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Abstract Book

The 7th
London Geothermal Symposium

5 November 2019

The Geological Society, Burlington House, London

Convenors

Charlotte Adams (Assistant Professor, Durham University)
Guy Macpherson-Grant (Managing Director, EGS Energy)
David Townsend (Managing Director, Town Rock Energy)

Background image: Ásgeir Eggertsson, Krafla geothermal power plant in Iceland, colour edited version (Creative Commons). Inset image: Hans Erren, Geothermal water pipes at community centre Gen Coel (interior) Heerlerheide, Heerlen, The Netherlands, cropped version (Creative Commons)

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Session One: UK and Industry Updates

The United Downs Geothermal Power Project

Ryan Law
Geothermal Engineering

The United Downs Deep Geothermal Power project is the first geothermal power project in the United Kingdom. It is located near Redruth in west Cornwall, UK and is part-funded by the European Regional Development Fund. The project consists of two deviated wells; a production well. The production well is the deepest on shore well in the UK at 5,275m total measured depth. Both wells target a sub-vertical, inactive fault structure that displays enhanced permeability relative to the surrounding granitic rock. Geothermal gradients in Cornwall are higher than the rest of the UK and the bottom hole temperature is in the region of 195^{O}C. The project is currently running further tests on both wells with the aim of entering the construction phase for the proposed power plant in Q2 2020. The aim of the project is to produce 3.15MW of net electricity to the grid by the end of 2021.

Getting ready for mine water energy research and innovation at the UK Geoenergy Observatory in Glasgow: update on construction progress, open datasets and facility access

Alison Monaghan and the BGS project team

The UK Geoenergy Observatory in Glasgow will provide infrastructure and open data to facilitate research and innovation in shallow, low-temperature coal mine water geothermal energy resources. The Observatory site has commonalties with many former coalfield areas of the UK where mine water energy systems could provide sufficient heat and heat storage for community-scale district heating schemes. The 12 continuously-monitored boreholes together with a wide range of environmental baseline monitoring equipment will provide an unrivalled opportunity to research topics such as thermal and hydrogeological subsurface processes, resource sustainability, and the potential environmental impacts on the subsurface-to-surface. The infrastructure will also allow development and testing of innovative technologies, sensors and processes, thus contributing to reducing uncertainty for sustainable and decarbonised mine water heat energy systems.

An update will be given on the progress of construction of the facility, including the condition of the target mine workings, and environmental baseline monitoring. The open data already available on www.ukgeos.ac.uk will be summarised, as will some examples of the kinds of research already enabled by early access 'during-drilling' sampling of rocks and fluids. The process for using the Observatory when it opens in Spring 2020 will be summarised.

“On the Rocks” – Exploring Business Models for Geothermal Heat in the Land of Scotch

David Townsend
Town Rock Energy Ltd

Despite valiant efforts, there are still no significant geothermal energy projects installed in Scotland, and only a few significant open-loop ground-source heat pump projects. This paper tells the stories, in brief, of these efforts, primarily made by a small company TownRock Energy, founded by a geology graduate and his father in 2013. They gathered insight and best practice from projects around the world, from New Zealand to Iceland, California to the Netherlands, Kenya to Hungary. Outlined in this paper are the most important factors to consider when designing an economically viable geothermal heat network in a country with old cold rocks.

In 2015 the Scottish Government launched the Geothermal Energy Challenge Fund, which awarded a total of £234,025 to five consortiums of business, local authorities and universities to complete site-specific geothermal heat network feasibility studies. TownRock Energy was heavily involved, and whilst none of the original projects were taken forward for test drilling, various consortium members went on to spend the following years hunting for the perfect demonstration sites. TownRock Energy has advised clients from all sectors, including airports, universities, and distillers, via over a dozen feasibility studies and business cases, evaluating fractured granites, hot sedimentary aquifers and most commonly flooded coal mines. The findings have been distilled in this paper.

Economic, environmental, social and political parameters all impact the business case. Risk analysis and mitigation is critical. However, with the decarbonisation of heat appearing ever higher on the political agenda, legislative, financial, and social barriers are closer than ever to being smashed down. A new dawn of low-carbon heat for a country which most importantly needs a sustainable fuel source for the creation of the fire water the world adores. Slainte mhath!

Deep Geothermal project by EGSE and Eden Project at the Eden Site

Roy Baria & Richard Day
EGS Energy Ltd

The deep geothermal project at the Eden site has secured £16.8 million of funding for drilling the first deep well to produce heat and power. It has taken around 10 years of campaign to bring clean, green technology to Cornwall in conjunction with the knowledge gained at the Hot Rocks project at the Rosemanowes Quarry (CSM) and the European project at Soultz (France).

The £16.8 million sum has been secured from a mixture of public and private sources. This consist of £9.9 million from the European Regional Development Fund (ERDF), £1.4m Cornwall Council and £5.5million from Institutional investors.

A legal entity (Eden Geothermal ltd) was formed from EGSE Ltd, The Eden project and BESTEC UK Ltd to receive the funds and execute the program. The scientific supporting partner will be Camborne school of Mines (Exeter University).

The initial planned program consists of drilling a well to around 4500 m depth into know natural fault at the Eden site to access hot in-situ fluid at a temperature of around 170°C. After establishment of the working platform/site, background seismic monitoring and various regulatory procedures, it is planned to start drilling around summer 2020. The drilling of the first well and scientific investigations of the in-situ properties will take around 12-18 months.

The hot water will be used initially to heat biomes at the Eden Project but a plan is in place to drill the second well to discharge the cooled water in to the deep formation and thus establish a deep geothermal system (EGS) that can provide both heat and power. This can form a model of future development of deep geothermal systems (EGS) in Cornwall and elsewhere, thus helping to mitigate the climate change issue.

A summary of high temperature geothermal research ongoing at the BGS

Chris Rochelle
British Geological Survey

The British Geological Survey (BGS) is involved in several large multi-partner geothermal research projects from near-surface to deep systems, and that span a wide range of pressure/temperature (P/T) conditions. Here, I present a summary of BGS projects focussed on deep, high P/T systems. Common to these is the need to understand how fluids interact with rock, modifying both fluid chemistry and rock properties. This is especially important where fluid flow is focussed along fractures. Examples include:

- CHPM2030: An EU H2020 project investigating the potential for metal production during EGS operations. BGS activities include studies of SW England, and mineral dissolution.
- GEMex: A joint Mexico-EU project investigating the potential for hot-EGS within the Acoculco caldera, and superhot geothermal operations at Los Humeros. BGS activities include surface gas and thermal monitoring, and mineralogical changes.
- United Downs Deep Geothermal Power project: Where the BGS is working with GEL and GeoScience towards the UK's first geothermal power plant. BGS activities include microseismic monitoring, and preliminary analysis of borehole materials.
- GWatt: A NERC-funded project to better understand fracture-hosted fluid flow in crystalline rocks in SW England. BGS activities will extend microseismic and fracture datasets, and the chemical and physical properties of fractures.
- REFLECT: This recently-awarded EU H2020 project will address uncertainties in the chemical properties of geothermal fluids. BGS activities include measuring high temperature silica solubility and speciation.

Session Two: De-risking Geothermal

De-risking UK Geothernal

C.A. Adams[1], J.G. Gluyas[2]
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[2] *Department of Earth Sciences, Durham University, Durham UK*

Fluid flow is key in developing geothermal systems because fluids have a key role as energy carriers that convey heat from source to surface. Temperature increase with depth is relatively easy to predict using the prevailing geothermal gradient, for the UK, this results in a temperature increase of around 35°C per km. Predicting porosity, transmissivity and hence flow at depth is not as straightforward and is difficult to constrain using currently available geophysical prospecting methods. These factors greatly contribute to the high upfront risk and capital cost associated with drilling deep (>1km) wells and is stifling deep geothermal development especially in countries that have no government supported risk insurance schemes for deep drilling. Risks are further compounded for lower temperature heat only wells rather than those that produce heat and electricity because the latter is more portable than heat and provides an additional revenue stream.

The Earth's subsurface contains naturally occurring rock formations and manmade infrastructure that has the potential to store and transmit the water and by virtue, the heat it contains. These natural formations include deeply buried sediments and radiothermal granites. The challenge is to find sufficient permeability at depth to deliver sufficient flows at surface for energy extraction. Despite the huge potential, there is a lack of information about the UK subsurface at depth and this has also limited geothermal developments in the UK. A more strategic approach is required to de-risk the low enthalpy geothermal potential of the UK by focusing upon developing systems known to flow water. This thinking has stimulated research into geothermal resources associated with manmade infrastructure such as water within flooded abandoned mines, produced water from petroleum fields and water within buried ancient cave (karst) systems. It is interesting to note all of these "lower risk" resources were originally excluded from previous UK geothermal resource assessments made in the 1980s yet they have the potential to increase the available resource over and above that originally identified and reduce the risk associated with its development.

De-risking mine water heat schemes

F. Todd[1], C. McDermott[1], A. Fraser Harris[1], S. Gilfillan[1], A. Bond[1]
[1]*School of GeoSciences, University of Edinburgh, Edinburgh UK*
[1]*Quintessa Ltd, Warrington and Henley-on-Thames, UK*

Interest in the utilisation of abandoned flooded mine workings as a low carbon heat source has seen a recent resurgence. This is driven by the aim of many industrialised nations to have net-zero CO2 emissions to the atmosphere by 2050, due to concerns over rising global temperatures and the understanding that decarbonising heat remains a significant challenge. Abandoned coal mines can provide higher temperatures and increased (man-made) permeability compared to regular ground source heat pumps. Both of these attributes, along with the co-location of mines with industrial heat demand make mine-source heat pumps attractive as a potential geothermal resource. Recent work estimates that heat from abandoned mine workings could provide ~8% of Scotland's heating demand [1]. These systems could also be used as potential heat stores (or batteries) to smooth out daily and seasonal energy demands. Our growing reliance on renewable energy sources means that energy storage is of increasing importance with the buffering capacity of underground energy stores being a useful way to help decarbonise the grid [2]. It has been argued that research into energy storage techniques should be wider than electricity alone; storing heat can be cheaper and covers a large fraction of domestic energy use [3]. The potential for abandoned flooded mines to be used as a heat store is high, making it important to understand the potential risks involved.

One of the risks of using abandoned mine workings as a heat battery is the potential for surface subsidence due to cyclical changes in fluid pressure and temperature leading to thermal stress changes and water flow impacting the integrity of the existing mine workings. It is known shallow mine workings can fail due to groundwater level fluctuations and any additional loading, including thermal cycling, could be an additional burden on already critically stressed systems. This presentation outlines the development of a coupled thermo-hydraulic-mechanical (THM) model to analyse the impacts of pressure changes and heat fluctuations on one layer of coal workings. It will highlight work undertaken to determine the stress levels that result in rock failure in this critically stressed system and what processes are important to control the risk.

1. Todd, F., McDermott, C., Fraser Harris, A. P., Bond, A. & Gilfillan, S. Coupled hydraulic and mechanical model of surface uplift due to mine water rebound: implications for mine water heating and cooling schemes. Scottish J. Geol. (2019). doi:https://doi.org/10.1144/sjg2018-028
2. Pfenninger, S. & Keirstead, J. Renewables, nuclear, or fossil fuels? Scenarios for Great Britain's power system considering costs, emissions and energy security. Appl. Energy 152, 83–93 (2015).
3. Elliott, D. A balancing act for renewables. Nat. Energy 1, 1–3 (2016).

De-risking Deep Geothermal Energy: Unconventional Well Designs

Theo Renaud[1], Hannah Doran[2], Gioia Falcone[2], Lehua Pan[3], Patrick Verdin[1]
[1]*Cranfield University.*
[2]*University of Glasgow.*
[3]*Lawrence Berkeley Laboratory*

Geothermal energy is a mature baseload technology which only represents 2% of the total renewable power generation. Enhanced Geothermal Systems (EGS) and drilling into supercritical/superheated geothermal reservoirs have been proposed to access geothermal energy more widely. However, these concepts are not yet fully validated due to technical and economic concerns. The use of alternative unconventional geothermal designs, such as closed-loop wells can help to de-risk deep geothermal systems.

In this study, an integrated T2Well/EOS1 reservoir-wellbore model was validated against an experimental Deep Borehole Heat Exchanger (DBHE) performed in Hawaii and then used to assess the potential energy recovery from a hypothetical DBHE). Two innovative patents based on the use of graphite in the cement to increase the heat transfer rate between reservoir and wellbore were investigated under different possible geothermal gradients, mass flow injection rates, well lengths and casing design. The results suggest that the best overall long-term thermal performance occurs with highly conductive materials.

An additional sensitivity analysis was performed on a hypothetical DBHE with highly conductive fillers in place of the current open NWG 55-29 well at the Newberry EGS in Central Oregon. Different values of mass flow rate, cement and casing thermal properties, and well diameters were tested, giving an insight of the potential energy generation using DBHEs from a known geothermal site. The findings provide guidance on how to further investigate innovative closed-loop well designs for heat and power generation.

The Feasibility of Repurposing Hydrocarbon Wells for Geothermal Use in the UK: a Critical Assessment

Gioia Falcone, Rob Westaway, Sean M. Watson, Alaa Al Lawati

Despite the potential of geothermal energy, the technical and economic risk at the exploration stage limits its development. One way to reduce this risk is to repurpose hydrocarbon wells for the production of geothermal energy and storage. This approach can substantially reduce drilling costs and defer the decommissioning of existing energy infrastructure.

The geothermal potential of hydrocarbon wells has been investigated by several authors, with pilot projects already implemented worldwide and pre-feasibility studies carried out. In the UK, unless the operator can identify a viable reuse option, once hydrocarbon production ceases, wells must be plugged and abandoned. This paper offers a critical assessment of ways in which existing onshore and offshore hydrocarbon wells could be repurposed in the UK for different end-uses, highlighting technical, financial and regulatory barriers.

For onshore wells, the key findings of an EPSRC National Centre for Energy Systems Integration research project are presented. This nationwide analysis was based on integrated data sets comprising well locations, depths, operational status, measured and estimated bottom hole temperatures, and the extent, depth and thickness of aquifers across the UK. Screening criteria were then applied to over two thousand onshore hydrocarbon wells in the UK, leading to the identification of potential candidates.

Regarding offshore wells on the UK Continental Shelf (UKCS), the UK's Oil and Gas Authority (OGA) forecasts that ~1500 wells will be decommissioned over the next decade at an estimated cost of £22 billion. There is an obvious urgency to identify viable repurposing options for those wells earmarked for abandonment. This talk discusses the results of a screening of fields that have previously been reported in the literature (somewhat optimistically) as having a high potential for geothermal energy co-production. By applying Decline Curve Analysis techniques to the latest UKCS field production data and checking for Cessation of Production and Decommissioning Programme applications, this talk presents a more realistic outlook.

The talk concludes that a significant number of onshore wells can be re-used for geothermal purposes, but the same cannot be said for the offshore candidates.

Session Three: UK Geothermal Research

Geothermal resource potential of the Carboniferous limestones in the UK

Abesser, C., Banks, V., Farrant, A., Jones, D., Kearsey, T., Kendall, R., Loveless, S., Newell, A., Patton, A., Pharaoh, T.C., Stewart, M.

Thick limestones of Mississippian age (359 to 323 Ma) provide a potential moderate-temperature geothermal resource in the UK, where they are widely present at outcrop or concealed within deep basins. The resource has not been proven but surface manifestations of hot water at depth occur at the warm springs at Bath and Bristol, the Taff Valley and the Peak District which issue thermal waters at temperatures between 16-48 ˚C.

Although Carboniferous limestones on blocks and basin margins are generally hard and compact, with low porosity and permeability and negligible inter-granular flow, their ability to transmit water may be significantly increased by karstification, evaporite dissolution, dolomitisation, mineralisation and fracturing. Understanding and predicting where these processes have occurred is key to unlocking the geothermal potential.

Inspired by successful developments of the resource in Belgium and the Netherlands, BGS is embarking on a research programme that will combine data from existing boreholes and geophysical surveys, geological mapping and field evidence to improve understanding of the permeability distribution within the UK Carboniferous limestone and identify areas where more detailed investigations are needed. Here, we will present first results from this programme and provide an outlook of our future research priorities in this field.

Geological controls on upper crustal heat flow for deep geothermal energy

Christopher J. Dalby[1,2], Robin K. Shail[1], Tony Batchelor[2], Lucy Cotton[2], Jon Gutmanis[2], Gavyn K. Rollinson[1], Frances Wall[1], James Hickey[1]
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[2]*GeoScience Ltd, Falmouth Business Park, Bickland Water Road, Falmouth, UK*

The United Downs Deep Geothermal Project is the first geothermal power project to commence in the UK, situated near Redruth, Cornwall, SW England. Two deep deviated geothermal wells have recently been completed to measured depths of 2393 m and 5275 m (2214 m and 5054 m true vertical depth) in June 2019. The wells target the NNW-SSE-trending Porthtowan Fault Zone (PTFZ) which cuts an Early Permian granite batholith and is hoped to form a natural fault-hosted geothermal reservoir.

SW England is a particularly favourable region for geothermal power production because it has the highest heat flow values in the UK, *c.* 120 mW m^{-2} at on-granite locations. Challenges exist for modelling the high surface heat flow values due to uncertainties relating to the radioelement concentrations at depth and the volume and distribution of the granites. The granites have a heterogeneous U, Th and K content controlled primarily by the temperature and degree of source rock partial melting and fractional crystallisation processes. Secondary to this, fluid rock interaction can leach and redistribute radioelements.

The aims of this research are to resolve the heat flow issues by investigating the radioelement concentration and thermal conductivity of the granite using data from the United Downs Deep Geothermal Project. Detailed mineralogical and geochemical analyses will be carried out to define different granite types and understand the host minerals of U and Th. These analyses in combination with wireline spectral gamma data will allow a detailed characterisation of the radioelements with depth and allow a high-resolution heat production profile to be produced. In addition to this, coupled thermal conductivity measurements will be carried out to examine the temperature dependence of thermal conductivity and characterise thermal conductivity with depth. The results of this will improve the thermal resource and sub-surface temperature evaluation of the region.

How much do we really know about heat flow in the UK's onshore sedimentary basins?

Mark T Ireland
Newcastle University, School of Natural and Environmental Sciences, Drummond Building, Newcastle Upon Tyne, NE1 7RU

Subsurface temperature prediction and a quantification of the uncertainty is vital for technical and economical evaluations in geothermal exploration. There is however limited data on the accuracy of temperature prediction for geothermal exploration in sedimentary basins. By comparison, in oil and gas exploration, numerous examples of discrepancies between pre-drill temperature predictions and subsequent results have led to the recognition that the controls on heat flow are more complex that previously recognised.

Temperature and heat flow data, primarily from wells >1000m depth, in the UK's onshore basins are used to investigate whether basin architecture is a key control. Through geostatistical techniques the spatial variance in heat flow is analysed to determine if patterns are clustered, dispersed, or random. In addition the influence of sampling bias on the distribution of data is tested. Finally the heat flow histories of individual wells are modelled with respect to basin evolution to investigate the significant of particular subsurface properties on temperature predictions.

By using geospatial techniques together with 1D modelling it is possible to evaluate the uncertainties associated with temperature prediction in sedimentary basins. Conditioning of data and systematic assessment of uncertainty can improve geological understanding and the characterisation of the potential geothermal resource.

Digging Deeper: The influence of historic mining on Glasgow's subsurface thermal state to inform geothermal research

Sean M. Watson and Rob Westaway
James Watt School of Engineering, University of Glasgow, James Watt (South) Building, Glasgow G12 8QQ, UK

Previous experience indicates that in order to understand the hydrogeology and geothermics of flooded mine workings, and to provide appropriate boundary conditions for numerical modelling, temperature measurements are needed from below the range of depths where the natural conditions have been disturbed my mining. This work assesses the influence of industrial activity and historic mining on geothermal observations across Greater Glasgow with a focus on two case studies.

As part of the ~£9M GGERFS development, BGS commissioned the drilling and logging of well GGC01 in Dalmarnock in the east end of the city of Glasgow during December 2018-January 2019. This well was drilled to 199 m depth to provide core, a temperature log, and a site for microseismic monitoring instrumentation to inform the development of the nearby GGERFS minewater geothermal field site. This site and the surrounding area have a long history of urban and industrial development. The nearby Dalmarnock and Govan Collieries were active from the late 18th century to the mid 19th century and early 20th century respectively, when several coal seams down to the Kiltongue Coal (part of the Scottish Lower Coal Measures Formation) were mined. These workings, now flooded, form the geothermal reservoir to be investigated at the GGERFS. The wider Dalmarnock area formerly hosted a concentration of industrial activity, including steel foundries and factories supplying equipment for the local textile industry.

The GGC01 temperature log indicates significant perturbation by human activity. This is reflected in the high temperature near the ground surface, of >11 °C (some ~2 °C above what is expected given the climate of the Glasgow area), which is indicative of anthropogenic heating of the shallow subsurface and consistent with the substantial atmospheric urban heat island that has been identified in Glasgow. It is also indicated by the low overall geothermal gradient evident in the GGC01 record, of only ~22 °C km-1, which implies that much of the upward geothermal heat flow originating at depth is being entrained by horizontal flow through mineworkings (e.g., in the Kiltongue Coal), below the depth range of measurement in this well, and/or is cancelled by downward heat flow caused by anthropogenic warming of the ground surface and shallow subsurface.

The Hallside borehole was drilled in 1976 for to investigate the Carboniferous stratigraphy in this locality (~10 km SE of Glasgow). A bottom hole temperature measurement of 11.8 °C was observed at 352 m which gives a resulting geothermal gradient of only ~7 °C km-1. The Hallside borehole is located on the site of the former Hallside Colliery and in close proximity to the former Hallside Steelworks. Pits at Hallside Colliery worked seams of Upper Coal, Ell Coal, Pyotshaw Coal, Main Coal, Splint Coal, and Virgin Coal, from the late 19th century to the early 20th century. This extensive mining activity had taken place at this site prior to the drilling of the borehole and the measurement of temperature therein. The seams worked were deeper than the base of the borehole and of the deepest temperature measurement.
This evidence suggests the influence of mining on the flow of heat in the subsurface is perhaps a contributing factor as to why a low geothermal gradient was observed in the Hallside borehole.

The regional heat flow for Glasgow is 80 mW m-2. At Hallside the heat flow is calculated as ~14 mW m-2. The heat flow at the GGC01 borehole is ~44 mW m-2. The differences between these values and the expected regional heat flow suggests a significant component of horizontal heat flow into surrounding flooded mine workings.

This deduction also influences the quantification of deeper geothermal resources, as extrapolation of the temperature gradient above mine workings would underestimate the temperature at depth. Future projects should consider the influence of historic mining on heat flow when temperature datasets such as these are used in the design of geothermal developments.

Session Four: People and Places

Taking the heat out of geothermal: a model for holistic public engagement from the United Downs Deep Geothermal Power project in the UK

Hazel Gibson[1], Nicola Langdon[1], Francesca Tirotto[1,3], Iain S Stewart[1], Alison Anderson[2], Sabine Pahl[3]

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[2]*School of Law, Criminology and Government, University of Plymouth, Plymouth, UK*
[3]*School of Psychology, University of Plymouth, Plymouth, UK*

The potential role of geothermal power in diversifying energy portfolios is being increasingly recognised in many countries. The adoption of this new technology is easier for some countries more than others, being particularly difficult where geothermal phenomena are less visible and more unusual. That is often the case with enhanced geothermal systems (EGS), where engaging the public with more unfamiliar technologies can be a significant barrier to progress.

EGS have the potential to increase the number of countries who are able to exploit geothermal power, not only for heat generation but also for electricity. However, as has been experienced in past EGS projects in Europe, effective public engagement which encourages positive public opinion is key to ensuring the safe and timely development of these resources. Furthermore, issues with community acceptance of EGS projects are sometimes exacerbated when located in highly populated, even urbanised areas. In order to address the possible disconnection between local populations and the new technology it is important to develop integrated and holistic approaches to community engagement.

At the United Downs Deep Geothermal Power (UDDGP) project in Cornwall in the UK, researchers have built a multi and interdisciplinary model for public engagement by conducting research across the fields of psychology, sociology, media communication, politics and science communication. By combining these fields researchers are discovering the way that personal values, media framing, culture, science capital, social identity and attitudes towards renewable energy shape the narratives of a community surrounding an innovative deep geothermal project. The study will provide tangible recommendations for effective communication, inclusive engagement, and trust-building within local communities, both directly, and through the media. While rooted in analysis of the UDDGP case study, the model also holds wider applicability and may provide a valuable framework for the successful adoption of other new energy technologies elsewhere.

Women are the largest reservoir of untapped talent: A discussion how WING UK works to a world of gender equality

C.Baxter, D.Cruz, **S. Magor** and **I Shafagh**

"The day will come when men will recognize woman as his peer, not only at the fireside, but in councils of the nation. Then, and not until then, will there be the perfect comradeship, the ideal union between the sexes that shall result in the highest development of the race."

Susan Anthony was an activist who played a pivotal role in women's suffrage. The suffrage movement made a drastic change for women's lives and 100 years on women are still under represented. In a male dominated industry the Women in Geothermal (WING) not for profit organisation aims to promote the education, professional development and advancement of women in the geothermal community. WING UK aims to be the acting force to generate a network of people and an environment of empowerment and openness. This will encourage women, as the largest reservoir of untapped talent in the world, to drive the UK geothermal industry forward into the future. WING's four goals are set out in the Roadmap to Iceland 2020. This includes 1500 WING members; 1 WING group in every geothermal country; 100% of geothermal associations to have a WING member of their board and the most important feature - 50% male membership. The current WING UK team look to set up a platform to share UK Geothermal news, networking events, knowledge sharing days and any other ideas members have. It will look to discuss areas of development in creating this environment in the UK Geothermal community to understand the next steps.

Session Five: Research Beyond UK

InSAR ground deformation monitoring at an operational geothermal power station

Nathan Magnall, Adam Thomas
CGG NPA Satellite Mapping

Understanding the impact of geothermal power generation on ground deformation is of critical importance to operators, regulators and local communities. Furthermore, ground deformation can give vital insight into subsurface conditions and operational performance. Here we show how satellite InSAR can be used to accurately monitor ground deformation at a geothermal power station.

The Olkaria geothermal power station, located on the edge of the Hell's Gate National Park in Kenya, consists of four separate power stations with a combined capacity of 570 megawatts. The first power station was constructed in 1981, with new stations being brought online between 2019 and 2021. InSAR processing techniques applied to open-access Sentinel-1 satellite radar data reveals a complex ground deformation pattern across the Olkaria geothermal power stations. Ground subsidence of up to 50 mm per year is detected at some of the stations and extractions wells, and up to 30 mm per year of heave is detected at possible injection wells.

In addition to monitoring operational geothermal power stations, InSAR can be used to establish baseline ground deformation prior to active production, providing a valuable benchmark against which production-related deformation can be assessed and managed. Our results show that satellite remote sensing can play a crucial role in understanding both the historical and ongoing impact of geothermal energy production.

Determining tectonic controls on geothermal expression: Examples from New Zealand

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The Taupo Volcanic Zone (TVZ), a bark-arc rift, hosts the majoirty of New Zealand's geothermal reservoirs. The structural architecture of the plumping of these geothermal systems is important to characterise and understand as it controls geothermal fluid circulation at a local scale (within individual reservoirs) and at the regional scale (geothermal expression across the rift). Information on the structure, stress, and their inter-relationship in a geothermal field is essential for understanding structurally controlled permeability, and when related to larger scale structural mapping can help us refine fault, fracture and fluid flow architecture. We present here new data from active fault mapping, borehole image logging, and well testing in the Te Mihi production area of the Wairakei Geothermal Field, New Zealand.

Data shows the Te Mihi area to be structurally complex, with a set of active NW dipping master faults, with pervasive SE dipping antithetic and splay structures in their hangingwalls, intersected by a second active master fault set striking E-W, dipping south. Further subordinate, spatially localized, N-S striking structural trends are also identified. In consideration with GNSS vectors both active NE-SW, and E-W fault trends are thought to creat biaxial extension in this region of the TVZ. However, the dominant NE-SW SHmax orientation found within boreholes suggests that NW-SE extension dominates the regional stress, or that N-S directed extension is temporal.

Fluid flow within boreholes is supported by NW dipping master faults, travel time fractures on acoustic image logs, halo fractures on resistivity image logs, NE-SW and E-W striking fractures, intervals of high fracture density, and spatial concentrations of wide aperture fractures and recently active NE-SW and E-W striking fractures.

This study suggests that the Te Mihi geothermal expression is a result of this area undergoing biaxial extension, evident from active structural trend intersections in the area, and the predominance of NE-SW and E-W striking structures within permeable zones. Biaxial extension is therefore an important control on crustal fluid flow within the Taupo Volcanic Zone and thus geothermal resource delineation.

Hydrochemistry of Produced Water from the Pohang EGS Project Site, Korea: Implications for Water-rock Reactions and Associated Changes to the State of Stress Accompanying Hydraulic Fracturing of Granite

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During August 2017, ~1700 m3 of water was injected into, and subsequently allowed to flowback from, the ~4 km deep PX-1 well, drilled into Permian granite at Pohang, Korea. Sampling of this produced water and its hydrochemical analysis, for major elements, trace elements, and stable isotopes, has provided an important dataset for the investigation of water-rock reactions in granite. As a first approximation, the variations in composition of this produced water are consequences of mixing of end-member compositions representing the injected surface water and in situ groundwater. The majority of the produced water was in situ groundwater, indicating that only a small proportion, estimated as only ~400 m3, of the injected surface water was recovered; the rest remained in the subsurface. Superimposed on these variations are increases in concentrations of ionic species, which reflect chemical reactions between the injected surface water and the granite. These include silica from hydrolysis of quartz, sodium from hydrolysis of feldspar, and sulphate probably from hydrolysis of pyrite, this latter mineral forming deposits that line fractures within the Pohang granite. The MW 5.5 Pohang earthquake occurred on 15 November 2017, three months after this injection experiment, in close proximity to the EGS site, initiating discussion regarding the possibility of a cause-and-effect connection. This oblique reverse-faulting earthquake occurred on the Namsong Fault, which passes above the injection point and transects the wellbore, its hypocentre being within a kilometre of the injection. We explore the possibility that injection at the EGS site might have caused this earthquake. Assuming that the injected surface water that was not recovered entered this fault, and given the ~160 °C ambient temperature, we calculate timescales for chemical re-equilibration of different ionic species. Re-equilibration of silica, for example, is thus estimated to require roughly three months, the time difference between the injection and the earthquake. We thus derive a quantitative model for this process, in which hydrochemical re-equilibration is envisaged as occurring by dissolution of asperities, where patches of fault are in mechanical contact, thus 'unclamping' the fault. This model leads to a new scaling law between injected volume and the maximum seismic moment, or magnitude, of resulting induced seismicity. This new scaling law is less conservative than existing theory, which assumes that pore space throughout a rock volume is flooded with injected fluid, because only the volume of the fault is flooded, the surrounding granite having extremely low porosity. It is thus shown that net injection of ~1000 m3 of surface water can account for an induced earthquake comparable to that observed, provided that the seismogenic fault was already critically stressed. This analysis does not prove, of course, that the August 2017 injection experiment caused the MW 5.5 Pohang earthquake; this earthquake might, for example, have been a consequence of the combined effect of all five injection experiments that took place at this site during 2016-2017 (three in well PX-2, including one in September 2017, and two in well PX-1), before the Korean authorities forced suspension of the EGS project. It nonetheless provides a salutary warning of a potential adverse consequence of injection of surface water into granite. A conceivable remedy, albeit at considerable cost, would be to inject water containing dissolved ionic species that match as closely as possible, or indeed exceed, the concentrations in the local groundwater.

Geology of Subsurface Fractures – Applications to the Geothermal Industry

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Fractures are ubiquitous in most geological formations and are a result of brittle rock failure under various states of stress. Fractures are characterised as linear features, either diffuse and strata bound, clustered in fracture swarms or associated with a fault or fold system. The key descriptive characteristics of a subsurface fracture are the depth, density, strike orientation and aperture. Those fractures with an aperture ranging from micron to centimetre in width are currently beyond the resolution of most subsurface tools, however a large data contrast or a tight cluster of fractures can influence the tool readings. These measurements are derived from a variety of sources and tool types that are acquired through the process of geological, geophysical, drilling, petrophysical and production data acquisition and often the anomalous data readings are symptomatic of fractures. In order to identify the geology of fractures in the subsurface, an ensemble of supporting evidence is accrued through the life cycle of a borehole. Many of these findings, presented in this paper are derived from a mature oil and gas exploration methodology; we suggest that these 'lessons learnt' can be applied to the developing geothermal industry. The need for such transfer of expertise to the geothermal sector is dramatically illustrated by the recent case study provided by the Pohang geothermal project in Korea. Here, overlooking the fractures during project design and well stimulation caused a large (magnitude 5.5) earthquake, most likely through the mechanism of 'hydrochemical corrosion' whereby chemical reactions between injected surface water within a critically stressed fault and minerals in the granitic fault rocks resulted in dissolution, 'unclamping' the fault. Subsequent intervention by the Korean government led to this project being shut down and resulted in bankruptcy of the developer.

Session Six: Policy and Regulation

Decarbonising Heat: Challenges and Opportunities

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The UK has committed to pursue an ambitious target to reduce greenhouse gas emissions to 'net-zero' by 2050. As heat accounts for a third of UK greenhouse gas emissions and 44% of the UK's primary energy demand, decarbonising heat is critical in order to meet this target. Changes on this scale will involve significant challenges as well as opportunities and this talk will explore both aspects of heat decarbonisation as well as the Government's short-term and long-term heat decarbonisation plans.

Lessons learned from Dutch Geothermal licencing and support schemes

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Since 2007, some 18 injector-producer well pairs with a combined capacity of 221 MW_{th} were realised in the Netherlands. The associated annual heat production of approximately 3 PJ/yr is mainly used for greenhouse heating. Although the Netherlands hosted one of the fastest growing geothermal industries in Europe in the past decade, heat In place estimates indicate that the resources are actually underdeveloped. In this study, we first made an overview of key parameters Dutch development focussing on the West Netherlands Basin, which was the geothermal epicentre of the country. Based on trends of the geothermal expansion rate in this region, predictions were made on future annual heat production, the recovery efficiency and available production license space in the WNB. We show that if expansion would continue like it did in the past years, only 1% of the heat that is stored in the resources will be recovered by 2050. Also, available space for new operators would form a bottleneck for expansion long before a significant part of the heat would be recovered. This is because of inefficient doublet deployment on a ‘first-come, first served’ basis with operational parameters that focus on objectives of different independent operators. Instead, similar to the common-practise approach in the hydrocarbon industry, a regional coordinated ‘masterplan’ approach could be used optimise well deployment and to increase heat recovery efficiency. Utilising numerical simulations for flow and heat transfer in the subsurface, we show that there is significant scope for such optimisation. Finally, based on calculations of the Levelized Costs Of Heat for both deployment strategies, we also show that current financial support schemes do not favour heat recovery optimisation.

This study emphasises that geothermal heat production has the potential to cover a significant part of our energy demand. To achieves this, however, a radical change in financial support schemes and legislation are required to unlock the true geothermal potential. Dutch licencing and support schemes is based on the French approach that was developed in the 80’s for exploitation of the Dogger aquifer in the Paris Basin. Lessons learned from Dutch development could be used for potential development of such schemes for the UK.

GSL CODE OF CONDUCT FOR MEETINGS AND OTHER EVENTS

INTRODUCTION

The Geological Society of London is a professional and learned society, which, through its members, has a duty in the public interest to provide a safe, productive and welcoming environment for all participants and attendees of our meetings, workshops, and events regardless of age, gender, sexual orientation, gender identity, race, ethnicity, religion, disability, physical appearance, or career level.

This Code of Conduct applies to all participants in Society related activities, including, but not limited to, attendees, speakers, volunteers, exhibitors, representatives to outside bodies, and applies in all GSL activities, including ancillary meetings, events and social gatherings.

It also applies to members of the Society attending externally organised events, wherever the venue.

BEHAVIOUR

The Society values participation by all attendees at its events and wants to ensure that your experience is as constructive and professionally stimulating as possible.

Whilst the debate of scientific ideas is encouraged, participants are expected to behave in a respectful and professional manner - harassment and, or, sexist, racist, or exclusionary comments or jokes are not appropriate and will not be tolerated.

Harassment includes sustained disruption of talks or other events, inappropriate physical contact, sexual attention or innuendo, deliberate intimidation, stalking, and intrusive photography or recording of an individual without consent. It also includes discrimination or offensive comments related to age, gender identity, sexual orientation, disability, physical appearance, language, citizenship, ethnic origin, race or religion.

The Geological Society expects and requires all participants to abide by and uphold the principles of this Code of Conduct and transgressions or violations will not be tolerated.

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The Society considers it unprofessional, unethical and totally unacceptable to engage in or condone any kind of discrimination or harassment, or to disregard complaints of harassment from colleagues or staff.

If an incident of proscribed conduct occurs either within or outside the Society's premises during an event, then the aggrieved person or witness to the proscribed conduct is encouraged to report it promptly to a member of staff or the event's principal organiser.

Once the Society is notified, staff or a senior organiser of the meeting will discuss the details first with the individual making the complaint, then any witnesses who have been identified, and then the alleged offender, before determining an appropriate course of action. Confidentiality will be maintained to the extent that it does not compromise the rights of others. The Society will co-operate fully with any criminal or civil investigation arising from incidents that occur during Society events.

Burlington House
Fire Safety Information

If you hear the Alarm

Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings.

Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshal on that floor.

Fire Exits from the Geological Society Conference Rooms

Lower Library:
Exit via main reception onto Piccadilly, or via staff entrance onto the courtyard.
Lecture Theatre
Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the staff entrance.
Main Piccadilly Entrance
Straight out door and walk around to the Courtyard.

Close the doors when leaving a room. **DO NOT SWITCH OFF THE LIGHTS**.

Assemble in the Courtyard in front of the Royal Academy, outside the Royal Astronomical Society. Event organizers should report as soon as possible to the nearest Fire Marshal on whether all event participants have been safely evacuated.

Please do not re-enter the building except when you are advised that it is safe to do so by the Fire Brigade.

First Aid

All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

Facilities

The ladies toilets are situated in the basement at the bottom of the staircase outside the Lecture Theatre.

The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.
The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly