PROCEEDINGS, 47th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 7-9, 2022
SGP-TR-223

An Update on the United Downs Geothermal Power Project, Cornwall, UK

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Keywords: Geothermal, UK, United Downs, Cornwall

ABSTRACT

The United Downs geothermal project is owned and operated by Geothermal Engineering Ltd (GEL) and is the first geothermal electricity project in the UK. The site was selected in 2010 for its geology (strongly faulted, radiogenic granite), surface infrastructure, grid connection and potential community acceptance. The deep drilling programme started in 2018, with the production well drilled to 5,275m MD and deviating from 3,390m to a final inclination of 33.5°, representing the deepest onshore well in the UK. The injection well was then drilled to 2,393m MD, deviating from 1,020m to a final inclination of 40°. The drilling of a deep production well and shallow injection well into a natural fault zone is a novel concept developed by GEL, based on some of the results from research at the Hot Dry Rocks project in Rosemanowes, Cornwall. The production well has successfully encountered temperatures of 180°C, world-class lithium concentrations and significant permeability horizons within the fault zone. It is expected to provide 2-3MW_e to the National Grid during 2023 and carbon neutral heat to local businesses. The project has also been associated with a number of world leading research institutions.

Despite the slowdown caused by the Covid-19 pandemic the United Downs project has seen a number of exciting milestones, including completion of drilling, extensive well testing, and signing of the first Power Purchase Agreement (PPA) for deep geothermal electricity in the UK with Ecotricity. The team has also secured grant funding for a demonstration plant that will trial Direct Lithium Extraction (DLE) from the deep geothermal fluid. This paper presents an overview of the initial results of drilling and testing, briefly highlighting the success of hydraulic stimulation and management of induced seismicity during development. It also provides a forward look to the final stages of the United Downs development and the future of geothermal power projects across Cornwall.

1. INTRODUCTION

The United Downs geothermal power project is the pioneering geothermal power development in the UK. It has been developed, owned and operated by Geothermal Engineering Ltd (GEL) since the company was founded in 2009, and is designed to demonstrate that Cornwall has the potential to generate electricity using the natural heat from the extensive, radiogenic Cornubian granite batholith.

After a significant period of raising investment, GEL began drilling in November 2018 and completed two deep wells at the end of June 2019. The wells have since undergone extensive injection and production testing to understand the hydraulic environment and further define the geothermal reservoir. This testing has generated months of data, used to define the requirements for a 2-3MW_e power plant, due for commissioning in 2023.

This paper provides background to the United Downs project, explores the project milestones achieved since drilling began, and looks forward to a bright future for geothermal development across Cornwall.

2. GEOLOGICAL OVERVIEW

Cornwall's geology is unique within the UK and for decades it has been considered as a potential geothermal resource. The Cornubian granite batholith stretches from Dartmoor in the east to the Isles of Scilly in the west and contains a high concentration of heat-producing isotopes such as thorium (Th), uranium (U) and potassium (K). This natural heat production means that the heat flow in southwest England is approximately double the UK average at 120mWm^{-2}, and much of Cornwall has the highest geothermal gradient in the UK at 33-35°C/km, almost 10°C/km hotter than large parts of the country (*Ledingham et al. 2019*). Temperature measurements from boreholes across Cornwall allow predictions that temperatures exceed 200°C at depths of 5km throughout the batholith (*Beamish & Busby, 2016*).

However, granite is not naturally permeable, so to find a productive reservoir at depth requires targeting permeable structures that penetrate deep into the granite. Cornwall is divided by a number of faults and fracture zones with a preferred orientation of NNW-SSE or ENE-WSW that may display enhanced permeability at depth. Both fracture systems are believed to have been reactivated by post-orogenic extension after the Variscan Orogeny, with the ENE-trending fractures later hosting magmatic mineral lodes and 'elvans' mined throughout the 19th and 20th centuries (*Alexander and Shail, 1995*). However, the NNW-trending fracture systems form the 'crosscourses' which are less commonly mineralized and often observed in local mines to terminate economic lodes. They can be of considerable length and show significant movement on the order of hundreds of metres (*Putrich et al. 2016; Hill et al. 1906, Dines 1956*). These crosscourses are aligned parallel to the regional maximum horizontal stress and therefore are believed to be the most 'open' structures in southwest England, providing enhanced permeability (*Brereton et al. 1991*).

3. THE UNITED DOWNS CONCEPT

Whilst GEL has been working on the United Downs project since 2009, it is the natural progression of the original Cornish Hot Dry Rocks (HDR) project undertaken in the 1980s at Rosemanowes quarry. Rosemanowes was a pioneering research project associated with the Camborne School of Mines, designed to test and prove the theory of inducing a fracture network within the heat-producing granite to create a geothermal reservoir. It consisted of three phases:

1. Drilling 300m boreholes to demonstrate that water circulation could be established between boreholes following hydraulic stimulation of natural fractures.

2. Investigation of reservoir development at ~2km depth. Targets for a commercial system were set at 210°C, flow rate of ~100 l/s and maximum water loss of 10%.

3. Investigation of techniques for enhancing the deep reservoir to improve its performance.

Temperatures were significant but water losses of about 70% were observed during circulation. The analysis of microseismic event locations suggested that this high loss was associated with the downward growth of the reservoir to depths of around 3 to 3.5 km (*Parker 1999*). It was clear that permeability and circulation at depth in the granite was achievable, but before this could be tested at greater depth and taking into account the water loss data, funding was pulled, and the project effectively shelved.

In 2009, GEL picked up where Rosemanowes left off, identifying a more promising site on a significant permeability structure, and tweaking the well design to exploit this natural fracture network in a new way. The observations at Rosemanowes suggested that water injected would flow down through the fracture network, so GEL developed a system with a deep production well and a shallow injection well which penetrate the Porthtowan Fault Zone (***Error! Reference source not found.***).

Drilling of directional wells UD-1 and UD-2 to measured depths of 5,275m and 2,393m, respectively, has successfully identified temperatures of 180°C and significant mud-loss zones. This proves the presence of enhanced permeability and provides sufficient temperature and flow for a binary power plant to generate electricity in the near future.

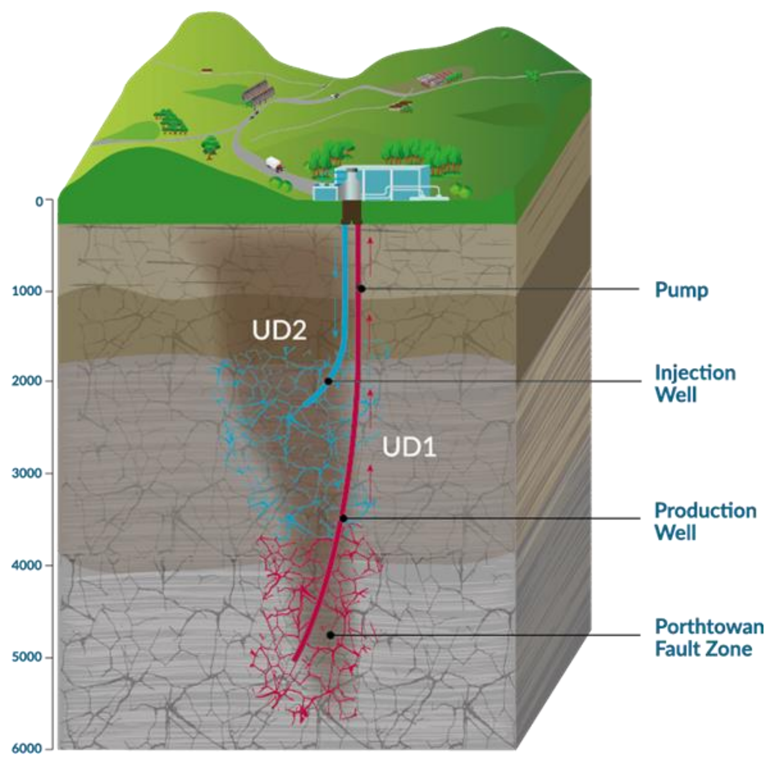

Figure 1. Schematic of the geothermal doublet at United Downs, drilled into the Porthtowan Fault Zone

4. PROJECT PROGRESS

The United Downs site was acquired by GEL in 2010 after a number of feasibility studies to find an appropriate site. It was selected both for its geological setting and its surface attributes with existing grid connection, close proximity to access roads and limited anticipated impact on the local communities. Once all the relevant permits were secured, it then took five years to obtain the appropriate funding from a combination of the European Regional Development Fund, Cornwall Council and private investors, with the final funding agreements signed in 2017.

Procurement and drilling took place throughout 2018-2019. Contracts for drilling and site equipment were tendered and awarded following European guidelines. Drilling then started on 08 November 2018 with UD-1, the production well, and drilling of the injection well started on 11 May 2019, reaching TD on 29th June 2019. A summary of each well is provided in ***Error! Reference source not found.***.

Table 1. Key parameters for the wells at United Downs

Item	**UD-1**	**UD-2**
Well Classification	Geothermal – Production Well	Geothermal – Injection Well
Target	Porthtowan Fault Zone	
Completion	8½” openhole	8½” openhole
Reservoir Rock Type	Granite	
Temperature	188°C at 5,275m MD	N/A
Well Depth	5,275 m MD (5,057.6 m TVD bGL)	2,393 m MD (2,214 m TVD bGL)
Casing Depths (MD bGL)	18⅝” casing to 244.8 m 13⅜” casing to 899 m 9⅝” to 3,985 m	13⅜” casing to 804 m 9⅝” to 1,820 m

From August 2020 to July 2021, both wells have undergone a series of injection tests to analyse the hydraulic environment of the reservoir and stimulate the near and far field to ultimately improve productivity/injectivity. The purpose of this period of testing was to:

- Define the injectivity of the fractures to gain a greater understanding of the character of the granite reservoir.
- Improve the injectivity of the reservoir using hydraulic stimulation to achieve sufficient flow rates to sustain the power plant.
- Monitor any injection-induced seismicity to map the growth of the reservoir during stimulation.
- Understand safe flow rate levels (pressure and volume) to inform any future well treatment
- ‘Destress’ the reservoir to prevent microseismic events occurring during long term operation

In addition, in July 2021, full reservoir testing was undertaken for seven days. An Electrical Submersible Pump (ESP) was lowered to a depth of approximately 1km into UD-1 and coupled to injection pumps on UD-2 to simulate power plant operation and test the performance of the whole reservoir. Successful testing enables GEL to move forward with the purchase of a power plant, with commissioning anticipated in 2023.

Beyond work onsite, throughout drilling and testing a number of research projects have been associated with the United Downs geothermal project to help further the understanding of the resource and apply lessons learnt more generally to geothermal systems in fractured granite. Research projects include Science for Clean Energy (*S4CE*) – EU Horizon 2020, Geothermal Power Generated from UK Granites (*GWatt*) – UK NERC, and Multi-sites EGS Demonstration (*MEET*) – EU Horizon 2020.

5. LITHOLOGICAL ANALYSIS

5.1. Sampling

During drilling, MWD data was collected and interpreted in real-time to identify intersections of the target fault zone during drilling. Comprehensive openhole wireline logging suites were performed in the 12.25” and 8.5” intervals of UD-1, including ultrasonic and micro-resistivity (12.25” interval only) image logs and full waveform sonic for the identification of fractures. In the 17.5” interval, caliper, temperature and gamma logging was carried out.

In addition, sample cuttings were taken every 10m, with sampling frequency increasing to every 5m within the main target of the Porthtowan Fault Zone. Bulk samples weighed approximately 1,000 g and were split equally between GEL and the British Geological Survey (BGS). An extra bulk sample was taken at each interval, washed and dried to remove drilling mud from the cuttings, and analysed on site.

Great care was taken to preserve full grain size representation throughout the samples, with material passing through a series of sieve sizes. Selected sieved samples were weighed to obtain the grain size distribution. Bulk samples did not account for particles below 63 µm, therefore specific samples were taken to include the finer size range. Mud samples were also collected every 12 hours and kept in the dark to avoid rapid degradation of polymers.

5.2. Mineral Identification

Initial mineral identification for each sample was undertaken through optical assessment on site, and automated SEM (QEMSCAN) and XRD analyses were subsequently performed by Camborne School of Mines on selected samples.

5.3. Lithology

Each well comprises three main lithologies: 1) Killas; 2) Microgranite; and 3) Granite. The depth of each lithology within UD-1 and UD-2 is depicted in *Table 2* and descriptions of each lithology are provided below. Mineralogical assessment was carried out optically every 10 metres and initial analysis using QEMSCAN and XRD was undertaken on spot samples from a variety of depths across each granite type and known cross-course and lode structures. The ratios of quartz, feldspar and mica fluctuate between granite types, whilst the occurrence and percentages of accessory minerals identify the individual structures.

Table 2. Depth of the major lithologies encountered in the two wells at United Downs.

Lithology	Depth of first occurrence in UD-1 (mBGL)	Depth of first occurrence in UD-2 (mBGL)
Killas	0	0
Microgranite	210	250
Granite	800	830

Killas is a low-grade, regionally metamorphosed and deformed mudstone of the Upper Devonian Mylor Slate Formation (Leveridge *et al.*, 1990). High frequency, small aperture (millimetric scale) quartz veins exploit the foliation of this upper formation with traces of magmatic-hydrothermal W-Sn-Cu-Zn oxide-sulphide mineralisation occupying steeply dipping lode systems (typically E-W trending).

The microgranite is extensively greisened and kaolinized, with a geometry thought to have been influenced by the syn-emplacement interaction of ENE-WSW striking extensional faults with NNW-SSE striking strike-slip faults at the eastern margin of the Porthtowan Fault Zone. The lithology could be part of a moderately dipping NNW ‘elvan’ dyke mapped by the BGS in 1989 but the thickness of the feature intersected in the wells is consistent with a body that is subvertical and/or has a more irregular geometry at depth. Lode structures such as the distinctive chlorite rich ‘Hot Lode’ and the tourmaline heavy ‘South Lode’ were intersected within the microgranite.

Finally, a variety of granite types persist within both wells. Whilst there are mineralogical and textural variations, almost all unaltered types of granite plot within the monzogranite field (*Figure 2*). Muscovite is always dominant over biotite and, whilst there may be minor secondary white mica, the granites correspond to the two-mica (G1) and muscovite (G2) granite types as defined by the recent re-classification of Cornubian granites (Simons *et al.*, 2016). The accessory mineral assemblage comprises tourmaline, apatite, ilmenite, rutile, monazite, zircon, topaz and fluorite with allanite recognised in the deeper granites. There is a strong similarity between the granite types encountered in UD-1 and those encountered to a depth of 2,600m within the Carnmenellis granite at the Rosemanowes Hot Dry Rocks (HDR) research site.

The varieties of granites have distinctive radioelement signatures and are sub-divided into five classifications according to their radioelement concentrations from the Baker Hughes DSL spectral gamma ray tool. These are largely defined by concentrations in Th which vary by *c.* 22ppm compared to variations in U of *c.* 4ppm. Step changes in Th were previously used to classify granites at the Rosemanowes HDR site (Parker, 1989). Granite classification based on radiometric content is included in

Table 3.

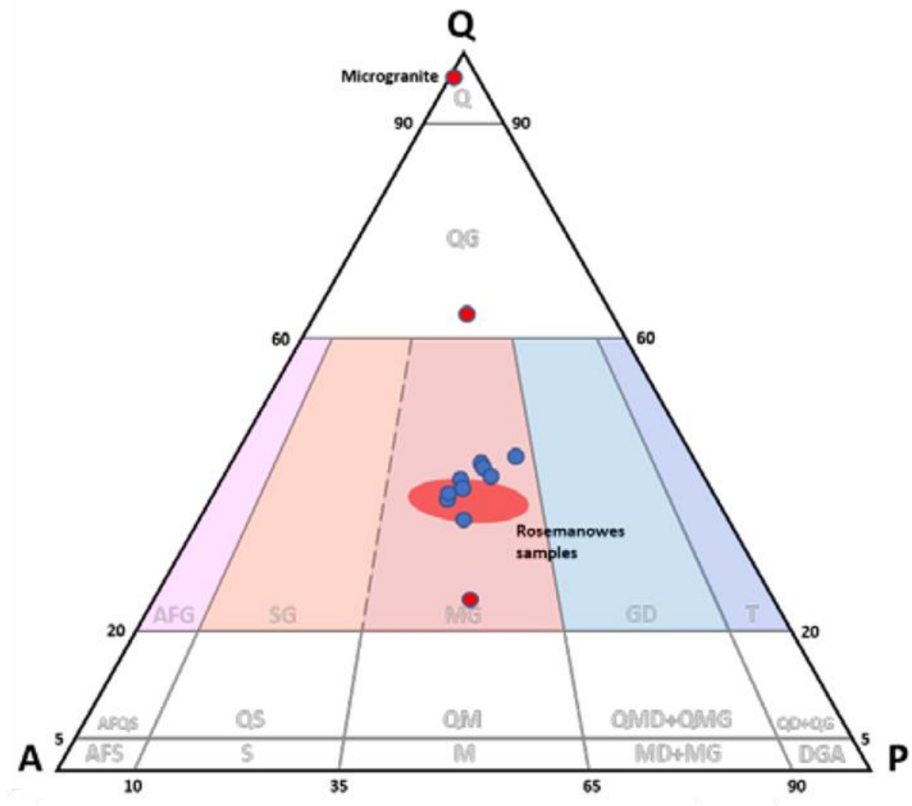

Figure 2. QAP classification of UD-1 granite cuttings from 720-5,275m MD, analysed by QEMSCAN. Almost all samples plot within the monzogranite field and are similar to samples from the nearby Rosemanowes HDR site (red ellipse). UD-1 samples in red are found to have anomalous compositions due to cutting bias or alteration of the microgranite. Diagram courtesy of Camborne School of Mines.

Table 3. Total gamma API and radioelement concentrations of granite types at United Downs. Courtesy of Chris Dalby, Camborne School of Mines.

Granite Type	Total API	U (ppm)	Th (ppm)	K (%)
Microgranite	185	-	-	
Granite A	220	15	8	3.5
Granite B	260	17	15	3.5
Granite C	<175	-	-	-
Granite D	310	18	30	4

6. RESERVOIR TESTING

6.1. Overview

Throughout 2020 and early 2021, the wells underwent a significant testing and hydraulic stimulation programme whereby water was injected at varying volumes and flow rates into both wells to assess and develop the hydraulic properties of the deep reservoir.

The project reached an important milestone at the beginning of July 2021, when an Electrical Submersible Pump (ESP) was lowered to a depth of approximately 1km into UD-1 (*Figure 3*), and coupled to injection pumps on UD-2 to simulate power plant operation and test the performance of the whole reservoir. The equipment was successfully installed, and the UK's first geothermal steam was produced. The ESP was run over a seven-day period, coupled with simultaneous injection into UD-2. Some additional injection into UD-1 was also undertaken along with full geochemical analysis of the geofluid/ vapour produced from UD-1.

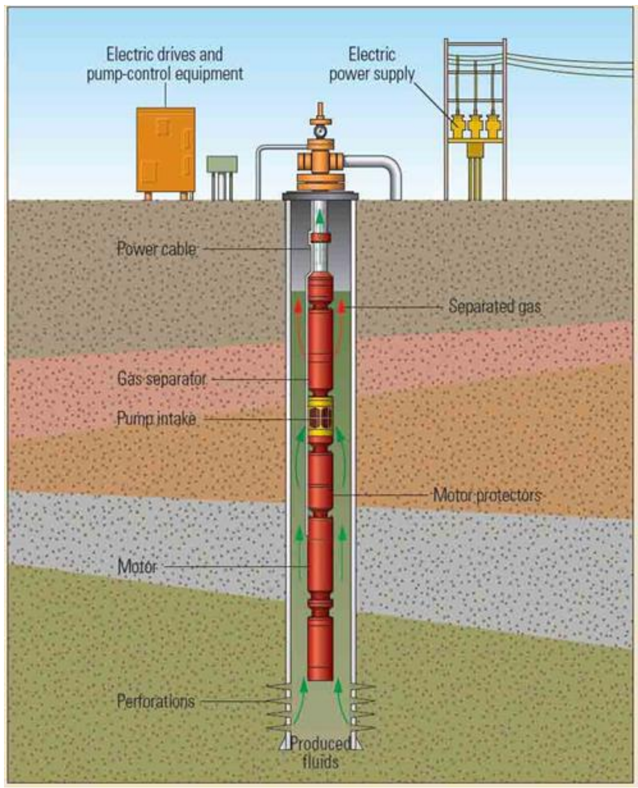

Figure 3. Schematic cross section of the key components of an electrical submersible pump in-situ. Image courtesy of Schlumberger.

The principal aim of the tests was to understand how the reservoir performed during simulated power plant operation. Building on the data from previous testing phases at United Downs, the reservoir tests focused on the following:

- Potential flow rates and associated drawdowns/ pressures whilst producing geofluid from UD-1 and injecting into UD-2 (i.e., operational conditions).
- Monitoring seismic activity to understand the risk of microseismic events during operation.
- Assessment of drawdown in UD-1 to identify the optimal depth of placement of an ESP and the associated flow rate for the power plant.
- Identifying any change in the flow parameters during testing to understand how the subsurface environment may develop during operation.
- Analysing the geochemistry of the produced fluid to inform the design of the power plant and a Direct Lithium Extraction (DLE) unit.

On 01 July 2021, well testing culminated in the first ever production of geothermal steam in the UK, proving the concept that generating electricity is possible from the natural heat of the Cornubian granite.

6.2. Data Collection

During the final seven-day test period, a live stream of hydraulic data such as injected and produced flow rate, injected volume and ESP intake pressure was monitored by the GEL Data Manager, Drilling Manager (DM) and Drilling Supervisor (DSV) to ensure accurate and reliable data capture, and elimination of irregularities. Key data points were recorded at regular intervals by the relevant service company to supplement the digital data, with comments noted at significant points. In addition, seismicity was monitored 24/7 by specialists at Altcom Ltd via the GEL seismic network which can detect events down to less than magnitude -1.

GEL senior management were in constant contact with the DM and DSV to assess reservoir performance in real-time and adapt the testing program in response to results. Conversations occurred approximately every hour during active testing, or after each agreed volume had been pumped, and included the full GEL team, DM, DSV and a seismicity specialist. This enabled rapid, safe and informed decision making to maximise the data output from the testing period.

During this time, GEL also oversaw the collection of fluid samples at regular intervals and for geochemical analysis. In total, approximately 140m^3 of bulk fluid samples were taken and stored in IBCs. High pressure samples were also taken by Expro at the choke manifold, and thermos flask samples were taken regularly from the steam separator sampling point. These samples have been independently analysed by Expro, Geocubed and the BGS.

6.3. Hydraulic Analysis

Extensive testing of the two wells has provided a wealth of data which shows that injection rates of at least 60 l/s are both safe (no induced seismicity, *see next section*) and achievable at sustainable pressures into UD-2 (injection well). The production well, UD-1 is able to sustain injection rates of at least 70 l/s at pressures far lower than in UD-2, suggesting significant permeability in the deep reservoir.

Analysis of the hydrogeological data concludes that, in the initial stages of operation, an ESP pump should be sited at approximately 1,300m in the production well with an initial target flow rate of 40 l/s. AQTESOLV modelling and comparison with analogous operational systems shows that this flow rate appears to be sustainable over the lifetime of the project and that the permeability of the reservoir will continue to improve over time.

7. MICROSEISMICITY

Induced seismicity is a common occurrence during testing of geothermal developments and in some geological environments can also occur during operation. During initial injection testing at United Downs, small seismic events were induced by fluid injection into UD-1, but none were induced when injecting into UD-2. During all testing of UD-1, the largest microseismic event produced had a magnitude of 1.7 and PGV of 0.8mm/s.

Over time, seismic events can be used to identify new growth of the permeable fracture system which makes up the United Downs deep reservoir. For example, two minor events were detected during final injection testing into UD-1 on July 05, 2021 (see ***Error! Reference source not found.*** and *Figure 4*). The location of the second small event was significantly shallower than any previous testing-related event. This indicates a possible growth of the reservoir upwards, potentially identifying a new fluid pathway which we believe will increase hydraulic connectivity between UD-1 and UD-2 over time. This event mapping has been invaluable for delineating the growing reservoir, enabling the calculation of a minimum estimate for the reservoir volume of 50,900,000m^3 (*Figure 5*).

Table 4. Two seismic events produced during injection into UD-1.

Trigger #	Origin Time (UTC)	X (m)	Y (m)	Z (m)	ML (UK)	PGV (mm/s)
4149	2021/07/05 11:50:36	-696.9	-361.7	-4844.5	-0.31	0.014
4150	2021/07/05 12:10:19	-385.2	25.0	-4174.2	-0.95	0.002

In comparison, injection into UD-2 at high flow rates (up to 70 l/s) identified stable pressures and no detectable seismicity. In addition, when testing the reservoir in an operational state (production from UD-1, injection into UD-2), no seismic events occurred. This suggests that the fault zone and reservoir is stable, with a very low risk of seismicity occurring during operations.

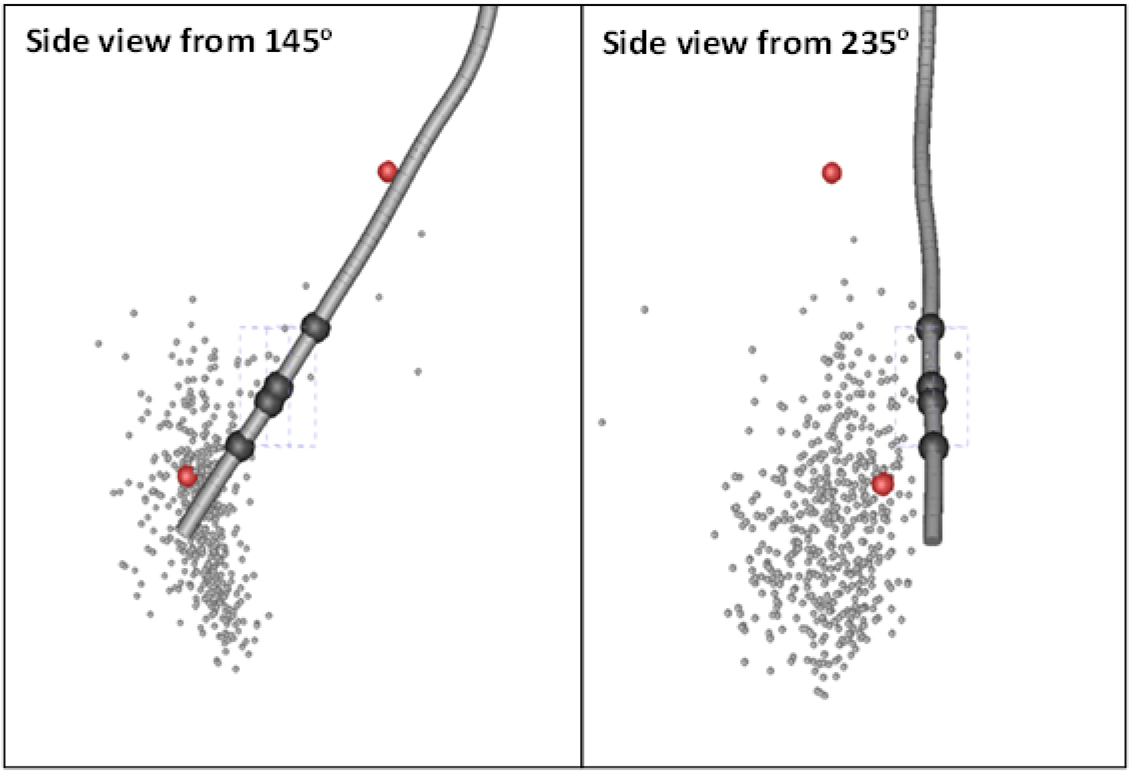

Figure 4. Location of the only two microseismic events which occurred during injection testing in July 2021 (red spheres), plotted against all previous seismic events during well testing at United Downs (grey spheres). The grey tube shows the well trajectory, with black sections indicating significant mud-loss zones during drilling. Images courtesy of Altcom Ltd.

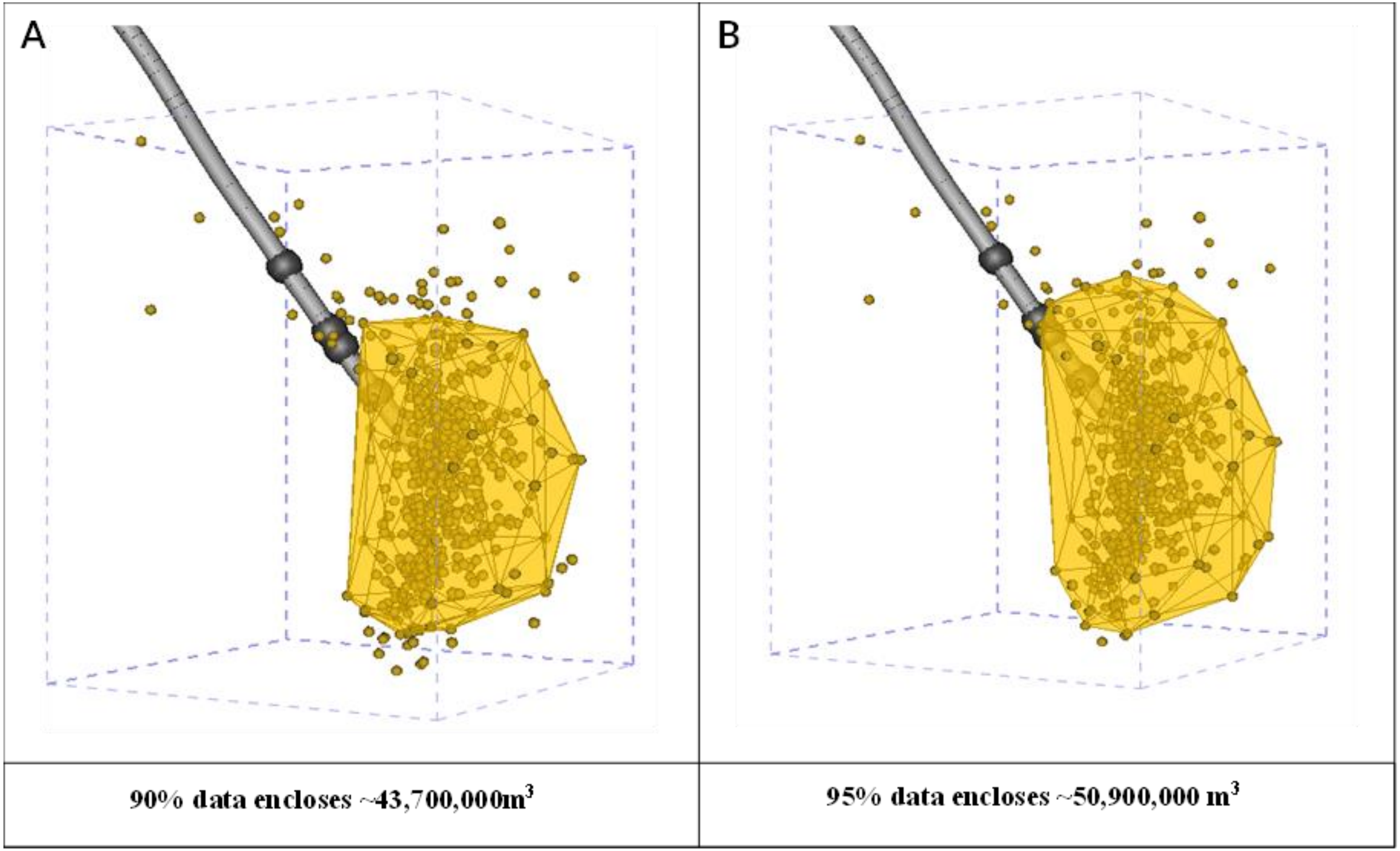

Figure 5. An estimate of stimulation volume after initial injection testing (up until February 2021) is provided by enclosing (A) 90% and (B) 95% of seismic events (closest to the centroid). Images courtesy of Altcom Ltd.

8. POWER PLANT COMMISSIONING

The United Downs project is entering its final stage of development: construction of the power plant. Based on the results of testing, a 2-3MW$_e$ unit will be installed, with the aim of commissioning in 2023. A pioneering Power Purchase Agreement between GEL and Ecotricity will enable geothermal electricity to be sold for the first time in the UK.

9. COMMUNITY ENGAGEMENT

Community engagement has always been at the heart of the United Downs project and has been vital for the project to be accepted by local communities. A number of different activities have been crucial to ensure its success:

9.1. Background Research

Before active engagement with the community can begin, background work must take place to find out the nature of recent and past issues in the area and how they could be relevant to a geothermal project. This information was obtained from parish and town council meeting minutes, Neighbourhood Development Plans, comments made on planning applications, newspaper archives and social media. This research provided a picture of how amenable the local authority and community would be to a geothermal project, what information to disseminate and to anticipate questions that may arise. For example, it was found that demographic is an important factor. Where school-age children and older adults aged 65+ are more likely to engage with a new renewable source, the age group 30 – 60 are less likely to engage and predominantly less informed about the need for drastic change to address climate change.

9.2. Finding the "Community"

"Informing the local community" is cited by many academics and researchers but finding them is not straight forward. Inviting people to a pre-arranged meeting or information seminar is reliant on people being available at the set time and able to travel to the venue, so only a small number will be able to attend. Instead, GEL selected a dedicated person to attend pre-arranged community events, interact with members of the community, and become a familiar face by attending regularly. Becoming an accepted member of the group and a reliable, trusted source of information provided key insight into local problems and concerns and encouraged an open dialogue between GEL and the community. It was also made easy for members of the community to contact GEL directly through our website and social media, and public events have been held on site regularly.

9.3. Dissemination of Information

The dissemination of information is a two-way process. Not only is a GEL representative working with the local community to give out information about the project, but they must also feed back to the rest of the project team any concerns and information about the local community so they can be successfully addressed. GEL disseminated information in many ways; the type of venue and event mostly dictating the information medium. Large public events required lots of visual, eye-catching information, whereas small gatherings enabled a formal, tailor-made presentation to be given, providing relevant information for that group. On a regular ongoing basis, informal chatting with small groups of 2 or 3 people or even a one-to-one conversation at pre-existing community events was found to be the most productive form of engagement.

9.4. Education

Working with education establishments, from primary schools through to universities, was found to have a multi-faceted advantage. Young people are knowledgeable about climate change and the need for action, and inherently interested in renewable energy projects. Students also consistently informed their peers and family members on the information learnt during outreach sessions, spreading the interest in the project well beyond the school walls.

9.5. Virtual Events and Resources

Whilst the Covid-19 pandemic has restricted the previous forms of community outreach throughout 2020-21, it has made new types of outreach a necessity. Social media has helped inform people about day-to-day activity and future plans, but it does not reach all members of the community. Regular virtual meetings and webinars with local decision makers has therefore been vital to reach out into the community and enabled two-way interaction, which is difficult to achieve via social media.

10. FUTURE SITES IN CORNWALL

As the United Downs project draws closer to electricity generation, GEL's focus is shifting towards future geothermal heat and power projects across Cornwall and the UK. Given the successful demonstration of generation potential at United Downs, exploration for new sites has focused on areas where the subsurface environment is anticipated to be similar to that at United Downs. This includes two key geological factors (*Figure 6*):

- Relatively shallow depth to granite from ground level (<2.5km)
- Proximity to a permeable fracture zone (crosscourses trending approximately NW-SE)

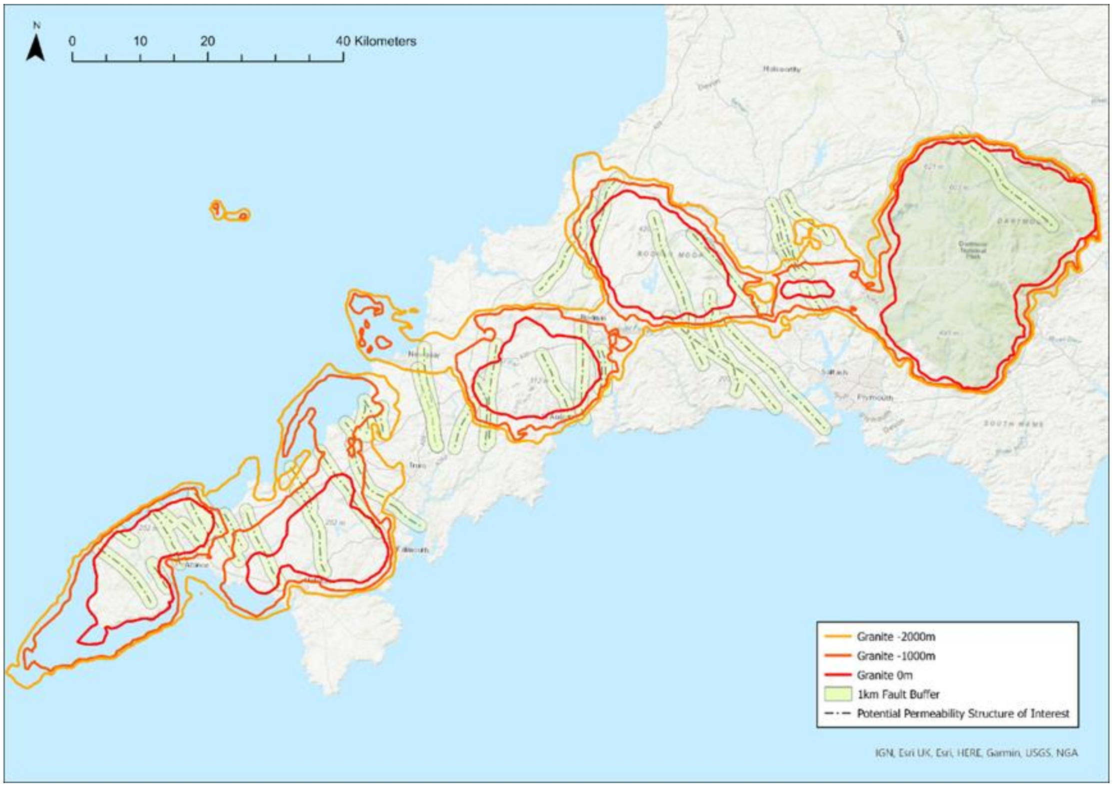

Figure 6. Depth to granite contours and permeability structures of interest across Southwest Britain. Structures have been filtered out if they lie wholly outside the 2,000m depth to granite contour.

However, the geological constraints are just the start of the site identification process. There are numerous other factors that must also be considered, with the three most critical development constraints being:

- Access to a significant A road which would allow transport of HGVs with rig equipment into and out of site during drilling.
- Proximity to a grid connection to minimise additional infrastructure requirements.
- No locally or nationally designated sites of environmental sensitivity, such as National Parks, World Heritage Sites (WHS), Areas of Outstanding National Beauty (AONB), Sites of Special Scientific Interest (SSSI), Heritage Coast, National Nature Reserves (NNR), Local Nature Reserves (LNR), Areas of Great Landscape Value (AGLV), Special Areas for Conservation (SAC) and others, where known.

These three constraints significantly reduce the area of Cornwall suitable for a geothermal development. However, a number of additional factors must also be considered to identify the most ideal development sites. These include, but are not limited to:

- **A level working area of more than 15,000 m^2 -** Space to accommodate a large, land-based drilling rig and associated units during drilling.
- **Population density -** A lower population density should reduce the potential for disturbance to local communities.
- **Minimal impact on local road network -** Taking into account bridge heights, weight limitations and access via village through roads.
- **Proximity to immovable infrastructure -** Railway lines, major service lines and mine workings can add complexity to a development.
- **No public rights of way**
- **No flood risk**

- **Proximity to existing geothermal projects –** If a new site were too close to an existing geothermal development, reservoir interference could occur.
- **Proximity to potential heat customers -** Low-carbon heat will be available for use by existing industries and may attract further developing industries with a high heat demand, so scope for these businesses to grow is preferred. Potential customers may include future housing developments, food growing or processing businesses with heating or cooling needs, warehouses, leisure centres and spas, and educational establishments.
- **Land use -** A number of land use constraints were identified, including land already permitted for development, associated with active quarrying, or close to holiday developments could not be used due to conflicting priorities of the current landowners or developers.
- **Fresh water supply -** Water is required for drilling and testing so potential supply points need to be considered.

Therefore, whilst much of Cornwall has the ideal geological conditions for producing geothermal energy, the potential for development in Cornwall is severely restricted by surface infrastructure and features.

GEL has undertaken significant due diligence across the Duchy and continues to identify areas suitable for geothermal development. Discussions with local landowners are ongoing and as new land is secured, applications for the required permits and permissions will be submitted to the relevant authority. With the resource now proven at United Downs, Cornwall's geothermal potential is significantly de-risked and offers exciting opportunities for a rapidly expanding UK geothermal industry.

11. CONCLUSION

The United Downs geothermal power project has successfully reached numerous milestones over the past three years, with the drilling of the deepest onshore well in the UK, extended testing of the geothermal doublet, successful production of the country's first geothermal steam and the signing of the UK's first Power Purchase Agreement for the sale of geothermal electricity. It is truly a pioneering project, demonstrating the incredible potential that this renewable energy source offers and paving the way for the expansion of a new industry for Cornwall and the country. It offers exciting prospects for low-carbon electricity, district heating and lithium extraction from a single resource, offering a vital step towards achieving Britain's net-zero targets.

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