Cornish Rocks – Hotting Up?

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ABSTRACT

The use of earth's heat for a wider application has been the conviction of the authors for a long time. As the cost of hydrocarbons continues to increase with additional constraint on the emission of CO_2 in the environment, the vision of using heat and electricity from geothermal for industrial and recreation application is becoming a reality.

EGS Energy has always campaigned to bring its original vision of a much wider application of geothermal energy in to reality. There is a proposal to fund two deep wells in Cornwall in 2013, one at the Eden Project near St Austell by EGS Energy Ltd and the other at United Downs near Redruth by Geothermal Engineering Ltd.

The vision of EGS Energy is not only to successfully drill the wells and produce heat and electrical power at the Eden Project, but also to establish a road map whereby future EGS developers can see the potential industrial application of the use of heat. The plan is to develop a cascade of industrial heat users at the local, community level - horticulture, fish-farming, crop-drying, etc. initially. This will be followed by the regeneration of Cornwall by enhancing its recreation industry through building water-based parks such swimming facilities, marinas, spas, etc., so that Cornwall can have visitors throughout the year and not just in the summer only.

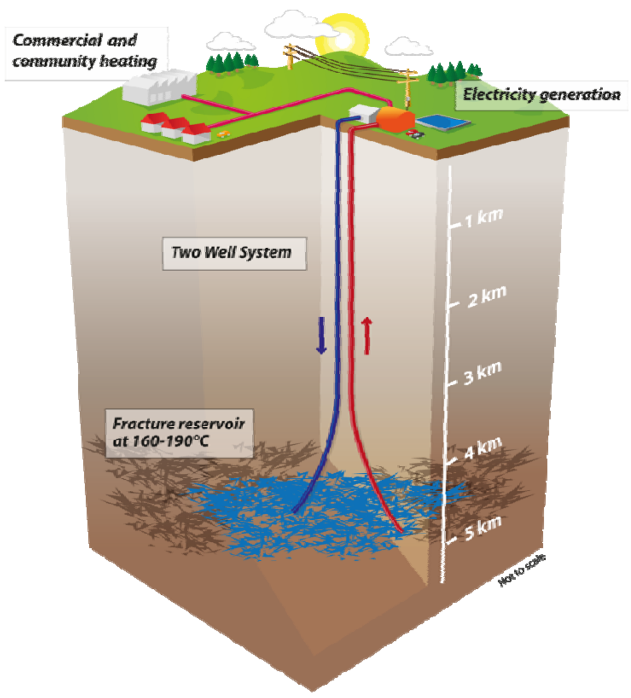
This paper describes the current plan and stages involved in the development of the first commercial EGS power plant in the UK.

1. INTRODUCTION

EGS Energy Limited is proposing to develop a deep geothermal plant at the Eden Project (the 'EDGP') in Cornwall, utilising technology based on engineered geothermal systems (EGS) to provide heat and power (***Fehler! Verweisquelle konnte nicht gefunden werden.***). The EDGP will have a nominal gross output of 4 MW_e, using a well doublet that will primarily supply power and direct heat to the Eden Project, with an off-take of surplus power either to the National Grid or to a local industry user. The Eden Project, which is Cornwall's largest tourist attraction and a UK role model for environmental sustainability, has been chosen as the optimum location for the company's first plant in the UK. The district surrounding the Eden Project is one of the most deprived rural areas in England and the development of deep geothermal energy fits well with Cornwall Council's strategic designation for this to be a priority area for regeneration and investment, with particular emphasis on establishing it as the 'Green Capital' for Cornwall.

Experience originally gained by the EGS Energy team from the Hot Dry Rock Geothermal Energy Project at Rosemanowes, in Cornwall, during the 1980s and subsequently developed at the European EGS plants at Soultz, in France, and commercial plants at Landau and Insheim, in Germany, has provided realistic parameters of output for the EDGP. An assessment by RTZ Consultants for the development of a deep prototype geothermal power plant in the UK, carried out in the early 1990s, identified a temperature

Figure 1: The Engineered Geothermal System



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requirement of 200°C at a depth of 6,000 m to produce 5 MW_e, but the current proposal is to produce 4 MW_e utilising a binary generation process with a reservoir temperature of around 180°C.

Experience from research into the exploitation of fractures for fluid flow carried out at the various EGS projects in western Europe has shown that the most permeable fracture zones are likely to be sub-vertical and strike parallel to the maximum horizontal stress direction. This has formed the basis for the design proposals for the EDGP by identifying and targeting these deep permeable structures which are aligned in a favourable orientation.

2. RESOURCE EVALUATION

The initial resource assessment of the EGS potential for Cornwall and Devon was carried out by CSM and the Imperial College in 1986. This included 76 km of normal incident seismic reflection survey and coring of a number of shallow wells. EGS Energy has undertaken to re-assess this data by carrying out a desktop deep geothermal resource evaluation study of Cornwall and west Devon. The methodology for this involved the development and application of a set of automated EGS screening criteria via a Geographical Information System (GIS). The two key elements of this process were (i) inclusion/exclusion filter and (ii) scoring criteria. The filter parameters were:

- Depth to top of granite (based on inverse numerical modelling of gravity data by CSM)
- Temperature data analysis and heat flow study (based on the CSM 3D conductive heat flow model)
- Proximity to geological structures (constructed from a variety of published data)
- Environmental and planning constraints (based on Cornwall Minerals Development Framework)
- Infrastructure/transport constraints (based on OS maps)
- Connectivity to the National Grid (based on the 33 KV network)

Other criteria that needed to be considered for site selection were:

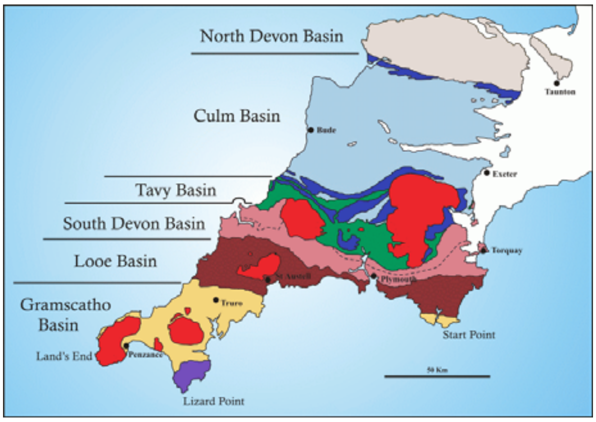
- Availability of the water resource required for the development of EGS
- Potential for industrial use of the surplus heat for economic development (i.e. horticulture, spa, etc.)

The St Austell Granite has the highest density of candidate sites in Cornwall, where at least seven potential sites are associated with disused china clay pits and the proposed Eco-towns. On this basis the Eden Project was identified as a site of preferred choice for EGS Energy's first deep geothermal plant in the UK. In addition, the proactive marketing and interpretation skills for which the Eden Project is renowned were seen to be of significant benefit for promoting and raising public awareness of the potential that deep geothermal energy has to offer to both Cornwall and the UK.

3. REGIONAL GEOLOGY

The EGS resource is primarily geologically dependent. The near surface geology of Cornwall and west Devon is relatively well documented and understood (*Figure 2*). Much of this knowledge is due to the extensive historic mining activity that has taken place and to the research to a depth of 2,500 m at the Rosemanowes Hot Dry Rock site. However, at present there have been no wells drilled to confirm the structural geology and temperature at a depth >3,000 m. Although the shape of the batholith is well constrained by the numerical models using gravity and seismic data (Willis-Richards and Jackson, 1989 and Taylor, 2007) these data need to be confirmed at the depth and position selected to assist commercial development of EGS plants.

Figure 2: Geological map of Cornwall and west Devon (Leveridge & Hartley, 2006)



The granite batholith that underlies much of Cornwall and west Devon was formed by a process of 'anatexis' that occurred towards the end of the Carboniferous Period and early Permian Period, approximately 295 – 270 million years ago. Including the Isles of Scilly, there are seven main granite plutons exposed at surface. The majority (>90%) of the exposed granite masses comprise megacrystic biotite granite. The overall appearance of the batholith is a tabular body that is 40 – 60 km wide at its base, with steep sides and an irregular upper surface with an overall area of approximately 3,000 km^2. The precise date of intrusion and the characteristics of each of the exposed granites vary.

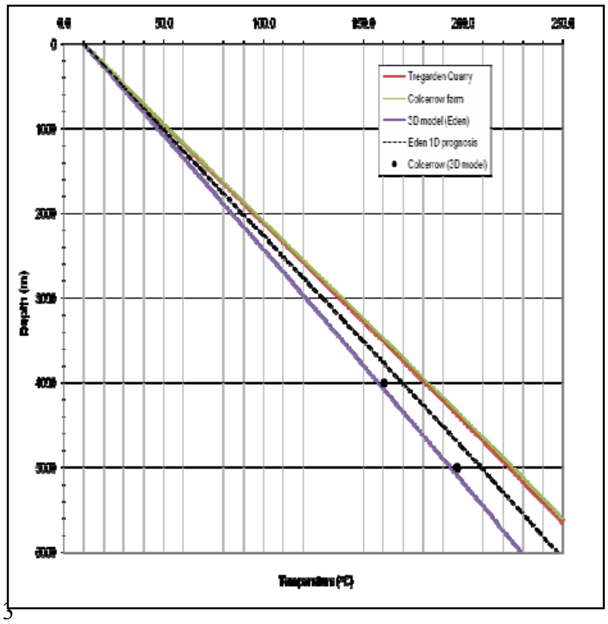
The EDGP is sited on the southeast flank of the St Austell Granite. The western half of the St Austell Granite comprises lithium-mica granite, which has been extensively exploited for china clay, whereas the eastern half comprises biotite granite. Gravity modelling has indicated that the batholith may be wedge-shaped, with the base lying approximately 17 km deep below Dartmoor and gradually decreasing westwards to less than 10 km at Land's End, whereas data obtained from seismic reflection surveys infer the granite base may lie at slightly shallower depth, but still well below the target depth.

4. TEMPERATURE ASSESSMENT

The Cornubian Granite is indicated to be hotter than granites found elsewhere in the UK. The heat flow in this granite is approximately 120 mW/m², which is significantly higher than the average 65 mW/m² found in the surrounding meta-sediments. The heat flow is primarily conductive and much of this heat is derived from the decay of radionuclides within the granite. The only available temperature/depth data for SW England is from the 3D conductive heat flow modelling undertaken by Camborne School of Mines (Willis-Richards, 1990) and the only published results are a description of the numerical model and estimates of temperature at 6km depth.

Therefore, it has been necessary to re-build the 3D heat flow model, to re-run it to produce the necessary modelled temperatures for this study, and to validate this new model against the CSM 6 km temperature profile. Results from 3D heat flow modelling at the EDGP site by EGS Energy, indicate a rock temperature of ~160°C at 4,000 m depth (TVD) and a temperature gradient of ~37.5°C/km. However, it is known that the 3D model has a smoothing effect on the predicted surface heat flows resulting in an underestimate on the granite outcrop and overestimate on the country rock. There is evidence of this in the area of the Eden Project because surface measurements taken within 5 km of the site suggest a slightly higher heat flow and geothermal gradient than predicted by the 3D model.

Figure 3: Estimated geothermal gradient at the EDGP

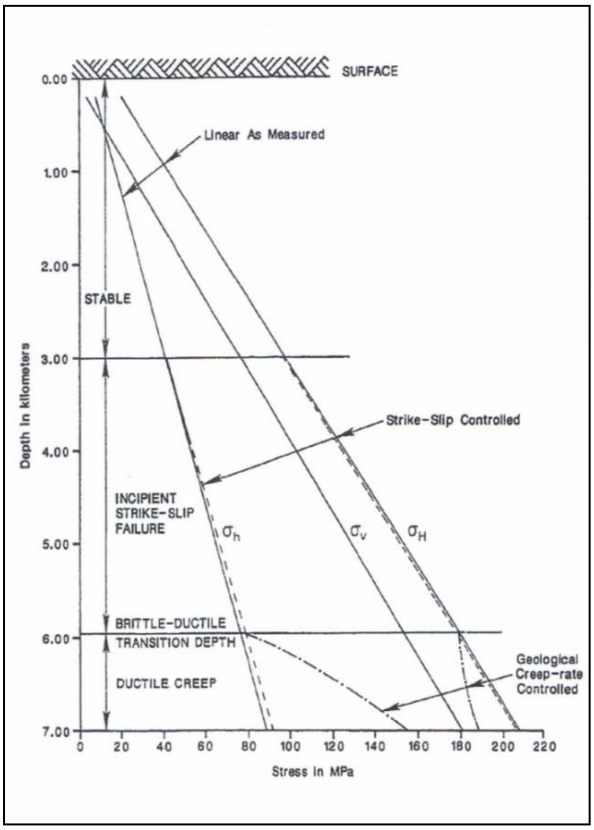


Results of 1D temperature modelling, using the surface heat flow as boundary conditions, suggest subsurface temperatures of 180°C at a depth of 4,000 m and a temperature gradient of ~42.5°C/km (*Figure 3*). The geothermal gradient in the vicinity of the EDGP is estimated to be approximately 40°C/km which equates to a temperature of 180°C at a depth of 4,500 m (allowing for a near-surface temperature of 10°C). The dominant effects on subsurface temperature appear to be the local distribution of heat producing minerals and the thickness of the granite. Both the Penwith and eastern St Austell granites are indicated to have relatively higher densities of heat producing minerals than other areas. This model confirms confidence that the required rock temperature will be achieved at the proposed target depth of the EDGP.

5. IN-SITU STRESS REGIME

The stress regime in Cornwall and west Devon is reflective of the regional stress regime across northern Europe. Evidence from Rosemanowes, Soultz and other EGS projects has shown that the growth, orientation and dimensions of the reservoir in a fractured crystalline rock are dependent on the natural fractures in the rock. The orientation of the principal stresses determines which fault or fracture alignments are likely to preferentially reactivate. The stress

Figure 4: Anticipated in-situ stress regime (ETSU, 1992)



regime comprises a minimum horizontal stress (σ_h), which acts in an ENE – WSW direction and an orthogonal maximum horizontal stress (σ_H), acting in a NNW – SSE direction. The vertical stress (σ_v) is a function of depth of overburden. Below a depth of 500 m the stress regime in Cornwall is strike slip.

Based on data obtained at Rosemanowes (ETSU, 1992) the in-situ stress regime at a depth of 4,500m will result in strike slip failure is predicted to be (*Figure 4)*:

- vertical stress (σ_v) : ~115MPa
- min. horizontal stress (σ_h) : ~65MPa
- max. horizontal stress (σ_H) : ~140MPa

6. RESERVOIR DESIGN

Detailed study by EGS Energy on the reservoir design has shown that the design parameters for the EGS reservoir does meet the gross electrical output for the base-case system of 3.8 MW_e required for the EDGP to produce the requisite heat and power over the intended operational lifetime of the plant of 27 years.

P10 (MW)	P50 (MW)	P90 (MW)
3.1	3.8	4.5

The intention is to target large scale faults and fractures associated with the regional cross-courses. The assumption in this study is 100% forced circulation, but with the recognition that any substantial fluid recovered from the far-field would be of significant benefit. This type of system is considered analogous to the systems developed at Soultz and at Rosemanowes.

At Rosemanowes, the peak production flowrate from an approximately 300 m long production interval was 27.5 l/s. For the EDGP system the plan is to more than double the production interval length and therefore it is reasonable to assume a doubling of the production flow (i.e. 55 l/s). There is significant uncertainty in the reservoir impedance estimate. The minimum impedance observed at Rosemanowes over a separation between the wells of 180 m was ~0.4 MPa/l/s, however the separation between the wells at Soultz was 600 m and the impedance was 0.2 MPa/l/s. In the reservoir at Rosemanowes, the production well RH15 was incorrectly located, which meant that a large proportion of the fluid migrated downwards and was not recovered due to the strike-slip regime. This gave the poor value for the impedance. At Soultz the wells were in normal faulting regime at a depth of 3,600 m and the production well was located properly so significantly more injected fluid was recovered with a much better impedance value. This shows the importance of optimising the target location of the production well.

For the base case, a total system output of 3.8 MW_e at a production flow-rate of 55 l/s equates to a unit output of 0.07 Mw/l/s. Based on the relationship between electricity output and production temperature at given re-injection temperatures (MIT, 2006), the average output temperature for an electrical unit output of 0.07 Mw/kg/s is 177°C. A reduction in the re-injection temperature from 75°C to 60°C would increase to 4.3 MW_e. However, the major uncertainties in the pumping power requirements are the reservoir impedance and the recovery of the injected fluid

A key performance parameter during forced fluid flow will be the amount of thermal drawdown of the system during its operational lifetime. In order to assess the thermal drawdown behaviour the model of heat extraction from a set of planar parallel fractures has been used; this model consists of circular fractures with a diameter equal to the well separation. This is useful in scoping well separation for the worst case of 100% forced fluid flow, but can be refined once additional reservoir data is available. The thermal drawdown is dependent over time on the well separation, on fracture spacing and the flow through the system. The conclusions from the scoping model are that for the case of 100% forced flow a well separation of >600 m will be sufficient to meet the 10% thermal drawdown target (over 27 years) if the reservoir consists of 10 or more flowing fractures with at least 50m fracture spacing. The ability to produce significant quantities of far-field fluid could be highly beneficial. This is consistent with the study carried by Shock 1985 to assess the economic viability of an EGS system and the life of system.

7. EGS RESERVOIR TARGET

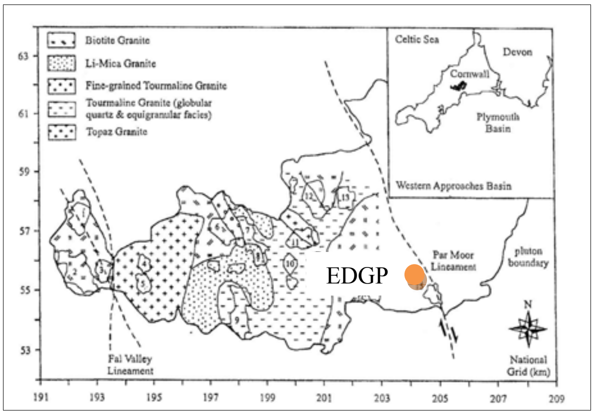
The Eden Project is situated on the southeast flank of the exposed St Austell Granite, close to the contact with the meta-sedimentary host rock. Experience has shown that in a strike slip stress regime the critically aligned joints are those which lie at ~22° from the direction of σ_H, which in Cornwall corresponds to NNW – SSE striking faults, generically known as cross-courses. The St. Austell granite district is traversed by a series of NNW – SSE striking cross-courses and fault zones. The characteristics of cross-courses vary considerably, extending from major wrench faults, over 100 m in width, to minor fractured faults or veins <1 m in width. They can be divided into two main types that predominantly comprise:

1. Fissure fill type (cross-veins) – clay and quartz infill and have a ‘vughy’ nature.

2. Shear/wrench type (fluccans) – zones of intense micro-shearing of clay gouge infill.

EGS Energy has undertaken a desktop geological review and target zone assessment in conjunction with Camborne School of Mines. This study has identified a major NNW – SSE coursing dextral wrench fault, known as The Great Cross-course, or Par Moor Lineament (Psyrillos et al, 2003), which has been proven through coastal outcrop at Crinnis, 4km south of the site, and in former mine workings, up to 200 m deep, in the meta-sedimentary rocks 2 km south of the site (*Figure 5)*. This cross-course extends inland from the coast, displaces the granite/meta-sedimentary host rock contact just south of the Eden Project and extends northwards through the granite, for a strike length of over 10 km. It is recorded to pass immediately east of the EDGP site. The dip of the structure is recorded to be 75° – 80° east, but the consistency of this dip is unproven at depth. Recorded observations have shown that the Great Cross-course consists of several fissures over a width of 45 m, all heaving south.

Figure 5: St Austell Granite (Psyrillos et al, 2003)



The major wrench faults that extend for tens of kilometres across the county pre-date the granite and the evidence suggests that they should continue well below the intended target depth of the EDGP reservoir. It is believed that the angle of dip should remain near vertical and relatively constant. Evidence from other major shear zone structures in Cornwall, such as the Great Crosscourse at South Crofty Mine (Dominy, 1994), indicates this structure is likely to be characterised by ramifying networks of intense microfractures and quartz veins. Based on the geological and geophysical information with local observations, a target zone has been identified to be intersected at around 4000-5000m depth.

8. SITE SELECTION

After careful consideration of a number of options, the site selected at the Eden Project for the EDGP was chosen based on minimising the potential environmental impact to the nearby residents and on meeting the following criteria:

1. Large, flat space for the drilling rig and its associated working area
2. Good connectivity to the National Grid (for export of surplus power)
3. Minimal environmental impact (noise and visual) to neighbours
4. Potential to screen the site
5. Source(s) of fresh water for construction and operation
6. Good access for HGVs with minimal transportation impact
7. Minimal geotechnical risk
8. Minimal flood risk and impact on watercourses
9. Minimal risk to public safety
10. Minimal impact to the daily activities of the Eden Project

9. PLANNING CONSENT

Planning Consent for the development of the EDGP was obtained on 16 December 2010. This is a hybrid consent, with full permission for the drilling of the deep wells and creation of the sub-surface reservoir and outline permission for the surface heat and power plant. The application for consent involved addressing and satisfying the Local Planning Authority and its statutory consultees on a number of environmental factors to ensure that the site is suitable for purpose. Certain aspects of potential ecological impact were identified during the planning application process and as a result appropriate mitigation and control measures have been addressed and where necessary approved by Natural England. The subsequent recommendations for ecology monitoring and control are on-going.

10. SITE AND GROUND INVESTIGATION

A detailed topographic survey has been undertaken and an initial ground investigation, comprising shallow drilling and trenching, has been completed on the site to assess the ground conditions and the risk of contamination and ground gas and to assist in the flood risk assessment for the planning application. A desk-top study has identified that there is no risk from recorded metal mining activity or china clay extraction, the nearest of which took place during the nineteenth century 500 m to the south and 200 m to the southwest of the site respectively. A detailed ground investigation is about to be carried out in close proximity to the site of the two deep wells. This will comprise a 60m deep borehole to ascertain ground conditions for the design of the rig foundation pad and for the design of the conductor installation.

11. SEISMIC HAZARD STUDY

EGS Energy has undertaken an assessment of the potential for subsurface seismicity associated with the development and operation of the EDGP in relation to the design parameters identified in the reservoir scoping report. This study has provided a preliminary assessment based on an analysis of empirical data and theoretical considerations. It has considered the hazard associated with both "induced" and "triggered" seismicity. For induced seismicity, three published approaches have been used to constrain the maximum size of induced seismicity; these approaches have been calibrated using data from the Rosemanowes Hot Dry Rock Geothermal project by reasonably assuming that conditions at the two sites will be similar. It assumes that all input energy is released as a single large event, whereas empirical evidence from EGS operations indicates that the seismicity is likely to occur as a number of less energetic events. The analysis of natural seismicity in the area of the proposed project indicates that the potential for triggered seismicity appears low. The BGS earthquake catalogue indicates that there have been no instrumentally recorded earthquakes (ML>1.5) within a 5 km radius of the Eden site within at least the last 25 years. The absence of seismicity at this level indicates that there are no seismically active, and hence seismically vulnerable, faults within the likely area of influence of the EGS operations. There are only two instrumentally recorded events around 10 km of the site. Both are reported as ML~1.6 and were not felt at surface.

The assessment report also makes a recommendation that continuous monitoring of background seismicity (as per the standard protocol recommended by IEA/GIA), using a broadband seismometer, should be carried out for at least six months prior to commencement of drilling to establish a baseline for the background natural seismicity in the immediate vicinity of the EDGP site.

12. ENVIRONMENTAL IMPACT STUDY

A full range of environmental considerations have been assessed as part of the EGS proposal at the Eden Project, the findings of which formed part of the planning application and detailed in the supporting technical reports. There are no significant environmental impacts associated with the long-term operation of the EGS plant, and it is considered that any environmental impacts predicted during the construction phase can be mitigated effectively. The nearest residential property lies 190 m ENE of the well site. In accordance with the noise thresholds defined in BS 5228-1:2009 it is concluded that construction activities are unlikely to result in a significant impact during normal working hours. However, night time noise levels during the drilling of the deep wells are likely to result in an adverse impact on nearby residents. As a result of this, one of the conditions of the planning consent is: *The noise emissions from drilling operations shall not exceed 45dB LAeq, 1 hr measured 1 m from any noise-sensitive receptor at any time.* In this regard, a number of mitigation measures can be implemented, including:

- The quietest drilling rig practically possible will be selected;
- The construction plant equipment and activities employed will be selected to ensure they are the quietest available for the required purpose;
- The working area of the drilling rig will be screened by an acoustic barrier as close to the source of noise as possible and the provision of an additional acoustic barrier along the eastern boundary of the site will be considered.

The most visually noticeable phase of the EDGP development will be during the drilling of the deep wells whilst a large land-based drilling rig will be on site for approximately 10 – 11 months and removed at the end of the drilling process. The rig floor will be approximately 10 m above ground level and the mast will extend approximately 45 m above this (total height approximately 55 m above ground level). The drilling rig will be visible in the local area, but will be a temporary landscape and visual impact only. In the longer term, the power plant and associated operational structures will be a maximum 10 m in height.

The site is located in flood zone 1 (low risk) in which the probability of flooding is less than 1 in 1,000 years. However, the site is over 1 ha and therefore a flood risk assessment (FRA) has been undertaken. The main source of flood risk at the site arises from surface water (rainfall) run off due to the low permeability of the underlying ground conditions. The overall surface water run-off and risk of flooding will be minimised, in accordance with local plan policy. The existing attenuation pond will be re-engineered into an online balancing pond that will incorporate a flow control device to minimise run-off from the site. The exception to this system is the concrete hard-standing on which the drilling rig and power plant will be sited, whereby any spillage likely to present a risk of contamination will be drained into the mud lagoon and cuttings pit.

A desktop hydrogeological study has been carried out by EGS Energy. A local water impact assessment has been carried out as part of this study and has been approved by the Environment Agency. The nearest licensed groundwater abstraction is located 133 m to the north east of the site. Risks to groundwater during the construction phase of the development will be minimised through the adoption of safe working practices to control runoff and treatment of leachates (e.g. oil/water interceptor) and the storage of fuels in accordance with current regulatory and industry guidance.

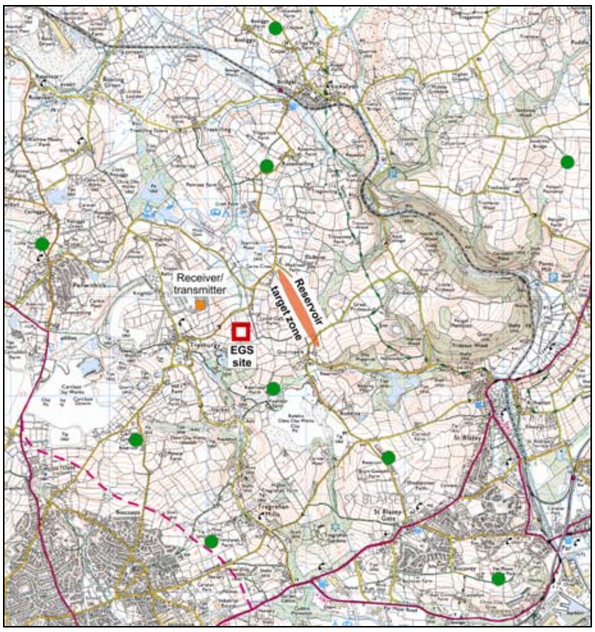
13. SEISMIC MONITORING

Following internationally recognised IEA/GIA protocol, a seismometer has been installed at the Eden Project to monitor background seismicity for a period of at least 6 months prior to the commencement of development. Data is stored continuously on to a hard disk within the data logger and is downloaded as necessary.

As part of the development of the EDGP a comprehensive seismic network will be installed ahead of any drilling activity at the site. This will include deployment of high gain seismic sensors with broad bandwidth at surface and down-hole. This system will incorporate a facility to locate and analyse in real time. The seismic monitoring network will comprise a combination of downhole accelerometers (up to 8 sondes) and surface seismometers (up to 4 units) installed within a 4 km radius of the EGS site. Deployment of down-hole sensors to a depth of around 100 – 150 m is regarded as sufficient to overcome the effect of environmental surface noise and to produce better results for signal to noise ratio, wider bandwidth and the detection of smaller seismic signals. The minimum number of sensors required for the system is six and a network of eight sensors is required to obtain reliable fault plane solutions. Once commissioned, the seismic system will need to be calibrated for the velocity model.

Eight sites have been identified within a 4 km radius of the EDGP site where remote seismic stations could be established (*Figure 6*) The owners of each of these sites have been approached and all have signed a Heads of Agreement in which they agree in principal for EGS Energy to install and operate these stations. EGS Energy has also negotiated agreement with Imerys for an intermediate receiver/transmitter aerial on Imerys owned land, at a prominent site at Trebal Clay Refinery, to enable radio telemetry links between the sites and the EDGP. Planning consent for this mast has been obtained. EGS Energy have purchased the seismic equipment and software required for the seismic network. The next stage is to finalise the legal agreements and to install the equipment. Structural damage from an induced or triggered seismic event is normally assessed from peak velocity and frequency on the surface. For this reason, strong motion seismometers will be will be deployed in strategic populated areas in the locality to record peak acceleration and frequency should there be any insurance claims for damage to property.

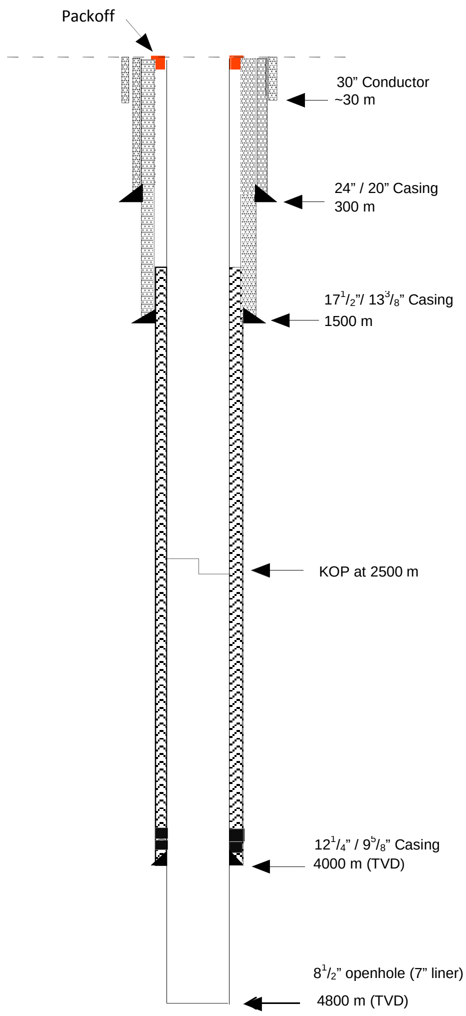
Figure 6: Proposed microseismic monitoring Network



14. DESIGN OF THE 1ST WELL AND DRILLING PROGRAM

EGS Energy with partner BESTEC (UK) Limited has produced a detailed Drilling Programme Report that includes the plan and design for the first well (named EP-1) at the EDGP (*Figure 7*). The trajectory for the first well is aimed to intersect the target structure at optimum depth and spatial location. The design of the well is based on oil and standard gas industry well design adapted on the basis of geothermal wells that have been successfully drilled and operated at EGS plants in France and Germany. The well will commence at 24” diameter, completed with 20” casing, then 17½” diameter to 1,500 m completed in 13⅝” casing and 12½” diameter to 4,000 m,

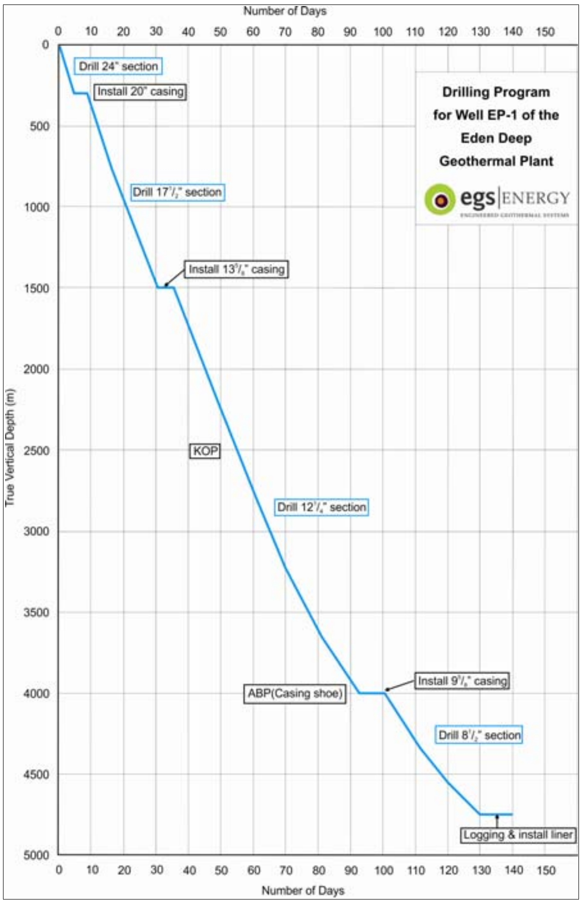
Figure 7: Proposed well design for EP-1



completed in 9⅝" casing. At midway depth the well will be kicked off to gradually build angle to 30° from the vertical by casing shoe depth at 4,000 m. The production section of the well will be 8½" diameter for a length of over 700 m. 7" liner may be installed in the 8½" hole, dependent on formation conditions. The design criteria for the casing of the first well will accommodate the provision to use it as either an injection or a production well.

The programme for drilling and completing Well EP-1 is estimated to be 140 days from spud. However, if a hydraulic rig is used, with associated slower tripping time, it is estimated that the programme will take at least 170 days to complete (*Figure 8*). This programme does not include any hydraulic testing or stimulation required for the reservoir development that is proposed for the first well. An important requirement of the first well is to provide an accurate assessment of the geology, lithology, temperature, stress regime and fracturing at target depth. This information will be crucial to determining, firstly, whether the ensuing stages of the proposed EGS development are feasible and then, if so, enabling the development programme to be refined on the basis of the conditions encountered.

Figure 8: Estimated drilling program for EP-1



15. LOGGING AND TESTING

During the drilling of the first well the geology will be continuously logged by inspection of chippings obtained on the rig shaker tables. It may be difficult to characterise weathered or weak structures within the granite using this method, but, at present, it is envisaged unlikely that cores will be taken during the drilling; coring in crystalline rock can be extremely expensive and normally generates a very low success rate.

Temperature logs will be run at regular intervals to assist determination of the temperature gradient.

A standard wire-line logging suite will be carried out at a depth of approximately 1,400m and upon completion of the well. The prime objective of these logs will be to assess the geological conditions with increase in depth, especially in relation to fracture assessment. The completion logs in the 8½" openhole will provide essential information on wellbore conditions; near well geology; fracture distribution; porosity and permeability. A variety of commercially available logging tools will be run by a specialist logging service company, including:

1) Geophysical logs – to assess the physical characteristics of the well and the lithology.

2) Borehole imaging logs – to identify the orientation, aperture and density of fractures.

16. RESERVOIR CREATION, MONITORING, DRILLING OF THE 2ND WELL, TESTING AND INSTALLATION OF CHP PLANT

Typically the creation of a forced fluid flow EGS reservoir requires hydraulic stimulation, injecting either water or viscous fluid, at relatively high flow rates to shear open natural fractures and thereby enhance the permeability of the rock until an effective reservoir of sufficient size has been established. The targeted size of an EGS reservoir is in the order of magnitude of several km^3. In order to assess the requirement for stimulation a variety of tests will be run, including:

- initial hydraulic tests - small scale injection tests will be required to assess the undisturbed initial hydraulic properties of the open section of the well;
- production tests - in the event that significant production fluid is encountered in the formation (production from the well will be passed through a steam separator);
- pre-stimulation tests - a pre-stimulation test is carried out to test that all sensors and seismic system, etc., are working satisfactorily prior to the main stimulation.

The stimulation design is dependent on: injection pressure, volume and flow rate; injection fluid temperature and chemistry; duration and continuity of injection. EGS Energy has developed a reservoir creation and assessment strategy, but the precise design of this stimulation will depend on the conditions encountered in the first well at target depth, on the findings of the logging and on the results of the pre-stimulation test. At present it is anticipated that the main stimulation will comprise the injection of approximately 30,000 m^3 of fresh water at stepped increase flow rates (typically 30 l/s, 40 l/s, 50 l/s and 70 l/s) up to a maximum of 100 l/s over a period of approximately 10 days.

After the main stimulation a post-stimulation test is undertaken to evaluate and quantify the enhancement in the permeability of the reservoir achieved by the main stimulation.

The seismic monitoring network will be used to detect and locate the microseismic noise generated by a joint when it fails, either due to jacking or shear displacement, when fluid is injected in a jointed media. In addition to monitoring reservoir growth, microseismic data can be used for source parameter calculations, fault plane solutions and tomography, as has been successfully demonstrated at the Soultz EGS project. Data from the remote seismic sites will be transferred or relayed to a central data acquisition unit at the EDGP site for storage and treatment.

Once the stimulation programme and the post-stimulation tests have been completed on the Well EP-1, an assessment will be made to see if the extent and the quality of the reservoir are suitable for immediate progressing to the next stage.

The results obtained from the drilling of the first well and of the subsequent hydraulic testing and reservoir creation will be fully assessed to see if a remedial treatment is needed to full fill the design parameters. The next step is to identify a precise target zone for the second well, EP-2, and the plan and design of this well in order to achieve the target. The objective for Well EP-2 will be to intersect the reservoir in the optimum location for reservoir performance. The precise spatial location of this target will depend largely on the information obtained from the microseismic activity during stimulation whilst meeting certain overall design requirements, including a minimum well separation. The drilling design and plan for Well EP-2 is likely to be very similar to that of EP-1, although the trajectory required to achieve the target location may be slightly longer and more complex. Once the Well EP-2 has been completed and any required stimulation has been undertaken the drilling rig will be demobilised.

Once a hydraulic link between the two wells has been established the characteristics and performance of the reservoir will need to be assessed to determine whether further treatment is required. The final phase of the development will be to complete the design with the relevant details of the reservoir and its resulting resource, install and commission the CHP plant.

17. PROGRAMME

The project is currently within Phase 2 of development. The anticipated programme from the commencement of main funding is shown below:

Phase	Activity	Duration
1	Planning application	completed
2a	Detailed design	3 months
2b	Site preparation	6 months
2c	Drilling Well EP-1	5 months
2c	Reservoir creation/testing	1-2 months
3a	Drill Well EP-2	5-6 months
3b	Reservoir characterisation	2-3 months
4	Design/build/install plant	10 months

18. CONCLUSIONS

EGS Energy Ltd using its long standing experience have successfully evaluated, designed and planned the first commercial plant in the UK at the EDEN Project and are awaiting the decision of DECC for the grant to be allocated for the first deep well in the UK.

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