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The Newberry Super-Hot EGS Project

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ABSTRACT

Super-hot dry rock (>375°C) is much more energy dense than conventional hot dry rock (<225°C), and production of supercritical EGS steam would represent an energy breakthrough. A super-hot EGS well would produce 5 to 10 times as much electricity as other well types. To fill the knowledge gaps and break the technological barriers, we propose a super-hot EGS proof of concept at a location where very hot rocks are close to the surface (~5 km) and the cost of drilling and stimulation will be lowest. The project will be sited on Newberry Volcano, in Oregon, one of the largest geothermal heat reservoirs in the USA and a suitable, ready-to-go site. Another important and more fundamental goal of this project is to contribute to better understanding of the distribution of geothermal systems in a volcanic area and, in the case of the Newberry Volcano, why high thermal gradient can be sustained kilometers away from the main axis of the volcanic activity focus (caldera and associated shallow magma chamber). Drilling into the brittle-ductile transition to test the efficiency of thermally induced fracturing and reservoir creation is an important goal of the project as well as the development of drilling techniques and borehole instrumentation adapted to high temperature. Preliminary thermal and geomechanical modelling and drilling and stimulation strategies will be presented and discussed.

1. INTRODUCTION

Recovery of just 1–2% of the thermal energy stored in hot rock at 3 to 10 km depths would be sufficient to meet world energy consumption for many centuries. Recovery of this energy can be achieved through creation of Enhanced Geothermal Systems (EGS), which involves injection of high-pressure water into a well to enhance or create fracture permeability and connect two or more wells separated by several hundred meters of hot rock, effectively creating an underground heat exchanger. Despite significant worldwide investment in the last two decades, EGS development has been limited, and the goal of economic EGS may not be achieved unless power production per well can be greatly improved. Typically, EGS developers target rock temperatures between 150 and 225°C, but super-hot rock (SHR) (>375°C) is much more energy dense, and production of supercritical EGS steam would represent an energy breakthrough. A SHR EGS well would produce 5 to 10 times as much electricity as other well types (Figure 1).

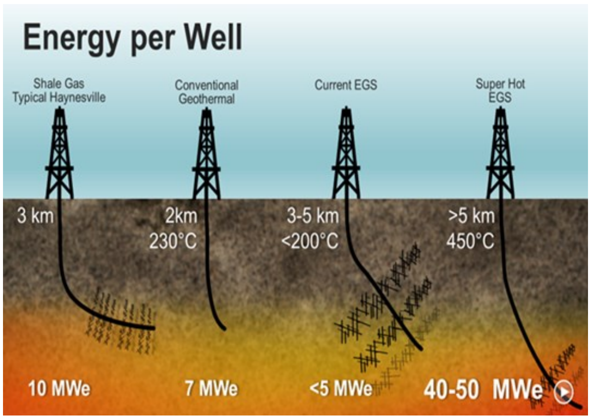

Figure 1: The energy per well of super-hot rock geothermal wells exceeds even shale gas wells.

To fill the knowledge gaps and break the technological barriers, we propose the Newberry Deep Drilling Project (NDDP)—a drilling and SHR EGS proof of concept at a location where very hot rock is close to the surface (~5 km) and the cost of drilling and stimulation will be lowest. The project will be sited on Newberry Volcano, in Oregon, one of the largest geothermal heat reservoirs in the USA and a suitable, ready-to-go SHR site. Another important and more fundamental goal of this project is to contribute to better understanding of the distribution of geothermal systems in a volcanic area and, in the case of the Newberry Volcano, why high thermal gradient can be sustained kilometers away from the main axis of the volcanic activity focus (caldera and associated shallow magma chamber). Our project will lead to more comprehensive knowledge of the thermal behavior of the whole volcanic system.

Newberry Volcano is an active volcano that has been extensively studied for the last 40 years. The detailed characterization of this continental volcanic system reveals it is an excellent choice for drilling a well that will reach temperatures greater than 450°C at relatively shallow depths (<5000 m). The large conductive thermal anomaly (320°C at 3000 m depth) at Newberry has already been well-characterized by extensive drilling and geophysical surveys. Although geothermal hot springs exist along the shores and floors of the caldera lakes, four >3000 m or deeper exploration wells completed in the geothermal lease area on the west flank of the volcano's caldera rim did not find natural hydrothermal systems. The impermeability of the zone between wells NWG 46-16 and NWG 55-29 (Figure 2), at depths of 2000–3000 m has been indicated by extensive geophysical investigations and corroborated by fluid injectivity tests.

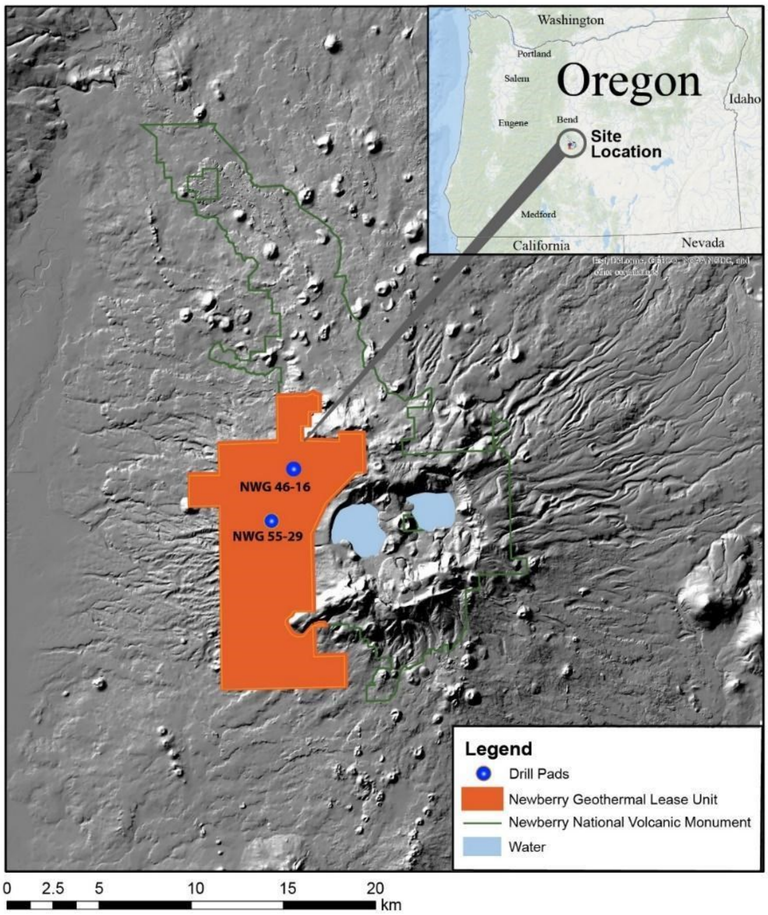

Figure 2. Location map for the proposed NDDP site, showing the Newberry National Volcanic Monument and geothermal leases. Blue dots with identification numbers correspond to the two existing deep wells, NWG 46-16 is the intended target for deepening.

We propose to deepen geothermal well NWG 46-16 from 3534 m to up to 4877 m MD (4813 m TVD) at the northwestern flank of Newberry Volcano where high-quality, graded dirt forest roads provide vehicle access to the three existing well pads and each of the seismic monitoring station locations. This will extend current knowledge from the existing ~3000 m boreholes at the sites, into the brittle-ductile transition (to projected temperatures >450°C), and potentially approaching regions of partial melt. Information gained at the Newberry site will be widely applicable across the Cascade volcanic arc, as well as other magmatically active areas throughout the Pacific Rim and beyond. In the first year of the project, through numerical modeling and laboratory testing, the team will develop procedures, technologies, and tools to ensure that the super-hot, deepened well, NWG 46-16D (D for deepened), can be drilled, and a SHR EGS potentially created.

2. STATE OF THE ART IN SUPER HOT ROCK EGS

Forty years ago, scientists and engineers at Los Alamos National Laboratory, started EGS technology at Fenton Hill, NM. From 2008 to 2015, the U.S. Department of Energy (DOE)-funded EGS demonstration projects with modest commercial successes adjacent to existing geothermal fields (Desert Peak, NW Geysers) but not at EGS greenfields. EGS and deep geothermal heat systems using resources below 200°C are economic in Europe (Weber et al., 2016; Boissavy et al., 2016).

The most geothermally savvy countries in the world, Iceland (Pálsson et al., 2014; Friðleifsson et al., 2017, 2018), Italy (Bertani et al., 2018; Palloti and Martini, 2018), Japan (Asanuma et al., 2015), Mexico (Jolie et al, 2018), and New Zealand, are pursuing projects to produce supercritical geothermal fluids. Geothermal wells have been drilled to 400°C or hotter in the USA, Japan, Iceland, and Italy (Reinsch et al., 2017). Drilling to 500°C or more has not been the primary challenge of producing supercritical geothermal fluids. Rather the project failures have been due to problems with well casing caused by thermal stress cycles and/or corrosive fluids.

Given the enormous potential economic benefits of supercritical geothermal wells, what is holding back the research, technology development, and testing needed to make super-hot geothermal energy viable? For the purpose of this proposal we identify the following scientific gaps and barriers:

- The in situ physical, geochemical, and mechanical characteristics of rock and produced fluids at temperatures up to 500°C are not well understood.
- Only limited studies and creation of an EGS reservoir in rocks near the brittle-ductile boundary has been attempted yet. That was in basaltic rock in the IDDP-2 well (Friðleifsson et al., 2018) which has elevated BD boundary, 200-300°C higher than in the acid rocks expected to be dealt with in NDDP.
- The enthalpy and corrosivity of produced fluids from a SHR EGS well needs to be better understood to design the most efficient and durable energy conversion technology.

A drilling and well completion success to 500°C was recently demonstrated by the DESCRAMBLE project in the Ventelle-2 well in the Larderello geothermal field in Italy (Bertani et al., 2018; Palloti and Martini, 2018).

3. NEWBERRY VOLCANO

3.1. Geology

Newberry Volcano is situated near the juncture of several geologic provinces in central Oregon: the Cascade Range and volcanic arc to the west, the Columbia Plateau to the northeast, and the Basin and Range to the southeast (McCaffrey et al., 2013; Cladouhos et al., 2011). The Cascade Arc is a long-lived feature with a magmatic history including several prominent eruptive periods; the Western Cascades from 35-17 Ma, the early High Cascades from 7.4 to 4.0 Ma, and the late High Cascades from 3.9 Ma to present (Priest, 1990; Hildreth, 2007).

Newberry Volcano (Figure 2) is a broad eruptive center active for approximately the last 600,000 years that rises 2,408 m on the southeastern side of the Deschutes Basin (MacLeod et al., 1982; Jensen, 2006; Donnelly Nolan et al. 2011). The current central caldera formed about 75,000 years ago. The volcano is an elliptical shaped massif approximately 50 km by 30 km, with some lava flows reaching more than 64 km north of the caldera (Jensen et al. 2009; Donnelly Nolan et al. 2011). Lower flanks are composed of ash and lahar deposits, basaltic lava, cinder cones, and minor silicic domes.

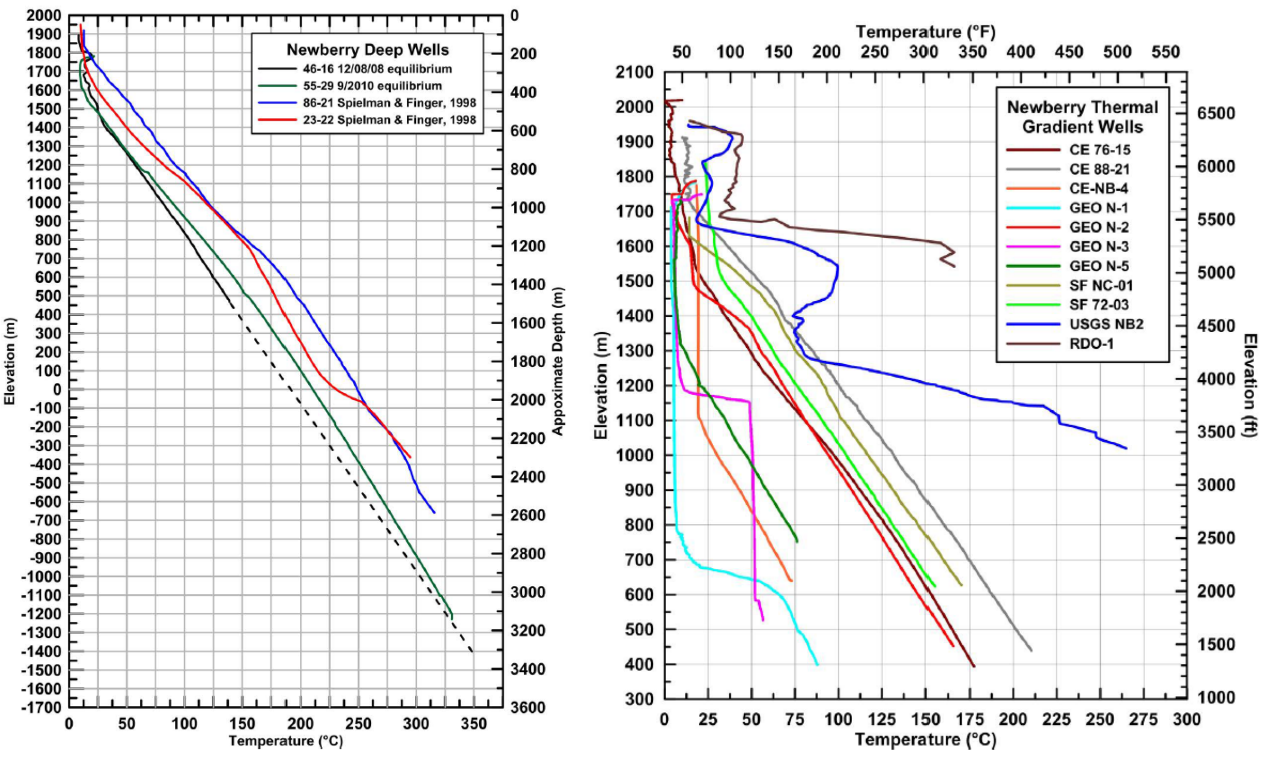

Figure 3. Equilibrated temperatures of core holes and exploration wells at Newberry Volcano from Frone (2015). The temperature profiles have been corrected for wellhead elevation and well path deviation from vertical and plotted as elevation on the left scale. The difference in surface elevation between NWG 55-29 and NWG 46-16 is 110 m. Depth scale on right side is approximate, with a zero-depth reference at the highest well, 23-22.

Several basalt flows sourced from rifts in the NW flank of the edifice are younger than 7,000 years, postdating the regionally extensive Mazama ash (7,700 years old) from Crater Lake (McKay et al. 2009). The more steeply sloped upper flanks of the volcano are composed predominantly of overlapping silicic domes and subordinate basaltic rock. The central caldera is about 8 km by 5 km and is a nested composite of craters and vents.

Two structural patterns dominate the Newberry Volcano area. The first are the volcanic and caldera-related structures of the volcano itself, including arcuate vents and ring fractures in its central portion. Four caldera ring fractures have been mapped on the NW flank of the Newberry Volcano (Sherrod et al., 2004). The second group of regional structural features is the northwest - and northeast-trending faults (e.g., the Walker Rim, Brothers, and Tumalo fault zones) that are found across and beyond the Newberry massif and are likely transitional between the Cascade Arc Central Graben and the Basin and Range extension.

3.2. Thermal Setting and Exploration Wells

Public domain equilibrated temperature-depth profiles are available for many of the temperature coreholes and geothermal exploration wells (Figures 3). Two coreholes and two relatively shallow geothermal exploratory wells were drilled in the caldera. The shallow exploratory wells were drilled by the U.S. Geological Survey (USGS) (N-2) and Sandia National Laboratories (RDO-1). A maximum temperature of 265°C was measured in USGS N-2 at its total depth (TD) of 932 m. A maximum temperature of 160°C at a TD of 411 m was encountered in RDO-1. Temperatures encountered in RDO-1 were significantly higher than those at comparable depths in USGS N-2.

Four deep exploratory wells have been drilled on the northwestern flank of the volcano, two by CalEnergy (CEE 86-21 and CEE 23-22) and two by Davenport Newberry Holdings (NWG 55-29 and NWG 46-16). The temperature profile for NWG 55-29 (Figure 4) indicates a conductive regime from an elevation of about +1700 m to a TD at -1,300 m. An equilibrated temperature profile to TD was never measured in NWG 46-16. Linear projections of the temperature profile determined on the shallower conductive portion of the profile give bottom-hole temperatures (BHTs) from 350°C (Figure 4) to 375°C (Frone, 2015) using a gradient of 112°C/km. Spielman and Finger (1998) reported that the two CalEnergy wells encountered temperatures in excess of 315°C below 2,740 m. Based on the two CEE wells and two temperature coreholes, they concluded that while adequate temperatures are present, the permeability in the area investigated was too low for a commercial geothermal (i.e., natural hydrothermal) resource.

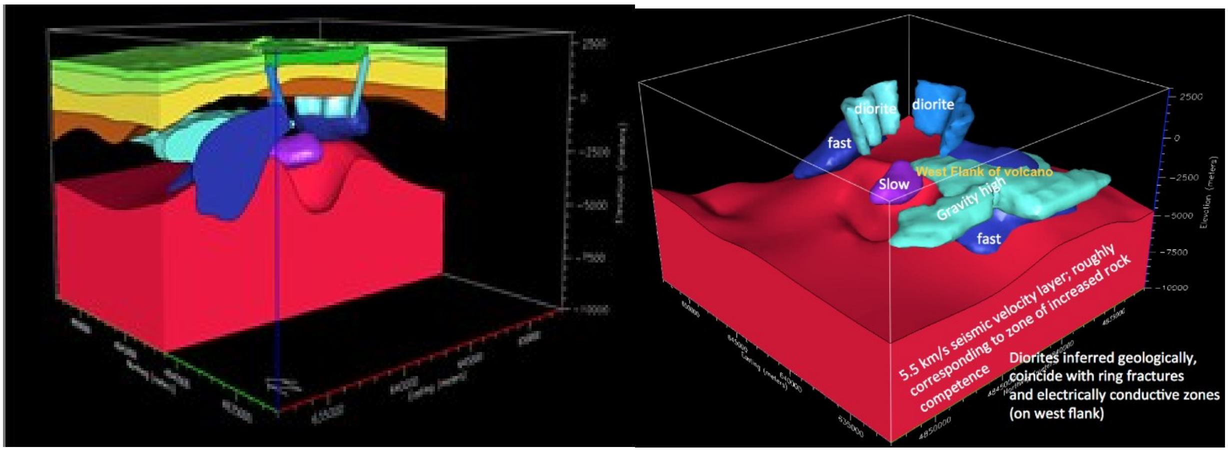

Figure 4. (left) Geophysically inferred intrusive bodies beneath Newberry Volcano, viewed from the northwest (nearest to viewer) to the southeast, showing ring dikes along periphery of caldera (labeled "diorite"), seismically fast zones (dark blue zones; inferred mafics), a slow zone representing the sub-caldera magma chamber (purple/lavender), and formations interbedded with dikes and sills and potentially a deeper plutonic body seismically fast, consistent with interbedded granites, all at depths greater than 3000 m below surface level. These features, and particularly the deeper plutonic body, would be important deep drilling targets. (right) Representative geophysical data layers displayed in EarthVision viewed from northwest looking toward southeast showing north-to-south cross section with zones of inferred increased chlorite concentration/potential epidote alteration removed to reveal intrusive bodies. The deep intrusive bodies and/or zones of interbedded dike intrusion beneath the drill site are the blue/cyan objects on the left side.

3.3. Geophysical data and 3D Conceptual Geologic Model

There has been an extensive geophysical data set collected at Newberry as part of a geothermal exploration program begun by the AltaRock predecessor and current subsidiary, Davenport Newberry Holdings, which added to more than three decades of previous geophysical data at the volcano. Starting in 2012, Oregon State University, in partnership with the US Dept. of Energy National Energy Technology Laboratory and Zonge International, carried out an extensive program of geophysical monitoring of subsurface conditions within the geothermal leasehold. This produced a geophysical baseline model from the compendium of pre-stimulation data, includes many hundreds of (micro)gravity and magnetotelluric stations, microseismicity, seismic velocity tomography, ground deformation monitoring using satellite InSAR and ground-based interferometric radar, and aeromagnetics.

Geophysical and geological data were synthesized in a robust conceptual geologic model built in 2016 (Figure 4) during Phase 1 of the US DOE FORGE program (NEWGEN, 2016; Mark-Moser et al., 2017; Bonneville et al., 2017). A three-dimensional model, developed using the EarthVision™ software environment, provides a unified framework that identifies the target reservoir units and their properties and constrains their spatial extent. In the conceptual model, the temperature profile within the target reservoir units is constrained by borehole equilibrium temperature measurements from deep wells, backed by thermal conductivity measurements of rock cores and cuttings, diffusive heat flow models, and coupled thermal-hydrological- mechanical-chemical (THMC) models that make use of constraints on porosity and permeability obtained from measured well data, bulk permeability data, and injectivity test data (Sonnenthal et al., 2012, 2015). Multiple terabytes of high-quality geologic, geophysical, geomechanical, and geochemical data from the site are now publicly available on the US DOE Geothermal Data Repository (NEWGEN, 2016).

4. GOALS OF DRILLING

- **EGS (supercritical and beyond-brittle)**
  Going deeper than existing wellbores at Newberry, for the first time into the brittle-ductile transition, will test the efficiency of thermally induced fracturing and reservoir creation during the drilling stage. The drilling fluid temperature should remain below 200°C in order to cool drill bits and logging equipment, which will induce a thermal shock while drilling into hot rocks at temperature above 400°C. In addition, a 3-day hydraulic well stimulation will both change the pore pressure in fractures and cool the fracture walls. The extent of thermal fracturing and the associated changes in the permeability of the formation remains a big unknown in this kind of thermally activated EGS and knowledge and modeling of it constitute important factors of development for supercritical steam (>374°C, >22 MPa) geothermal energy.

- **Collect samples of rocks within the brittle-ductile transition**
  IDDP-2 successfully collected some core at temperatures above 400°C. The mafic rocks from the IDDP-2 hole are not yet ductile because the brittle-to-ductile transition (BDT) temperature in rocks is heavily dependent on silica. According to ongoing petrological and fluid inclusion studies the BHTs in IDDP-2 seem to be pretty close to 600°C (Zierenberg et al., 2017; Fridleifsson et al., 2018; Bali et al., 2018) in the basaltic dike complex. However, NWG 46-16D will present the rare opportunity to collect silica-rich core from within the BDT. Note that at the expected temperature, it is anticipated that silica-rich rock will be ductile at tectonic strain rates, but not necessarily for drilling strain rates.

- **Geomechanics close to a magmatic system**
  Knowledge of the stress regime is key to understanding fracture generation and geometry and in controlling the location of dikes (see above), not to mention the importance of knowing and controlling the stress field when optimizing fracture generation during EGS projects. Stress models have been a challenge at EGS projects associated with volcanic systems in the past, starting at Fenton Hill (see recent re-analysis by Norbeck et al. 2016) and continuing with Hijiori and Ogachi Basin (Kaieda et al., 2010). Even at conventional geothermal fields in extensional regimes (i.e., Dixie Valley; Hickman et al., 1998), the stress can be heterogeneous in a single well. A mini-frac test, or extended leak-off test, is a pressurized in situ stress test conducted to provide information about rock reservoir permeability, mechanical strength, and especially the minimum principal stress. Developing and testing new, more reliable and easily performed methods of measuring stress in geothermal wells will be a useful R&D result.

- **Calibration of geophysical imaging techniques**
  The conceptual geological model built on several geophysical observations and models has identified several massive intrusive bodies in the western flank of Newberry Volcano below the deepest wells. Drilling a well to 5 km will offer a unique ground truth and verification of these interpretations, as well as validation of bounds placed on the temperature and permeability of these deeper formations. This will help define the best imaging tools that could be deployed in such a geological context, their optimal resolution, as well as their distribution in the field. This will have enormous value for future geophysical exploration and EGS monitoring efforts, and for understanding of the evolution of volcanic systems and related volcanic hazards.

- **Drilling and geophysical monitoring in a high-temperature environment**
  Drilling in very high-temperature environments, potentially with supercritical fluids, is a difficult task, as demonstrated by the IDDP-1 experiment (Pálsson et al., 2014), and requires special drilling bits, drill string, casing and cement, as well as a rigorous Environment, Safety & Health plan. The most innovative techniques available on the market at the time of the drilling will be evaluated and tested.

Downhole geophysical tools should also have exceptional tolerance at high temperatures and pressures and durability in chemically aggressive fluid environments. For example, what is the extreme limit of deployment of fiber-optic-based technologies that are now increasingly used in subsurface projects? During the NDDP, we propose to test different instruments and methods like high-temperature fiber-optic microseismic arrays, distributed well monitoring for production, deep borehole electrical resistivity tomography (ERT) electrodes, and high-temperature (HT) gauges for ESP monitoring.

4.1 Pre-drilling Planning

NDDP will be on the cutting edge of drilling, stimulation, and characterization technologies. Therefore, during the planning phase the team will need to evaluate products, vendors, and technologies to ensure that they meet the specifications required to drill NGW 46-16D and achieve the project's goals. Further, a well-documented decision process will be established, so that future projects can replicate our successes and learn from our inevitable failures. Best practice documents will be drafted to capture all lessons learned.

To achieve the scientific and drilling objectives, NDDP will prepare and execute a drilling program, considering the feasibility and technology gaps related to:

- Ultra-high temperature and pressure casing and couplings as well as cement designs capable of withstanding the geochemistry of super-critical fluids and thermal cycling,
- Drilling bits, muds and methods suitable at super-hot temperatures,
- Coring and stress measurements in a previously -drilled hole and during drilling,
- Open hole packers needed for stress measurements at super-hot temperatures,
- Rock mass mechanics derived from drilling monitoring,
- A suite of geophysical logs (including sonic velocity, imaging) for super-hot temperatures,
- Super-hot downhole energy sources or seismic instruments for vertical seismic profiling (VSP) and velocity calibration,
- Super-hot downhole ERT transmitter/receiver electrodes incorporated into electrically isolated well casing collars,

- Reservoir creation methods (hydraulic, thermal, chemical, gas, energetic source) suitable for semi-ductile rocks,
- Reservoir sustainability challenges including long-term geochemistry and permeability maintenance
- Syn- and post-drilling ground and borehole-based geophysical monitoring.

In cases where technology development is needed, NDDP will work with technologists, and other international high-enthalpy geothermal projects to identify and implement new solutions.

5. DRILLING AND COMPLETION STRATEGY

As reviewed in Section 3.2, the shallower conductive temperature profile in NWG 46-16 projects to a BHT of 350–374°C at 3494 m TVD (3536 m MD). If NWG 46-16D continues with a deviation from vertical of 10° and the gradient remains the same, 450°C will be reached at 4180 m TVD (4232 m MD), and 500°C at 4621 m TVD (4680 m MD) (Figure 5). If a more conservative value of BHT of 340°C is chosen then 500°C will be reached deeper, close to 4850 m. We can conclude that even if we use conservative estimates for the predicted temperature profile, the NDDP temperature goals can be relatively easily reached with 1000 to 1350 m of additional drilling.

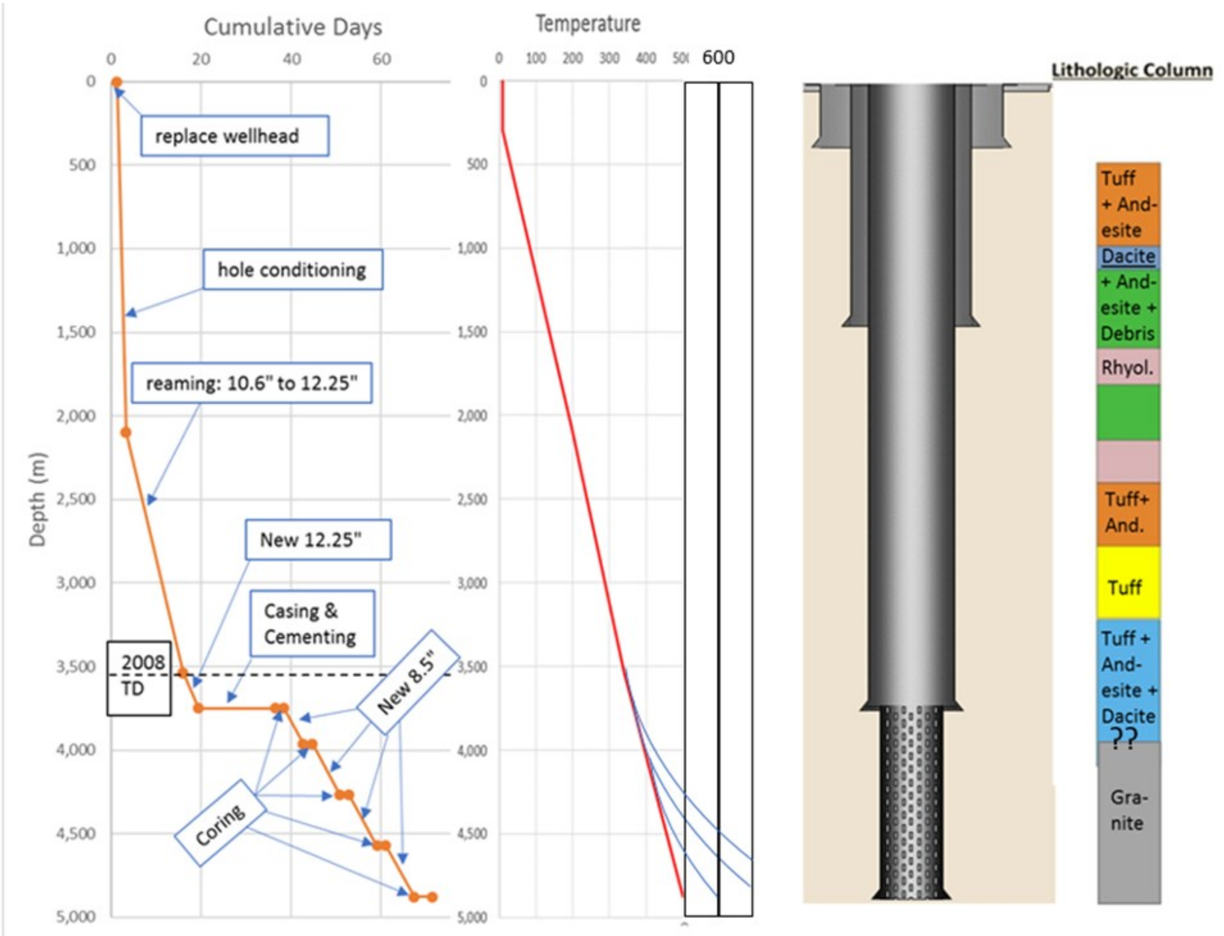

Figure 5. Summary of drilling plan for NWG 46-16D. From left, (1) projected rig time and drilling activities - orange circles delineate drilling intervals and drill-string trips; (2) projected temperature: in red using the observed gradient down to 2500 m, in blue various potential scenarios if the granite batholith is hotter than expected (cf. DESCRAMBLE project); 3) planned wellbore schematic; and 4) lithology with projected granite below 4 km depth. All depths are MD.

During the drilling of NWG 46-16, there were no significant lost-circulation zones deeper than 300 m and cuttings were fully recovered. Therefore, in NWG 46-16D we can expect high recovery rates of cuttings and core at temperatures at which the rocks are transitioning from brittle to ductile mechanical behavior.

NWG 46-16 is situated outside the Newberry National Volcanic Monument and the current caldera. The recent volcanic activity at Newberry is not limited to the caldera. Ring dikes, cinder cones, and lava flows are abundant outside the caldera, and these extrusives must be connected to a young magma chamber. Therefore, there is a possibility that feeder sills or dikes will be intersected in NWG 46-16D. Further, the center of the Newberry or pre-Newberry volcanoes has likely migrated across the NWG 46-16 location. Therefore, information about volcanic hazards and magmatic geomechanics is very likely to be obtained when NWG 46-16D intersects intrusive rocks.

In 2008, NWG 46-16 was targeted at the edge of a gravity anomaly with a southward trajectory designed to intersect a hypothesized intrusive body at depth (Al Waibel, pers. comm., 2017). Although the original hole did not reach a significant lithological or density change, the geophysical (MT and gravity) data and models presented above indicated that NWG 46-16D would likely intersect a higher density pluton. Note that the possibility of reaching temperature hotter than 500°C should not be totally disregarded if this granitic pluton is hotter than expected, as observed in the DESCRAMBLE project (Bertani et al., 2018) (Figure 8)..

NWG 46-16 has a TD of 3536 m. There is 13.375-inch casing set to 1446 m followed by a long open hole to TD (Figure 5). There is a blockage at 1525 m that formed during a flow-test in October 2008, and then was easily re-opened by a drill bit and well-conditioning. A wireline tool could not pass this depth in December 2008. From 2100 m to 3536 m, the hole needs to be reamed from 10.625-inch to 12.25-inch to allow for 9.625-inch casing to be run as the production string. Then, the well will be deepened to about 3750 m so that the open hole interval below is all above the critical point of water (374°C). The well will be cased back to the surface using materials capable of withstanding the potentially corrosive flow of supercritical steam from below, should that exist. Finally, the well can be deepened to 4621-4877 m, where Newberry intrusives are likely to be intersected.

A detailed plan with contingencies will be developed during the pre-drilling planning and qualification phase of the project. Casing point depth and total depth are subject to change based on further data analysis and technological review.

6. GEOPHYSICAL DOWNHOLE LOGGING AND IN SITU STRESS MEASUREMENTS

As part of the formation and fluids evaluation program, downhole logging tools will be deployed to understand the super-hot environment. The evaluation program will use conventional logging tools like gamma ray and temperature, coupled with more innovative tools like logging when drilling, and the borehole fluorimeter to characterize the subterranean rocks, fractures, and fluids. The downhole logging program will include the following technologies:

During drilling, it is expected that the wellbore will be cooled significantly through fluid circulation (Friðleifsson et al., 2017). With sufficient wellbore cooling, the drilling plan will include logging on a drill string using logging while drilling (LWD) tools used in the petroleum industry. Rather than constantly using LWD tools, increasing tool wear and risk of expensive tool loss, the LWD tool string will only be installed for logging runs at specific depths associated with bit changes. A LWD tool will provide a full suite of logging data for the NDDP well like resistivity, gamma ray, ultrasonic imager, caliper, borehole imaging and pressure.

Measuring stress magnitudes above 300°C will be extremely challenging; success will depend on whether very high-temperature removable packer technology is available to hydraulically isolate a short (<5 m) interval of formation and then safely remove the packer, allowing drilling to continue.

7. CORING AND SAMPLE ANALYSIS

Cores will provide intact geologic samples that are critical to achieving a range of NDDP goals. The anticipated core tool will cut a 6 in. hole and collect a 4 in. diameter core with a 10 m core barrel length. Paired with bit changes, we estimate that each core will add two days of rig time (28 hours for four one-way trips, 6 hours for tool makeups, and 14 hours of coring). The upper goal is to collect a core at every bit change starting at the current TD of NWG 46-16, provided each bit lasts 160 m or more, or about 10 cores total, with a minimum goal of 5 cores. The coring program will be flexible to allow for spot coring if cuttings or drilling behavior indicate that a distinct lithology has been intersected.

NDDP will use the capabilities of LacCore and the Continental Scientific Drilling Coordination Office (CSDCO) at the University of Minnesota, the U.S. National Science Foundation facilities for support of continental scientific drilling. Initial field analysis of core material will enable determination of the onset of ductility. Fluid inclusions in cores will provide uncontaminated samples of in situ, native fluids for both geochemical and microbiological analysis. CSDCO and LacCore will host additional core activities and will provide permanent sample and data curation and distribution alongside samples from other ICDP drilling sites so that researchers from around the world can access and use the cores for a range of scientific purposes.

8. CONCLUSION

The main goals of NDDP are to 1) test EGS above the critical point of water, 2) collect samples of rocks within the brittle-ductile transition, 3) study magmatic geomechanics, 4) calibrate geophysical imaging techniques, and 5) test technology for drilling, well completion, and geophysical monitoring in a very high temperature environment. The geologic, geophysical, and thermal setting of AltaRock's geothermal leases on Newberry and geothermal well NWG 46-16, are well-suited to meeting these ambitious goals. NWG 46-16D also supports the development goal of NEWGEN to produce electricity at Newberry, as with successful SHR EGS creation it can become the injector for the geothermal subsurface system, recharging one or two production wells.

Testing and developing the technology platform needed to produce SHR EGS will be worth the effort as this is the clearest route to making geothermal electricity cost competitive. The NEWGEN consortium has already held an ICDP workshop, set ambitious goals, and written an ICDP proposal. The next steps are to implement the project funding plan to attract additional investors and partners ready to contribute to this exciting challenge.

Geothermal, volcanic, geophysical, and engineering information gained at the Newberry site will be widely applicable across the Cascade volcanic arc, as well as other magmatically active areas throughout the Pacific Rim and beyond. NDDP and the other supercritical geothermal system projects in areas with shallow heat are the first step to making SHR EGS a viable, global resource. Eventually, advanced drilling methods such as energy drilling and casing-while-drilling, could allow wells to be economically drilled to 10-20 km, expanding SHR EGS power to much of the world's population.

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