need for a better understanding of the behaviour of the subsurface and how it responds to change. An increased understanding of subsurface properties, lithological heterogeneity, in-situ stress and geological structure is needed to facilitate new uses of the subsurface at multiple scales and understand the influence of micro-scale variation on macro-scale properties.

In recent years a wide range of technologies have been developed for the investigation of subsurface processes including 3D geophysical techniques, advanced core scanning and remote monitoring systems. The data from such systems can be used to optimize the design of subsurface energy facilities and provide real time data on system performance to reassure stakeholders and optimize system operation. Such considerations are very important, with drill sites in densely-populated localities requiring a social licence to operate, as well as environmental licensing and permitting.

To address these challenges and opportunities the British Geological Survey (BGS), on behalf of the Natural Environment Research Council and funded by the Department for Business, Energy and Industrial Strategy, is developing new subsurface research facilities collectively known as the UK Geoenergy Observatories.

UK Geoenergy Observatories

The UK Geoenergy Observatories facilities will be located in Cheshire (subject to planning consent) and Glasgow (Monaghan, 2018). At the Glasgow observatory research will be undertaken to develop a better understanding of the potential for shallow, low enthalpy, geothermal heat recovery from coal mine workings. The Cheshire observatory will provide data to underpin research into a number of new energy technologies that will directly help reduce atmospheric carbon emissions, for example CO2 storage, shallow geothermal, and aquifer storage of heat and compressed air.

The Cheshire facility, which is the focus of this paper, is located at the northern margin of the Cheshire Basin on Devensian-aged Quaternary deposits, overlain by a variable thickness of made ground. These deposits rest on faulted Permo-Triassic sandstone bedrock, varying in thickness from 250 metres on the horst to over 1000 metres in the graben (see Figure 1). Underlying the Permo-Triassic sandstone are older Carboniferous strata, with deep boreholes proving sedimentary rocks of the Warwickshire, Pennine Coal Measures, Millstone Grit and Craven Groups at depth. The geological succession therefore contains many facets of the UK's energy system: Carboniferous hydrocarbons source rocks and coal seams at depth, Permo-Triassic reservoir rocks and potential seals which act as drinking water aquifers near surface.

Focus areas for the UK Geoenergy Observatories Cheshire site:

1) Challenges to subsurface energy utilisation

The public response to hydraulic fracturing proposals in the UK has challenged the extractive industries on their social licence to operate. The incidence of seismic activity at the Preese Hall 1 well (Green et al, 2012) has caused public concern and has led to challenges to further drilling. The public debate over new uses of the subsurface is demanding clear unbiased data about the way rocks behave in-situ. These questions can only be addressed with a full range of the data types across multiple scales, for example from 3D seismic survey to nano-scale microscopy. The proposed UK Geoenergy Observatory at Ince Marshes provides an excellent opportunity to conduct research and collect data at all of these scales.

2) Micro-to-Macro

Research into the processes associated with faulting and fracturing are dominated by studies as extreme scales: crustal scale faulting and (sub-) microscopic scale features. Whilst these two scales are important to fully characterise an area, the processes which impact on and link them are poorly represented in the literature. For example sediments may be affected by late stage fine-scale cement in pore throats at scales visible only using microscopy / scanning electrons microscopes (SEM) which impacts their macro-scale permeability. The key topic of understanding transport pathways in the subsurface requires the location and properties of features at multiple scales to be considered. This approach will allow a better understanding of how the micro-scale features affect the macro-scale behaviour of rocks.

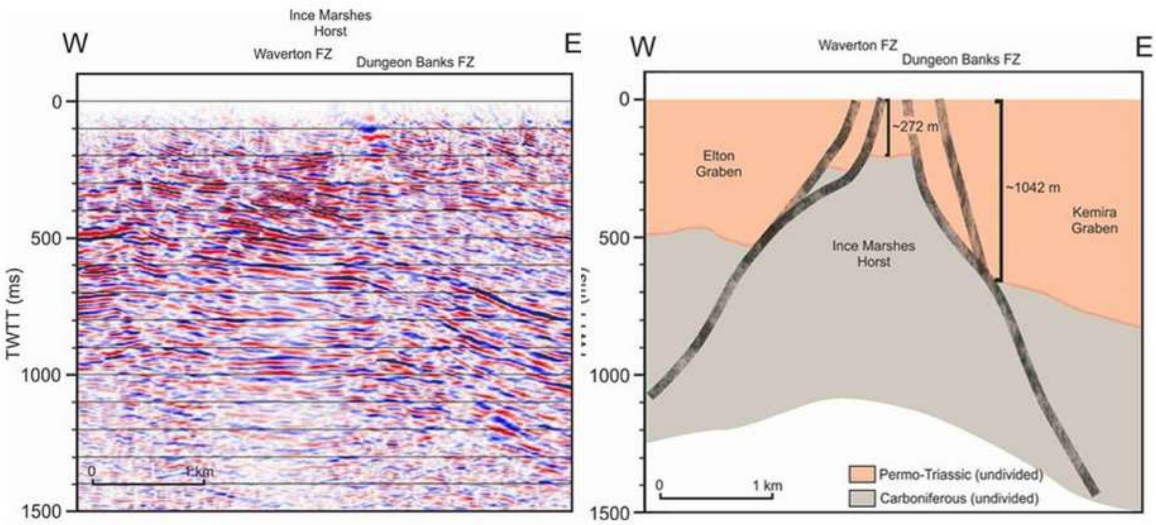

Figure 1 *General structure of the Ince Marshes area, based on 2D seismic line SC-83-128V, showing the Ince Marshes horst defined by the Waverton (W) and Dungeon Banks (E) fault zones (FZ)*

Design of Cheshire research facility

The planned UK Geoenergy Observatory at Ince Marshes in Cheshire will allow a wide variety of datasets to be gathered on rocks, fluids and fluid transport, bespoke experiments to be undertaken and the properties of a volume of the rock to be understood. It will consist of four different arrays of newly-drilled and extensively-cored boreholes which will characterize the subsurface in greater detail than has previously been possible. Data from these arrays will be combined with boreholes previously drilled for coal seam gas, shale gas and coal exploration. During 2020, an industry-derived 3D seismic cube will be released cross cutting this area. Collectively these data will enable properties derived from core at nano-metre to decimetre scales to be reliably upscaled into the rock mass at reservoir scale (10 metre to kilometre scale). The arrays are described below and in Kingdon et al., 2019.

Borehole Array Descriptions

A suite of up to 50 boreholes (see Figure 2) ranging in depth from 25 metres to 1200 metres will be drilled for the geological and hydrogeological characterisation that is essential to deliver a multi-scale in-situ understanding of the subsurface observatory. Some of these boreholes will be cored from surface and wireline logging is planned for a number of them. The boreholes have been divided into four arrays, each of which has a complementary research objective.

- **Array 1** will study the environmental baseline of the groundwater at 10 locations, each having both a 50 and 100 metre deep borehole, allowing understanding and geological characterisation of both the superficial (Quaternary) and bedrock geology. This array will deliver a more complete understanding of the hydrogeology and its regional connectivity in the Permo-Trias aquifer.
- **Array 2** consists of 9 locations across the different fault blocks (mostly co-located with array 1 boreholes) with boreholes drilled to either 200 or 300 meters deep for emplacement of borehole seismometers. The total array will (in combination with the deep seismometer in Array 2) allow

accurate recording of seismicity down to levels as low at -0.8 M. Each of these boreholes will be logged and cored

- **Array 3** consists of a single deep borehole which will be drilled open hole through the Permo-Triassic succession and cored through the Carboniferous Pennine Coal Measures Group through to the Carboniferous Millstone Grit Group. These boreholes will then be logged using a full suite of conventional geophysical logs including high resolution resistivity borehole imaging. Each core will be scanned using state-of-the-art core scanners and then sedimentary logged. Following wireline fluid sampling high-resolution seismometer will be installed before the borehole is cemented to surface.
- **Array 4** consists of a multi-scale array of some 30 boreholes both drilling through the complete Permo-Triassic succession and into the underlying faulted contact with the Carboniferous succession. At least one of these boreholes will be fully cored as well as logged and imaged. This array will allow highly detailed study of the complete Permo-Trias succession and hydrogeological properties of the in-situ fault materials. It will also facilitate advanced hydraulic experimentation with 4D hydrogeophysical monitoring.

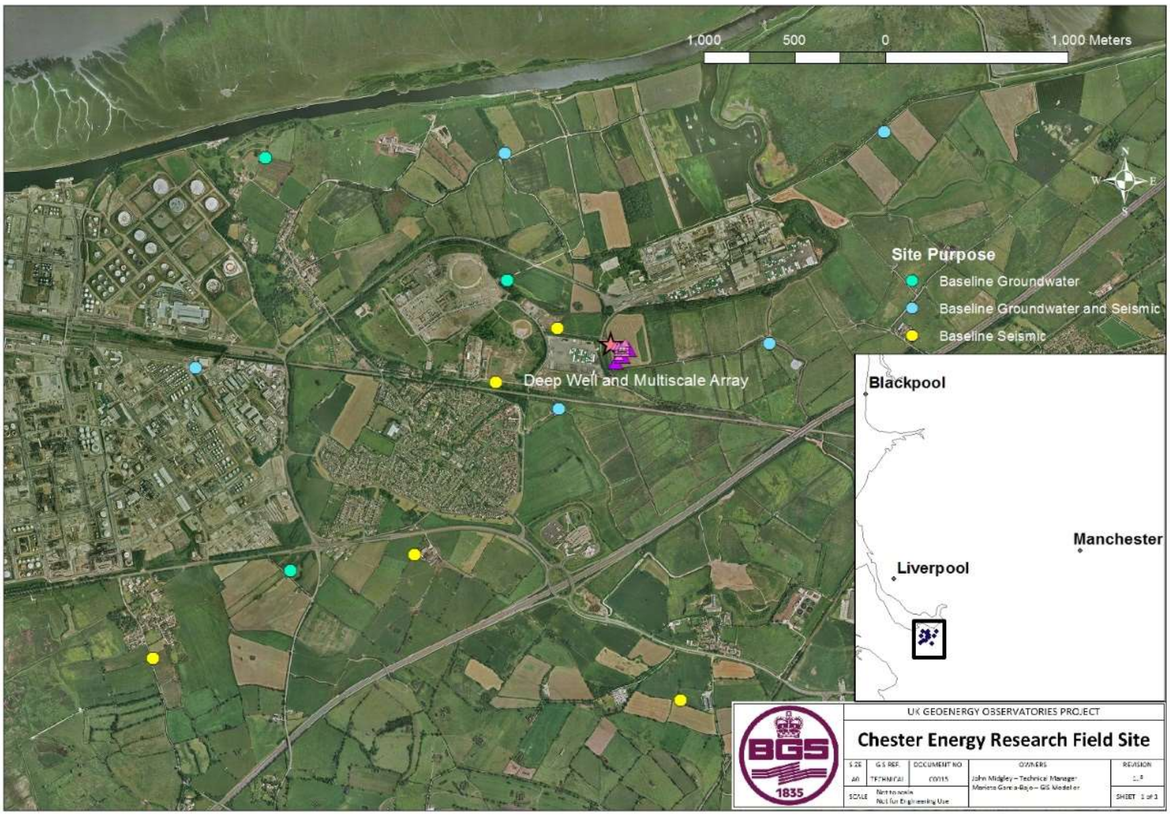

Figure 2 *Location of borehole infrastructure with their objectives at UK Geoenergy Cheshire Observatory and (inset) locations in reference to major cities. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2019] Ordnance Survey [100021290 EUL].*

Research Objectives: Geological characterization

New technologies, such as core scanners, will be utilised to determine the composition and physical properties of the lithologies present. Sedimentary logging will define the depositional character of the strata and input to the development of a complete stratigraphic interpretation. Researchers will sample the geological data at multiple scales to further develop the petrophysical and geological understanding of this succession. A key ambition of this programme is to determine the data and approaches required to upscale properties from very small scale features to much larger volumes of rock.

Research Objectives: Hydrogeological experimentation
Research boreholes from Array 1 and 4 will provide a hydrogeological research facility allowing hydraulic and tracer tests to investigate subsurface heterogeneity in order to understand fluid pathways and the connectivity of sandstone aquifers at different scales over distances of 10s to 1000 of metres.

Research Objectives: Time series monitoring of geological process in real-time
Monitoring of time-series analyses of multiple new dynamic data streams will allow a new understanding of the interactions between subsurface processes. A key deliverable is to provide sensor data via the web in real time for monitoring of the subsurface. Data on seismicity will be using measurements derived from both seismometer and fibre optic cabling. Geoelectrical imaging, temperature and multiple water chemistries and other hydrogeological properties will be continuously monitored. These data will be streamed using the UK Geoenergy Observatories portal (ukgeos.ac.uk) to allow the sensitivity of the geosphere to natural and induced perturbations to be easily studied.

Research objectives: Innovation Hub
A major research objective is that the geological facilities will be available for many years into the future. The boreholes will be available for at least 15 years to allow the testing of borehole fluids, sensors and new tools to aid geological characterisation (for example new geophysical logging technologies). The installation of network infrastructure will facilitate new sensors to be installed and tested in-situ from surface or significant depth into these boreholes thereby ensuring that this facility will become a key testing location for geological sensors.

Research Objectives: Open data provision
Despite extensive data collection by industry, much of the knowledge about geomechanics and geophysics is stored in databanks which are not freely available to the public. A fundamental objective of the UK Geoenergy Observatories programme is that all data will be openly accessible immediately, or as soon as possible following analysis and effective quality controlled. Rapid data delivery will allow data scientists to investigate relationships between multiple static and dynamic datatypes. We expect to develop improved understanding of subsurface processes and their interactions, and new techniques to study and describe them to be developed. The aim is to develop an ever growing archive of data that will facilitate world-class research. Collectively this will make the UK Geoenergy Observatories the default location for developing and testing new tools and techniques for geological characterisation and sensor technology.

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